TEXTBOOK

Textbook of Plastic and Reconstructive Surgery

Basic Principles and New Perspectives

Michele Maruccia
Giuseppe Giudice
Editors

SICPRE
Società Italiana di Chirurgia Plastica Ricostruttiva ed estetica

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Foreword 1

It is with great pleasure and honor that I, as President of the Italian Society of Plastic, Reconstructive and Aesthetic Surgery, introduce this new Textbook of Plastic and Reconstructive Surgery, which joins most, if not all, Italian plastic surgery names to provide the highest quality work.

As plastic surgeons we are always bound by the desire to perform the best care for our patients and this philosophy surely inspired all authors in writing their chapters. Many of the contributors are plastic surgery experts; however, there is also a new span of young surgeons whose contributions are equally outstanding, providing a new and contemporary input.

The Plastic Surgery School of Bari, with its old tradition in the South of Italy, has trained an entire generation of plastic surgeons in the last 30 years and has maintained its high standard in research and training. This book offers different approaches and techniques to classical and newer clinical problems.

We hope you enjoy this up-to-date Plastic and Reconstructive Surgery book, witness of the growth and advancement of Italian plastic surgery in Europe in the last decades.

Francesco D'Andrea
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Foreword 2

Plastic surgery deals with the entire body by representing the scaffold all surgeries are based on. There is a constant demand of comprehensive information and instruction on plastic surgery. The aim of this book is to give students, trainees, and young practitioners the opportunity to approach the spectrum that is plastic surgery, providing a comprehensive and single-volume textbook. The book is aimed at practicing plastic surgeons, residents, medical students, and physician's assistants to meet the need of intuitive, easy reading and effective homing of concepts of interest. This text does not aim to describe the entire body of plastic surgical knowledge, but it represents a practical source of information and it delivers an attractive introduction to the subject. Indications, anatomy, surgical techniques, and advantages and disadvantages of the discussed topics are mainly given by intuitive, readily available, and precise information to help a day-to-day learning. The chapters are described in such an accessible arrangement to help each individual reader to achieve a satisfactory plastic surgical knowledge. The high quality of this book is provided by the authors which are consultant plastic surgeons, and each adds exceptional value to the text. This core knowledge is a collection of current thoughts gleaned from the wide experience of the authors. Evidence-based advice from experts is fundamental to give information about typical difficulties than can occur during the decision-making process. The splitting of complex topics into simple notes makes the learning process easier to master every subject successfully. This is the first Italian book edited in English language. Each chapter represents the best combination of simplicity and comprehensiveness where the answer the reader needs can be easily found. We hope this attractive and comprehensible method will act as a stimulus to plastic surgery approach for all surgeons who are involved in this area.

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Preface

As we are living in an era of ongoing globalization, over the decades, plastic surgery took advantage of the exchange of information and knowledge within the international scientific community. Therefore, knowing how to express concepts in English, the most used scientific language, it is essential to students who often rely on English textbooks to deepen their knowledge.

The idea behind this book is to meet the demand of the new generations of future doctors with a complete and modern book which reflects the changes in the specialty that has immensely evolved in the last decades. This book was designed to become a "survival manual" for the study of plastic and reconstructive surgery, for medical students, but it could also be a useful tool for future plastic surgeons to study and review the principles of the discipline. To achieve this ambitious project, the authors understood that cooperation was vital. This is where globalization plays an important role and its positive sides can be seen. For this reason, for each specific section, world experts in each field have been involved and gave their contribution, making this book a joint effort.

The book is divided into six parts that cover all areas of interest in plastic, reconstructive, and aesthetic surgery. The first part deals with the basic principles of plastic and reconstructive surgery, covering issues ranging from the process of healing, flaps, and grafts to microsurgery; this latter branch is constantly increasing given the extent of the multidisciplinarity of plastic surgery. Once acquired these tools, the student will be able to understand deeply the following specialized chapters.

In particular, Part II deals with the malformative pathologies divided between head, neck, limbs, and genitals; Part III tackles the role of the plastic surgeon in trauma. In recent years, there are many popular disciplines such as orthoplasty or hand surgery that always see the plastic surgeon as the main character. Part IV is dedicated to skin and soft tissue tumors. Part V covers pathologies treated by the plastic surgeon divided by anatomical district: breast, abdomen, nerve, and lymphatic surgery. It also deals with topical issues such as transgender surgery and transplantation up to the most advanced reconstruction techniques. A relevant role is played by the regenerative surgery that has led in the last decade to a revolution in the concept of reconstructive plastic surgery. The final part deals with plastic and aesthetic surgery in which the main aesthetic surgical procedures are quickly described underlining how the plastic surgeon preserves not only the function but also the aesthetic aspects in making this a unique discipline.

The book ends with a chapter dedicated to the role of the plastic surgeon in the Covid-19 era. The pandemic has revolutionized the life of each one of us, has given us time to reflect on many aspects, and has seen the rediscovery of true and sincere values. The plastic surgeon has fought in the front lines against Covid-19 and the academic world has also done so through numerous scientific testimonies. This book was born in this era and wants to be a tool that highlights the role of reconstructive and aesthetic plastic surgery, not only in the biomedical world but also in modern society.

Bari, Italy Michele Maruccia

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Part I

Principles in Plastic Surgery

1 Anatomy and Physiology of the Skin

Michelangelo Vestita, Pasquale Tedeschi, and Domenico Bonamonte

Background

Skin is the most extensive organ of the body and consists of three layers: epidermis, dermis, and subcutaneous fat (Fig. 1.1). The outermost layer, the epidermis, consists of viable keratinocytes, which are bound by a keratin membrane, the stratum corneum. The complete cycle of keratinocytes renovation lasts about 30 days. The primary component of the dermis is collagen, a fibrillar structural protein. The dermis lies on the subcutaneous tissue, which consists of lipocyte lobules separated by collagenous septa containing neurovascular bundles. The relative thickness of these layers is of great regional variability. The epidermis on the palms and soles is thickest and measures around 1.5 mm. The dermis on the back is thickest, where it is 30–40 times thicker than the surrounding epidermis. The amount of subcutaneous fat also varies, being generous on the abdomen and buttocks when compared to other sites.

1.1 Introduction

Detailed anatomic knowledge down to the cellular level of the skin components and relative adnexa is of primary importance to fully understand their many functions, ranging from thermoregulation and UV protection to immune response and social interaction.

1.2 Epidermis

The adult epidermis consists of four basic types of cells: keratinocytes, melanocytes, Langerhans cells, and Merkel cells.

1.2.1 Keratinocytes

Keratinocytes are of ectodermal origin and have the special function of producing keratin, a complex filamentous protein that not only forms the epidermis surface coat (stratum corneum) but is also the structural hair and nail protein.

The epidermis can be divided into the innermost basal layer (stratum germinativum), the Malpighian or prickle layer (stratum spinosum), the granular layer (stratum granulosum), and the horny layer (stratum corneum). A thin, transparent to pink layer, the stratum lucidum, is noted on the palms and soles just above the granular layer (Fig. 1.2).

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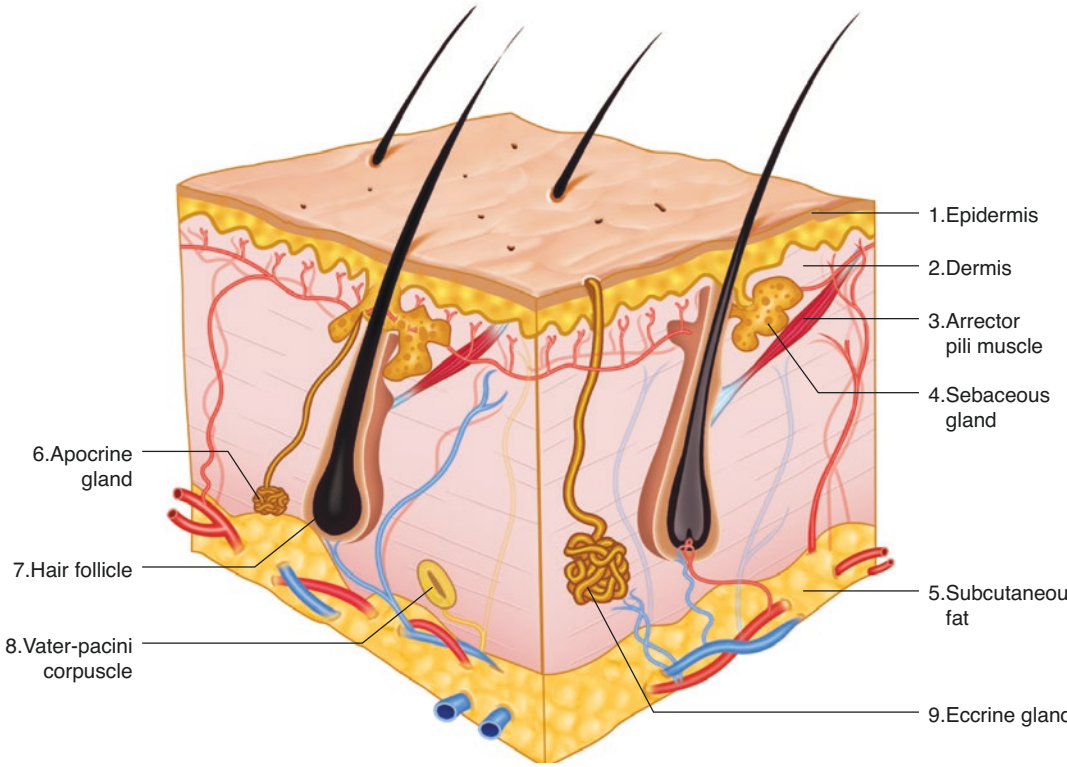

Fig. 1.1 Cross section of the skin and subcutaneous fat. (1) Epidermis, (2) dermis, (3) arrector pili muscle, (4) sebaceous gland, (5) subcutaneous fat, (6) apocrine gland, (7) hair follicle, (8) Vater–Pacini corpuscle, and (9) eccrine gland

Slow-cycling stem cells provide a reservoir for epidermis regeneration. Sites rich in stem cells include the rete's deepest portions, especially on palmoplantar skin, and hair bulge. Stem cells can be characterized by their elevated β1-integrin expression and lack of markers of terminal differentiation. The basal cells divide and flatten and their nuclei vanish as their progeny passes upward. During keratinization, the keratinocyte goes through a synthetic phase first and then a degrading process on its way to being a horn cell. In the synthetic phase, the keratinocyte accumulates intermediate filaments within its cytoplasm composed of a fibrous protein, keratin, arranged in a coiled pattern of α-helicals [1, 2]. Such tonofilaments are formed into bundles that converge and end at the plasma membrane, where they end up in special attachment plates called desmosomes [3]. The decaying keratinization process is marked by the disappearance of cell organelles and the aggregation of all contents into a mixture of filaments and envelopes of amorphous cells. This programmed maturation cycle resulting in cell death is called terminal differentiation.

Within normal skin, an intercellular space divides the plasma membranes of neighboring cells. Electron microscopic histochemical studies have shown that this interspace contains lipids and glyco buffer proteins. In this area, lamellar granules appear, mainly at the interface between the granular and cornified cell layers. Lamellar granules contribute to cohesiveness and impermeability in the skin. Glycolipids, for example, ceramides, contribute to the function of a water barrier to the skin. Desmosomal adhesion depends on cadherins including desmogleins and desmocollins, which are calcium-dependent proteins [4].

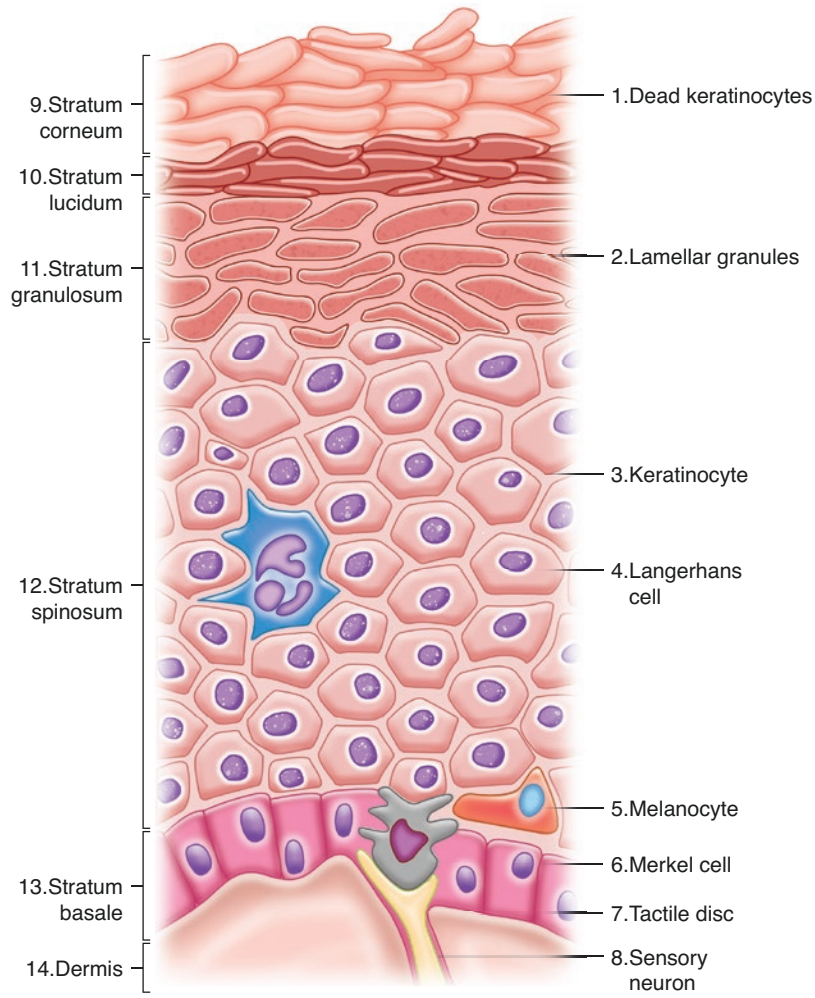

Fig. 1.2 Structure and layers of the epidermis. (1) Dead keratinocytes, (2) lamellar granules, (3) keratinocyte, (4) Langerhans cell, (5) melanocyte, (6) Merkel cell, (7) tactile disc, (8) sensory neuron, (9) stratum corneum, (10) stratum lucidum, (11) stratum granulosum, (12) stratum spinosum, (13) stratum basale, and (14) dermis

In addition to the keratin filament network, the keratinocytes of the granular zone comprise keratohyalin granules, consisting of amorphous particulate matter with high sulfur-protein content. This substance is a precursor to filaggrin. Conversion to filaggrin occurs in the granular layer, and this forms the mature epidermal keratin matrix of the electron-dense interfilamentous protein. Keratohyalin is hygroscopic, and regular hydration and dehydration processes lead to normal stratum corneum desquamation. Keratohyalin yields soft, versatile keratin formation. It is usually hard and rigid keratin that forms in the absence of keratohyalin granules: hair fibers and fingernails consist of such strong keratin.

Key Point

Throughout the immune system of the skin, keratinocytes play an important role. These cells participate in the induction of the immune response, rather than acting as passive casualties. Keratinocytes secrete a wide variety of cytokines and inflammatory mediators including tumor necrosis factor (TNF-α). They can also express molecules such as intercellular adhesion molecule 1 (ICAM-1) and major class II histocompatibility complex (MHC) molecules on their surface, suggesting that keratinocytes actively respond to immune effector signals [5].

1.2.2 Melanocytes

Key Point

Melanocytes are derived from the neural crest and reside at a frequency of about 1 in every 10 basal keratinocytes in the base layer (Fig. 1.2). Areas such as the neck, shins, and genitalia have a higher melanocyte density, and in heavily sun-damaged facial skin, Mart-1 immunostaining that displays melanocyte ratios to basal keratinocytes approaches 1:1.

Pearls and Pitfalls

Differences in skin color are not caused by differences in melanocyte counts. It is the number, size, and distribution within keratinocytes of the melanosomes, or pigment granules, that determine skin color differences. Pale skin has fewer melanosomes. There are more melanosomes in dark skin, and these appear to be larger and discretely distributed. Chronic sun exposure can stimulate melanocytes to produce larger melanosomes, thus resembling the pattern seen in dark-skinned individuals in relation to the distribution of melanosomes within keratinocytes.

Melanocytes appear as cells with ample amphophilic cytoplasm or as a clear cell in the basal layer of the epidermis in the histologic sections of the skin routinely stained by H&E. Keratinocytes also often present clear spaces but can be separated from melanocytes as they present cell–cell junctions and a cytoplasm layer peripheral to the clear space.

Melanocytes are dendritic cells. The dendrites spread long distances inside the epidermis, and so every single melanocyte is in contact with a large number of keratinocytes; together they form the so-called epidermal melanin complex. Keratinocytes purposefully ingest the tips of melanocytic dendrites, and the melanosomes are absorbed.

Melanosomes are synthesized in the cell's Golgi zone and pass through a series of steps in which the enzyme tyrosinase acts on precursors of melanin to create the densely pigmented granules. Melanocytes tend to be rounder in red-haired individuals and produce more pheomelanin. The receptor Melanocortin 1 (MC1R) is critical in regulating the development of melanin. The production of eumelanin is optimal at pH 6.8, and changes in cellular pH also result in improvements in the production of melanin and the ratio of eumelanin to pheomelanin. Melanin usually forms a cap over the nucleus within keratinocytes, where it presumably mainly functions in a photoprotective role. Melanocyte pigment also protects the melanocytes themselves against photodamage, such as membrane damage caused by ultraviolet A (UVA) [6].

Local areas of heightened pigmentation may result from a number of causes. The typical freckle results from a near-normal number of melanocytes causing a localized increase in pigment production. Within the stratum corneum, black "sunburn" or "ink spot" lentigines show basilar hyperpigmentation and prominent melanin. Nevi are benign melanocytic proliferations. Their malignant counterpart is melanoma.

1.2.3 Langerhans Cells

Langerhans cells are typically scattered among stratum spinosum keratinocytes (Fig. 1.2). They make up 3–5% of the cells in this layer. As with melanocytes, the desmosomes do not bind the Langerhans cells to adjacent keratinocytes.

Langerhans cells are difficult to detect at the light-microscopic level in regularly stained sections. However, in sections impregnated with gold chloride, a stain specific to the Langerhans cells, they appear as dendritic cells. They may also get stained with immunostains of CD1α or S-100. Ultrastructurally, they are distinguished by a folded nucleus called Birbeck granules and distinct intracytoplasmic organelles. The organelles are rod-shaped in their fully formed form at one end with a vacuole, resembling a tennis racquet.

Key Point
Langerhans cells are part of the monocyte–macrophage family and derive from bone marrow. They primarily function in the afferent limb of the immune response by providing for the recognition, uptake, processing, and presentation of antigens to sensitized T lymphocytes and are important in inducing both delayed-type sensitivity and humoral immunity. Langerhans cells move to the lymph nodes if an antigen is identified.

1.2.4 Merkel Cells

Merkel cells are located in the palm and sole basal layer, oral and genital mucosa, nail bed, and follicular infundibula (Fig. 1.2).

Located directly above the basement membrane region, Merkel cells contain intracytoplasmic dense-core, neurosecretory-like granules and function as slow-adapting touch receptors. They have direct connections through desmosomes to adjacent keratinocytes and contain a paranuclear whorl of intermediate keratin filaments.

Tips and Tricks
Merkel cells can be difficult to identify based on pure histologic examination. In order to recognize them, immunohistochemistry is used: they are positive to markers such as keratin 20, chromogranin, and synaptophysin.

1.3 Dermoepidermal Junction

The basement membrane zone forms the junction of the epidermis and dermis. Ultrastructurally, this zone is composed of four components: basal cell plasma membranes with specialized attachment plates (hemidesmosomes); lamina lucida, an electron-lucent zone; lamina densa (basal lamina); and basal lamina-associated fibrous components, including anchoring fibrils, dermal microfibrils, and collagen fibers [7, 8].

Key Point
The basement membrane zone is considered a semipermeable porous filter that allows the exchange of cells and fluid between the epidermis and the dermis. It also serves as a structural support to the epidermis and keeps together the epidermis and dermis. The basement membrane zone also helps in regulating keratinocyte and fibroblast growth, adhesion, and movement, as well as apoptosis.

1.4 Adnexa

The skin adnexa are composed of eccrine and apocrine glands, ducts, and pilosebaceous cells (Fig. 1.1). Embryologically, they derive from the epidermis as downgrowths and are thus usually ectodermal.

Although the different adnexal structures have various roles, they can all act as a replacement epidermis, in that reepithelialization occurs after damage to the surface epidermis, mainly due to the migration of keratinocytes from the adnexal epithelium to the skin surface. Therefore, it is not surprising that skin sites such as the face or scalp, which contain in abundance pilosebaceous units, reepithelialize faster than skin sites such as the neck, where adnexa of all types are comparatively scarce.

1.4.1 Eccrine Sweat Units

The acrosyringium is the intraepidermal spiral duct of eccrine sweat glands which opens directly onto the skin surface (Fig. 1.1). This is produced by mitosis and upward migration from the dermal duct cells. The straight dermal part of the duct consists of a double layer of cuboidal epithelial cells and is protected on its luminal side by an eosinophilic cuticle. Within the superficial pan-

niculus can be found the coiled secretory acinar part of the eccrine sweat gland. The eccrine coil is located in the deep dermis, surrounded by an extension of fat from the underlying panniculus, in areas of skin such as the back that possess a thick dermis. A sheet of smooth myoepithelial cells surrounds an inner layer of epithelial cells, the secretory part of the gland.

There are two types of secretory cells: large, light, glycogen-rich cells and smaller, darker-staining cells. It is thought that the pale, glycogen-rich cells initiate sweat formation. The darker cells may function similar to dermal duct cells, which actively reabsorb sodium, thus modifying sweat from a basically isotonic to a hypotonic solution as long as it reaches the surface of the skin.

By composition, sweat is similar to plasma, containing the same electrolytes but at a more dilute concentration. Eccrine sweat units are present in nearly every skin site in humans. As a result of many factors, physiological sweat secretion occurs and is mediated by cholinergic innervation. Heat is a prime incentive for increased sweating, but other physiological factors, including emotional stress, are also important.

1.4.2 Apocrine Units

As outgrowths, apocrine units form not from the surface epidermis but from the infundibular or upper portion of the hair follicle (Fig. 1.1). The duct's straight excretory part, which opens into the hair follicle's infundibular section, is composed of a double layer of cuboidal epithelial cells.

The coiled secretory gland lies at the junction between the dermis and subcutaneous fat. It is filled by a single layer of cells, which range from columnar to cuboidal in shape. A layer of myoepithelial cells surrounds that layer of cells. Apocrine coils tend to be more dilated than eccrine coils, and apocrine sweat stains tend to be darker red in H&E pieces, in contrast to light pink eccrine sweat.

Apocrine secretion contains protein, carbohydrate, ammonia, lipid, and iron. Apocrine sweat is odorless until it reaches the surface of the skin where bacteria alter it and makes it odorous. Apocrine release is mediated by the adrenergic innervation and the circulation of adrenomedullary catecholamines.

Apocrine excretion is episodic while the gland's actual secretion is continuous.

While sometimes present in an ectopic position, the human body's apocrine units are usually restricted to the following sites: axillae, areolae, anogenital area, external auditory canal (ceruminous glands), and eyelids. Apocrine glands do not start working until puberty.

1.4.3 Hair Follicles

The uppermost part of the hair follicle, stretching from its opening surface to the entrance of the sebaceous duct, is called the infundibular segment, which resembles the surface epidermis. The isthmus is the part of the follicle between the sebaceous duct and the insertion of the muscle arrector pili (Fig. 1.1). Within this isthmic section, the inner root sheath completely keratinizes and sheds. The lower section contains the follicle's lowermost part and the hair filament. The inferior part goes through cycles of involution and regeneration during life [9–11].

The hair follicles sequentially grow in three rows. The primary follicles are surrounded by two secondary follicles. The density of pilosebaceous units declines during life, likely as the secondary follicles drop out.

The actual hair shaft is formed by the matrix portion of the hair bulb, as well as an inner and an outer root sheath (Fig. 1.3). The sheaths form concentric cylindrical layers. The hair shaft and the inner root sheath move together as the hair grows upward until the isthmus level is shed by the fully keratinized inner root sheath. The upper two sections of the follicle (infundibulum and isthmus) are permanent; each new hair growth process complete replaces the lower segment. The active growth phase, on the scalp, anagen, lasts about 3–5 years. Approximately 80–90% of all scalp hairs are usually in the anagen process. Scalp anagen hairs grow at about 0.37 mm/day. Catagen, or involution, lasts 2 weeks or so. The resting period of the telogen lasts for around 3–5

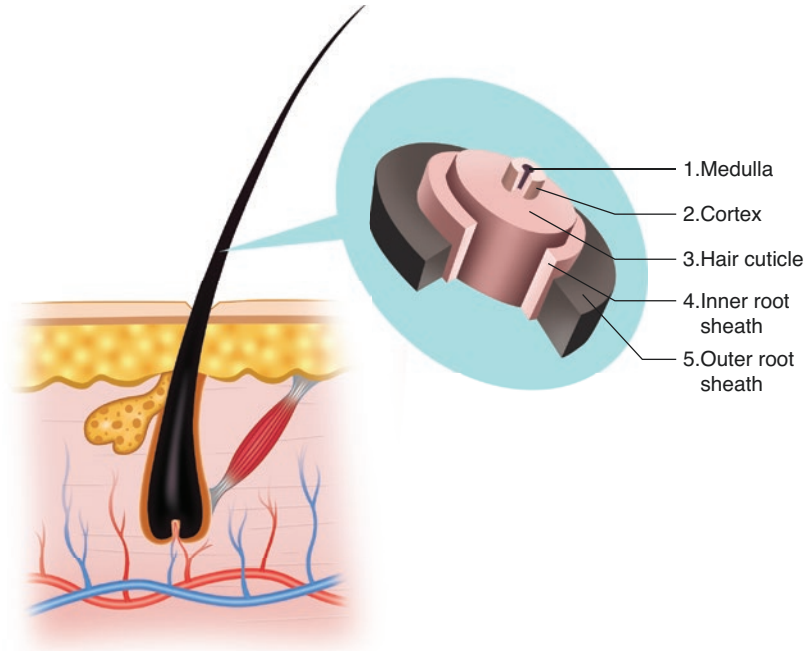

Fig. 1.3 Anatomy of the hair follicle. (1) Medulla, (2) cortex, (3) hair cuticle, (4) inner root sheath, and (5) outer root sheath

months. Most body locations have a much shorter anagen and much longer telogen, leading to short hairs that remain in place for long periods of time without growing longer.

Key Point
Human hair growth is cyclic, but each follicle operates as an individual entity. As a matter of fact, humans do not shed hair synchronously. Each hair follicle goes through sporadic stages of operation and quiescence. Synchronous anagen or telogen termination results in telogen effluvium.

Tips and Tricks
Telogen effluvium is most commonly the product of early release from anagen, such as that caused by weight loss, trauma, febrile disease, or surgery.

The color of hair depends on the degree of melanization and distribution within the hair shaft of melanosomes. Hair bulb melanocytes synthesize melanosomes and transfer them to the bulb matrix keratinocytes. Larger melanosomes are present in black people's hair; in white people's hair, melanosomes are smaller and are aggregated within membrane-bound complexes. Red hair is characterized by melanosomal sphericity. The hair graying results from a reduced number of melanocytes, which produces less melanosomes. Repetitive oxidative stress induces hair follicle melanocyte apoptosis, which results in normal hair graying.

Stem cells in hair follicles are found inside the outer root sheath, at the lowest permanent part of the follicle. These cells cycle more slowly than other cells and are capable of migrating as well as differentiating into various lineages, such as outer and inner root sheaths, hair shaft, sebocytes, and interfollicular epidermis.

1.4.4 Sebaceous Glands

Sebaceous glands emerge as an outgrowth from the upper portion of the hair follicle (Fig. 1.1), made of pale-staining cell lobules with abundant lipid droplets. Basaloid germinative cells are noted at the periphery of the lobules. Such cells

give rise to the lipid-filled pale cells, which are continually extruded into the infundibular portion of the hair follicle through the short sebaceous duct.

Sebaceous glands on the face and scalp are found in greatest abundance, although they are distributed throughout all sites except palms and soles.

Lipids by sebaceous glands contribute to the skin barrier function, and some have antimicrobial properties. Antimicrobial lipids include free sphingoid bases derived from epidermal ceramides and sebaceous triglyceride-derived fatty acids.

1.4.5 Nails

NailsNails act to help grasp small objects and protect the fingertips against trauma and serve a sensory function. On average, fingernails expand by 0.1 mm/day, taking about 4–6 months to remove a full nail plate. With toenails, the growth rate is much slower, with it taking 12–18 months to replace the big toenail [12].

The types of keratin found in the nail are a mixture of epidermal and hair types.

Nail cuticle is produced by proximal nailfold keratinocytes, while matrix keratinocytes form the nail layer.

1.5 Dermis

The dermis constituents are mesodermal in origin except for nerves, which are derived from the neural crest, as with melanocytes.

Below the epidermis, the papillary dermis is composed of fine, nonbundled collagen. Capillaries are present within the papillary dermis, and the postcapillary venule marks the junction of the papillary and reticular (deeper) dermis (Fig. 1.1). The main component of the dermis is collagen, a family of fibrous proteins in the human skin, which comprises at least 15 genetically distinct forms. Collagen is the main structural protein for the entire body; it is present in the tendons, ligaments, and bone lining, as well as in the dermis. Collagen accounts for 70% of dry skin weight. Fibroblasts synthesize the procollagen molecule, a helical structure of unique polypeptide chains, which are then secreted by the cell and assembled into fibrils of collagen. Collagen is rich in hydroxyproline, hydroxylysine, and glycine amino acids. The main component of the dermis is collagen of type I. Type I collagen structure is uniform in width, with each fiber displaying characteristic cross-striations with a periodicity of 68 nm. Collagen type IV is to be found in the basement membrane zone. Type VII collagen is the main structural component of the anchoring fibrils and is primarily provided by keratinocytes.

Elastic fibers differ from collagen both structurally and chemically. They consist of two-component aggregates: protein filaments and elastin, an amorphous material. Elastic fibers are fine in the papillary dermis, while the ones in the reticular dermis are coarse.

The dermis' extracellular matrix consists of sulfated acid mucopolysaccharide, chondroitin sulfate and dermatan sulfate, acidic mucopolysaccharides, and electrolytes.

Key Point
Collagen is the skin's principal stress-resistant substance. Elastic fibers do little to resist deformation and skin tearing but do play a role in maintaining elasticity.

1.5.1 Vasculature

The dermal vasculature consists mainly of two plexuses that are intercommunicating (Fig. 1.1). The subpapillary plexus, or upper horizontal network, contains the postcapillary venules and furnishes the dermal papillae with a rich supply of capillaries, end arterioles, and venules. At the dermal-subcutaneous interface, the deeper, lower horizontal plexus is found and is composed of larger blood vessels. The dermis vasculature at sites of adnexal structures is especially well

formed. The dermal lymphatics and the nerves are connected with the vascular plexus.

1.5.2 Muscles

Smooth muscle occurs in the skin as pilorum arrectores (hair erectors) and as the scrotum tunica dartos and in the areolas surrounding the nipples. The pilorum arrectores are attached to the hair follicles below the sebaceous glands and pull the hair follicle upward in contraction, producing gooseflesh (Fig. 1.1).

Specialized aggregates of smooth muscle cells (glomus bodies) are found between arterioles and venules and are especially prominent on the digits and lateral margins of the palms and soles. Glomus bodies serve for blood shunting and temperature regulation.

Striated voluntary muscle appears as the platysma muscle in the skin of the neck and in the face expression muscles.

Pearls and Pitfalls
The complex network of striated muscle, fascia, and aponeurosis at the face and neck level is known as the superficial muscular aponeurotic system (SMAS).

1.5.3 Nerves

Within the dermis, nerve fibers are contained as part of the neurovascular system, along with arterioles and venules. Nerves migrate parallel to the surface in the deep dermis.

Touch and pressure are mediated by Meissner corpuscles found in the dermal papillae, especially on the digits, palms, and soles, and by Vater–Pacini corpuscles located in the deeper portion of the dermis of weight-bearing surfaces and genitalia (Fig. 1.1).

The sense of temperature, pain, and itch is transmitted by nerve fibers that end in the papillary dermis and around the hair follicles (Fig. 1.2). The impulses travel through the dorsal root ganglia to the central nervous system. Itch evoked by histamine is transmitted by slow-conducting unmyelinated C-polymodal neurons.

The autonomic nervous system's postganglionic adrenergic fibers regulate vasoconstriction, apocrine gland secretions, and contraction of hair follicle arrector pili muscles. Cholinergic fibers mediate the secretion of eccrine glands.

1.5.4 Mast Cells

Mast cells with type I or connective tissue mast cells found in the dermis and play a major role in normal immune response, as well as the susceptibility of the immediate form, contact allergy, and fibrosis. Measuring 7–11 μm in diameter, with ample amphophilic cytoplasm and a thin, round central nucleus, normal mast cells in histological sections resemble fried eggs. Mast cells are distinguished by containing up to 1000 granules in diameter. One can see coarse particulate granules, crystalline granules, and scroll-containing granules. Their cell surface is occupied by numerous immunoglobulin E (IgE) glycoprotein receptor sites.

1.6 Subcutaneous Tissue

The subcutaneous tissue lies beneath the dermis (Fig. 1.1), with lipocytes lobules separated by fibrous septa composed of collagen and large blood vessels. Within the septa, the collagen is continuous with the dermis collagen. As the skin-site thickness of the epidermis and dermis varies, so does the subcutaneous tissue.

Key Point
The subcutaneous tissue offers buoyancy and functions as an energy repository and an endocrine organ. It is an important site for the conversion of hormones.

1.7 Functions of the Skin

Skin plays a vital role in creating a mechanical shield against the outside. The stratum corneum restricts skin water loss, while endogenous antibiotics, such as defensins and cathelicidins derived from keratinocytes, provide an innate immune response against bacteria, viruses, and fungi [13]. The epidermis also includes a network of Langerhans cells, which serve as sentinel cells whose primary function is to monitor the epidermal environment and initiate an immune response to microbial threats, although they may also contribute to immune tolerance in the skin. In addition to these, an array of tissue-resident T cells, macrophages, and dendritic cells also conduct cutaneous immune surveillance in the dermis, providing rapid and efficient immunological backup to restore homeostasis if the epidermis is breached [14].

Melanin, found mainly in basal keratinocytes, provides most of the protection from UV radiation damage to the skin cell's DNA.

Thermoregulation is another essential feature of the skin. Vasodilatation or vasoconstriction of the deep or superficial plexuses of the blood vessels helps to control heat loss. In all skin sites, eccrine sweat glands are found to play a role in heat control through sweating. Apocrine sweat gland secretions contribute to body odor. Sebum, which is secreted from sebaceous glands, provides skin lubrication and waterproofing.

Nails protect the ends of the fingers and toes and are essential for pinching objects.

Skin also has a key function in the synthesis of different metabolic products, like vitamin D.

Two primary forms of human skin exist: glabrous skin (unhairy skin) and hair-bearing skin. On palms and soles, glabrous skin has a grooved surface with alternating ridges and sulci giving rise to dermatoglyphics (fingerprints). Glabrous skin has a lightweight stratum corneum that can be up to 10 times thicker relative to other places of the body . Glabrous skin also includes encapsulated sensory organs in the dermis and a lack of hair follicles and sebaceous glands. Hair-bearing skin, by contrast, has both hair follicles and sebaceous glands but lacks encapsulated sensory organs. The size, shape, and density of the hair follicles vary among different sites of the body. The number of hair follicles remains unchanged until middle life, but throughout life, there is a changing balance between vellus and end hairs. Hair may have significant social and psychological value, reflecting the notion that human skin appearances and associated structures have a significant impact on interpersonal relationships and personal well-being.

Related to the specific function of different body districts, the arrangement and size of elastic fibers in the dermis vary from very large fibers in perianal skin to nearly no fibers in the scrotum. There is also a marked difference in the supply of cutaneous blood between areas of distensible skin such as the eyelid and more rigid areas such as fingertips.

Subcutaneous fat plays a significant role in cushioning damage, supplying insulation and calorie buffer. Around 85% of the total fat of the body is found in subcutaneous tissue in non-obese subjects. Fat also has an endocrine function and releases the hormone leptin, which acts on the hypothalamus to regulate the metabolism of hunger and energy.

Key Point

Many cells in the dermis, subcutis, and hair follicles have stem cell properties and participate in the wound healing process. These cells have been called "precursors" and can differentiate between progeny of the neural and mesodermal differentiation. A subset of dermal and subcutaneous fibroblasts can also have the potential for adipogenic, osteogenic, chondrogenic, and neurogenic differentiation [15, 16].

Take-Home Message

- Skin is the most extensive organ of the body and consists of three layers: epidermis, dermis, and subcutaneous fat.
- Melanocytes are dendritic cells that distribute packages of melanin pigment to

the surrounding keratinocytes to give skin its color.
- The skin adnexa include eccrine and apocrine glands, ducts, and pilosebaceous cells. They have various roles, but all contribute to reepithelialization after damage.
- Human hair growth is cyclic, but each follicle operates as an individual entity. Hair has protective as well as sociobehavioral importance.
- Nails act to help grasp small objects and protect the fingertips against trauma and serve a sensory function.
- The main components of the dermis are collagen, elastic fibers, and extracellular matrix. Dermis confers resistance to deformation and skin tearing as well as elasticity to the skin.
- Subcutaneous tissue lies beneath the dermis and serves as buoyancy, energy repository, and an endocrine organ.
- Many functions of skin include thermoregulation, immune response, UV protection, wound healing, and social interaction.

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Wound Healing: Physiology and Pathology

2

Francesca Toia, Fernando Rosatti, and Adriana Cordova

Background
Wound healing is a multiphasic process that restores the homeostasis of damaged tissues. In recent years, advances in biological and molecular knowledge have allowed for a deep understanding of its underlying mechanisms and phases. The derailments from normal healing have been characterized in detail from both a clinical and biological point of view. Clinical treatment must be based on this knowledge and modulated with regard to individual and wound characteristics.

2.1 Introduction

Wound healing is the response to injury of a tissue/organ and of the entire organism directed to reestablishing its own homeostasis. This process occurs with a considerable degree of variability in different tissues, organs, and individuals due to the normal biological diversity, thus leading to different outcomes in similar conditions.

It is important to differentiate in wound healing two ways of reestablishment of tissue integrity: scar formation and regeneration. Both are normal responses to insults in different tissues or organs, but with specific characteristics.

Scar formation is a mechanism of repair resulting in the formation of a scar, an aspecific connective tissue that replaces the injured tissue as a "patch" to ensure the maintenance of tissues' homeostasis.

Regeneration is the process through which the normal architecture of an organ or tissue is reproduced; this phenomenon occurs in fetal skin.

In the majority of wounds, these two processes coexist and try to find a balance, but usually one of them is more predominant. For example, for cutaneous wounds, scar formation overcomes regeneration, except for fetal wound healing, which does not lead to the formation of scar tissue.

Scar formation is usually a preservation mechanism for living beings, but in some cases, it can also be a medical problem, as for pathological scars or retracting scars, or even in the healing delay of wounds.

Key Point
In humans, perfect tissue regeneration has been demonstrated only in fetal skin; in the adult, individual epidermis, gut epithelium, and the hematopoietic system are the tissues with the highest regenerative capacity.

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2.2 Types of Wound Healing

Before analyzing the biological stages of wound healing, it is appropriate to clinically classify the different ways in which a wound can heal.

1. Primary wound healing: this is the name of the healing process of those wounds whose clear and clean edges are brought together shortly after the traumatic event. It usually involves sutured surgical or traumatic wounds.
2. Secondary wound healing: it represents the type of healing that we find in all those cases in which a space remains between the two skin flaps that will be filled only later by newly formed tissue. This is the case with most traumatic wounds and ulcers.
3. Tertiary intention healing or delayed wound healing: in the case of particularly "dirty" and contaminated wounds, e.g., following an animal bite, it is not recommendable to opt for the closure of the skin flaps by primary intention, as the infectious risk is too high. These wounds are left open to facilitate cleansing and a correct response by the immune system. After a few days, the edges of the wound, which by now will be granulating, will be brought together by a suture.
4. Healing in partial-thickness wounds:: it concerns wounds that do not affect the full-thickness skin, but only part of it, leaving a component of the dermis intact. In this case, there will be a epithelialization starting from the cells of the underlying skin.

2.3 Phases of Wound Healing

It is possible to distinguish four overlapping but different biological stages in wound healing: **hemostasis**, **inflammation**, **proliferation** and **remodeling** (Table 2.1). Although a distinction among these four independent phases can be easily made for didactic purposes, in vivo the boundaries between the end of the previous phase and the beginning of the next are not so defined (Fig. 2.1).

Table 2.1 Phases of wound healing

Phase	Hemostasis	Inflammation	Proliferation	Remodeling
Onset	Immediate	24–48 h	48–72 h	15–21 days
Duration	Minutes	3–7 days	7–15 days	6–12 days
Effectors	Platelets	Neutrophils, macrophages, limphocytes, mast cells	Fibroblasts, endothelial cells, keratinocytes	Fibroblasts, myofibroblasts
Function	Fibrin clot formation	Wound cleaning	Restoration of tissue function and structure	Maturation of granulation tissue into scar

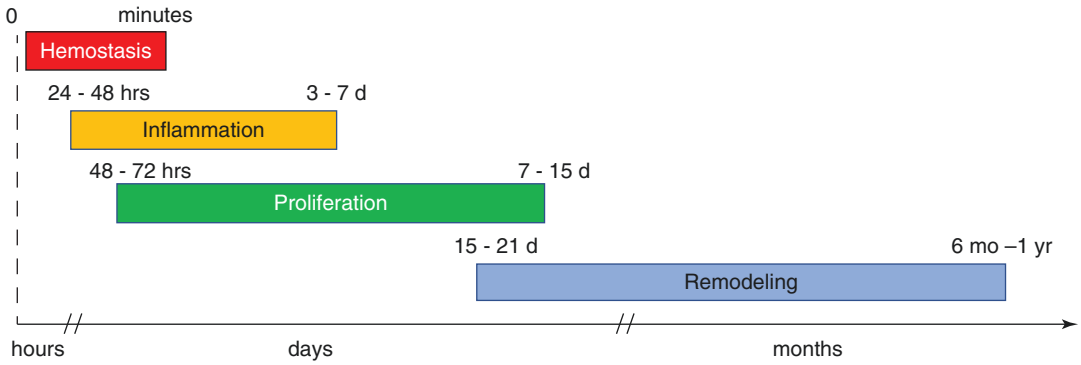

Fig. 2.1 Phases of wound healing

2.3.1 Hemostasis

Hemostasis is the response of blood vessels to the insult and occurs immediately after the injury to prevent exsanguination.

Platelets become activated when they recognize some damage indices through specific integrin receptors, as extravascular type I collagen.

Once the interaction between the platelets and the damaged endothelium has occurred, they begin to release growth factors, soluble mediators, and adhesive glycoproteins that give platelets the signal to aggregate.

Platelet alpha-granules release not only growth factors like PDGF (platelet-derived growth factor), TGF-β, TGF-α (tumoral necrosis factor α), VEGF (vascular endothelial growth factor), and bFGF (basic fibroblast growth factor), but also some glycoproteins that are crucial in the platelet's aggregation process, such as fibrinogen, fibronectin, thrombospondin, and von Willebrand factor. The fibrin clot acts as a provisional matrix. Once this has happened, a sort of "vascular patch" is built, made up from a new and provisional fibrin net and platelets trapped into this [1].

This first step of wound healing also provides the basis for the following phases, avoiding the recruitment of neutrophils and monocytes in the wound site by the secretion of TGF-β and PDGF.

2.3.2 Inflammation

This is the first and almost immediate process occurring within the first 24 h after tissues' injury.

The first cells acting at the wound site are neutrophils, recruited by platelets' degranulation factors (TGF-β), but also by bacterial degradation products. The role of neutrophils is to remove foreign bodies from the lesion and to eliminate pathogens, thus preventing infections. Moreover, they can self-support the inflammation cascade through the release of inflammatory mediators that in turn call, enroll, and activate other cells too (i.e., fibroblast).

By 48 h postinjury, monocytes appear into the wound and differentiate in macrophages, eventually becoming the predominant cell type within the healing wound after three days. The role of macrophages in wound healing is not only to phagocytize debris and bacteria but also to produce growth factors necessary for the production of ECM by fibroblasts and blood vessels.

Macrophages differ from neutrophils in the healing process because they have been shown to be able to regulate the proteolytic destruction of wound tissues more "specifically" through secretion of proteases inhibitors and they are also the main actors in the transition from the inflammatory to the proliferative stage of healing [1].

Depletion studies showed how the absence of macrophages in the first two phases of wound healing could lead to an insufficient deposition of scar tissue and also to hemorrhages [2].

However, Martin et al. demonstrated through studies on leucocyte-deficient mice that no inflammatory cells are absolutely necessary in the healing process. Knock-out mice for neutrophils and macrophages suggested that none of the chemokines produced by these two cell types are absolutely essential in wound healing and that other cells are probably able to supply these deficiencies. Moreover, it was observed that neutrophils were even inhibitory in some aspects of wound healing [3].

2.3.3 Proliferation

The proliferative stage of wound healing begins after three days and continues until almost the third week from the injury.

As it happened for macrophages in the inflammation phase, the proliferation phase is principally based on the activity of fibroblasts. The target of this stage is to replace the provisional fibrin matrix previously built with a new tissue, the granulation tissue.

Fibroblasts migrate into the wound site after being called by degranulation factors of platelets and cytokines of macrophages. Once there, they change their morphology and start producing granulation tissues components to fill the loss of tissue; main components of the granulation tissue are collagen, elastin, and proteoglycans.

Granulation tissue begins to replace the provisional matrix around the fourth day; it also acts as a scaffold for keratinocyte migration. It is a transitional replacement for normal dermis made up of a network of blood vessels, different cell types (fibroblasts, macrophages, endothelial cells), and a net of random organized type III collagen fibers [1]; during the remodeling phase, it will be replaced by type I collagen fibers.

In this process, endothelial cells have the role of recreating blood vessels through angiogenesis. They are activated not only by local factors, such as tissues hypoxia and low pH values, but also by all soluble mediators produced by macrophages or fibroblasts, such as VEGF (vascular endothelial growth factor), bFGF, and TGF-β.

To make reepithelization possible, basal cells (that are the only capable of proliferating) need to lose desmosomes and hemidesmosomes, which are connections between themselves and the basement membrane, respectively; this can happen thanks to the release of growth factors such as EGF (epidermal growth factor), KGF (keratinocyte growth factor), and TGF-α that dissolve these bonds and let migration from the basal layers possible.

2.3.4 Remodeling

After the wound gap has been filled in by the granulation tissue and keratinocytes have migrated, the longest part of the human wound healing starts: the remodeling phase.

It has been shown that it lasts 6–12 months and can continue up to 2 years; it results in the resolution of the initial inflammation process and the restoration of the most similar possible aspect of the wound tissue to the previous one; this aspect has very important clinical implications.

The goal of this phase is to produce the maximum tensile strength through extracellular matrix reorganization. Fibroblast of granulation tissue change their phenotype and acquire typical characteristics of the smooth muscle cells, thus differentiating into myofibroblasts; they can have different skeletal phenotypes, according to the filaments they present (desmin, vimentin, actin) [4]. Their role is to produce the wound contraction through specific cell–matrix interactions.

Remodeling of the extracellular matrix proteins occurs by action of proteolytic enzymes produced by granulation tissue's cells, metalloproteinases, and serine proteases.

Type III collagen is replaced by degradation by type I; there is a strong reduction in the number of cells and the disappearance of blood vessels. All this results in the formation of the scar.

The resistance and the strength of the "new tissue" gradually increase with time, from the 20% of the strength of the skin not affected by the injury at 3 weeks to the 80% at almost one year. This reflects the progressive reorganization of collagen fibers turnover and their cross-linking process.

Primary wound healing is characterized by a reduction of all the previously mentioned phases. The stage of hemostasis is reduced; consequently, the inflammatory one will also be reduced due to a lesser stimulation and to a greater cleaning of the wound. All this will lead to a reduced stimulation of the proliferative phase based on a lower need to lay new tissue to fill the gap. These are the reasons why primary intention wounds usually lead to the best cosmetic results. Also, as wounds that heal by primary intention are often surgical wounds, the surgeon can decide the orientation of the scar, and it is desirable to follow the lines of Langer to favor a correct orientation of the connective fibers.

Key Point

The four phases of wound healing are clearly distinguishable from each other only from a didactic point of view; in clinical practice, the boundaries between the previous and the next are blurred. The alteration of one or more of these four phases leads to a derailment of the process, with the production of pathological scarring.

2.4 Factors Influencing Wound Healing

Factors influencing wound healing processes are both systemic and local/locoregional.

Systemic factors to be taken into account comprehend age of the patient, general clinical conditions, diabetes, immune status, endocrine disorders, natural tendency to have hypertrophic scarring or keloid formation, hereditary healing diseases, and the nutritional state of the patient or smoking habit, while among the local factors there are wound type, presence of infection, presence of hemorrhage or hematomas, iatrogenic factors, and medications.

2.4.1 Systemic Factors

- Age: the age of the patient is in strict relation with the outcome of healing processes. As a matter of fact, older patients are more likely to be affected by systemic diseases, while younger subjects usually present faster recovery thanks to a better blood circulation and therefore tissue oxygenation (the repair speed is inversely proportional to age).
- Diabetes: in diabetic patients, there is a higher incidence of atherosclerosis, which results in a decreased blood flow and therefore in an insufficient oxygen delivery that makes healing more difficult. Another hypothesis is that there is an increased destruction of growth factors in the wound environment in diabetic patients [5].
- Endocrine disorders: the immune status of the patient can be altered by the presence of pathologies (i.e., Cushing syndrome) or because of the assumption of some drugs, such as corticosteroids.
- Wang et al. demonstrated that the chronic exposition to corticosteroids can increase the impairment of wound healing, while this is not true in acute administration [6].
- Hypertrophic scarring: a hypertrophic scar can be the result of systemic or local factors influencing the normal wound healing, but it can also be the expression of a personal predisposition.
- Hereditary diseases: Ehlers–Danlos syndrome, epidermolysis bullosa, Marfan syndrome, osteogenesis imperfecta, and Werner syndrome are only some of the multitude of genetically transmitted pathologies that could affect the process of wound healing, slowing it or not allowing it [7].
- Nutritional state of the patient: Research showed how malnutrition negatively affects the wound healing process prolonging the inflammatory phase by reducing collagen production and fibroblast proliferation; moreover, it can also put the patient at risk for infections by decreasing T-cell function [8]..
- Smoking: it has been demonstrated that smoking habit can reduce the healing potential not only by the direct vasoconstrictor nicotine effect but also by increasing the infection rate and decreasing neutrophils' activity.

2.4.2 Local Factors

- Wound type: a scalpel incision usually ensures a better recovery than a bruised wound.
- Infection: it has been demonstrated that a bacterial load greater than 10^5 per gram of tissue leads to infection and delayed healing [7]. It is important to perform an accurate debriding of necrotic tissue and exudate to ensure a better wound healing.
- Iatrogenic factors: an improper use of dressings as well as the wrong suture technique can result in a pathological or absent scar; also, the use of some drugs, such as corticosteroids, can delay the healing.

Key Point

The presence of infection is one of the local factors that most frequently make difficult the healing process of a wound. Careful cleaning of the wound margins is mandatory for proper wound healing.

2.5 Pathological Wound Healing

Alterations in the physiological healing process can lead to the formation of pathological scars. If the qualitative/quantitative alteration of the connective response is in deficit, an atrophic scar will form, while if the response is in excess, hypertrophic scars or keloids will form.

2.5.1 Insufficient Scarring

Insufficient scarring is found in atrophic scars and chronic ulcers. They represent two different degrees of the same phenomenon. In the former, the quantity of tissue produced is not sufficient to adequately fill the defect; in the latter, the pathogenesis resides more in a deficient supply of nutrients caused by a deficient microcirculation. In both cases, the degradation of collagen overcomes its synthesis.

Atrophic scars usually appear as whitish and poorly resistant surface depressions (Fig. 2.2); the main causes and risk factors are inflammatory processes (acne, cysts, discoid lupus erythematosus), patient related factors (genetic tendency), trauma, and iatrogenic factors [9]. They can be treated by filler or fat graft injection (lipofilling).

2.5.2 Exuberant Scarring

Hypertrophic scars and keloids are the results of excessive collagen formation. The clinical distinction between a hypertrophic scar and a keloid may not always be easy, given the existence of innumerable intermediate forms. By definition, a keloid, unlike a hypertrophic scar, extends beyond the margins of the original lesion, invading the healthy skin.

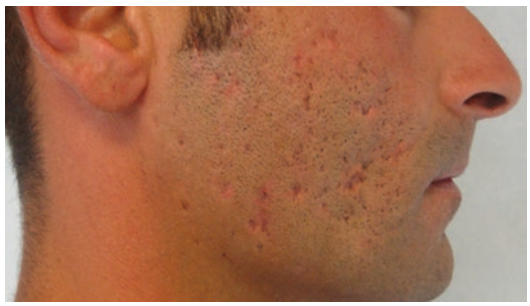

Fig. 2.2 Typical atrophic scars from acne in a young man

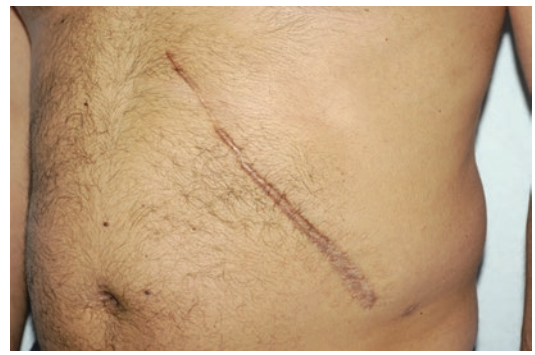

Fig. 2.3 Linear hypertrophic scar following abdominal surgery. Note the reddish color; the scar remains within the margins of the original surgical incision

However, didactically we can distinguish a hypertrophic scar as a reddened, anelastic scar, often painful or itchy, raised within the site of injury [10]; usually, it occurs in 4–8 weeks by the injury, in areas of high tension, and can tend to regression (Fig. 2.3).

Keloids are often clinically similar to hypertrophic scars, sometimes with the same characteristics but more accentuated. The term keloid derives from the Greek (χηλή: claws, offshoot), to indicate those scars that send offshoots that literally invade the surrounding healthy skin (Fig. 2.4).

One of the most important differences between them is that keloids may also appear years later and extend beyond the site of injury [10]. Moreover, once removed, they tend to relapse and get worse clinically (Table 2.2).

The pathogenesis of hypertrophic scars and keloids is not completely clear yet. What is certain is that one of the three physiological stages in wound healing is altered; in particular, there is a loss of balance between the pro-inflammatory cytokines (IL-6) and anti-inflammatory cytokines (IL-10).

Starting from the evidence that the fetal healing process is associated with a poor inflammatory process, as well as a scarless repair, Liechty et al. demonstrated a diminished fetal production of IL-6 in wound healing that resulted in a reduced macrophage recruitment in the healing site and therefore in a consequent reduction in inflammation observed [11].

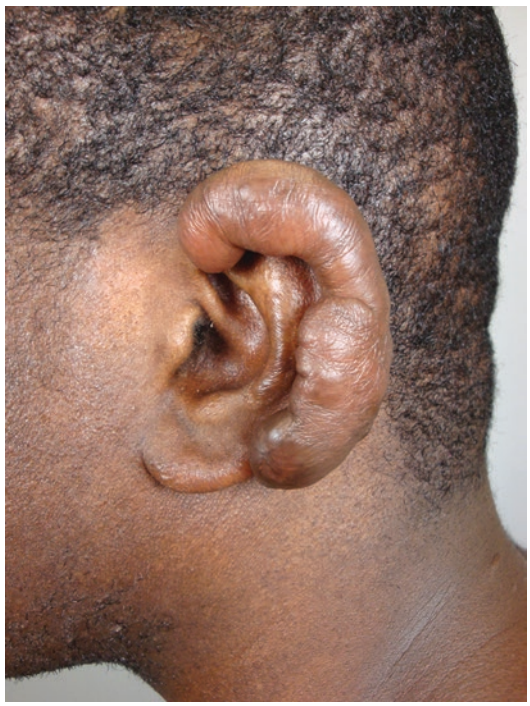

Fig. 2.4 Ear keloid in a young black man following a minor trauma

Table 2.2 Hypertrophic scars and keloids

Hypertrophic scar	Keloid
Red colored	Pink or red colored
Wrinkled surface	Smooth surface
Often itchy and painful More frequent in the sternal and deltoid areas	Rarely symptomatic More frequent in the ear lobe
Usually appears 4 weeks after trauma	Appears between 3 months and 1 year after trauma
Does not extend beyond the edges of the lesion	Extends beyond the edges of the lesion
Slow regression	No tendency to regression High tendency to relapse after excision
Low collagen concentration High fibroblastic component	High collagen concentration Low fibroblastic component

However, Van den Broek et al. in 2015 demonstrated that also in hypertrophic scars not only mRNA levels of anti-inflammatory cytokines were decreased, like IL-10, but also mRNA levels of some pro-inflammatory cytokines like IL-6 were decreased [12].

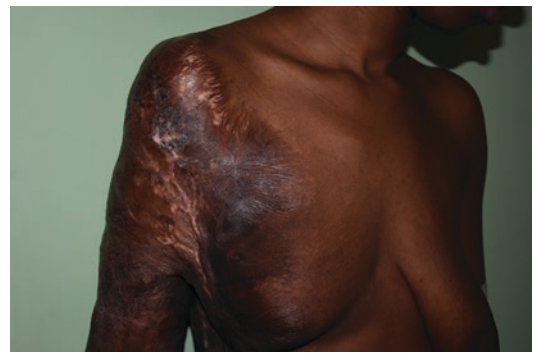

Fig. 2.5 Retracting scar following a burn injury in a young woman, which prevents shoulder abduction

2.5.2.1 Predisposing Factors to the Formation of Hypertrophic Scars

– Local factors:
  - Nature of the scar: i.e., burn scars tend to be hypertrophic more often. Burns also tend to cause retracting scars (Fig. 2.5).
  - Site of injury: anatomic regions subjected to traction have major probability of reaching out to hypertrophic scar formation (sternal region, deltoidal region, auricular region, periorificial region).
  - Healing by second intention.
  - Scar orientation: based on Langer's lines, scars transversal to them have a major probability of being hypertrophic.
– Systemic factors:
  - Age: children are more exposed with respect to elderly persons.
  - Race: black people are more exposed with respect to Caucasian people.
  - Gender: female gender is more exposed.

2.6 Scar Classification [13]

According to the classification by the International Advisory Panel on Scar Management, scars can be described as

- Mature scar: light-colored, flat (it can be flatter than the healthy cutis).
- Immature scar: reddish, itchy, elevated, can be painful; most of them will normally heal, reducing their height and becoming lighter.

- Linear hypertrophic scar: usually occurs after surgery or traumas; red, sometimes itchy, *confined* within the margins of the original surgical incision. It has rapid growth, and then it stops to regress; it definitely matures in almost 2 years.
- Widespread hypertrophic scar: usually occurs after extensive burns. It is red, raised, and itchy; *remains within* the borders of the burn.
- Minor keloid: red, elevated (<0.5 cm), itchy, and focally *goes beyond* the edges of the wound; it may develop up to 1 year after the injury and does not regress on its own. It tends to relapse after surgery.
- Major keloid: large, raised (>0.5 cm), often painful and itchy, red. It *extends over normal tissue.* It can spread over years.

2.7 Exuberant Scar Treatment

Hypertrophic scars can undergo spontaneous involution. If not, medical treatment is necessary for a better quality of life, as well as for considerations strictly related to esthetics.

Before reviewing possible treatments for hypertrophic scars and keloids, it is necessary to remind that all efforts must be put into their prevention, often easier than their treatment, adopting the correct intra- and postoperative tricks (Table 2.3).

Tips and Tricks

Table 2.3 Prevention of exuberant scars

Prevention of exuberant scars
– Carefully examine any preexisting scar on physical examination.
– Clean and disinfect the wound.
– Incise or correct the wound orientation by placing it along Langer's lines and parallel to the flexion folds.
– Minimize the tension of the margins by suturing the subcutaneous tissue well and applying patches perpendicular to the suture line.
– Use sutures with low inflammatory potential (monofilament) and absorbent dressing material, not waterproof.
– Protect the scar from sunlight, at least for the first 6 months.

Key Point

The surgical treatment of exuberant scars, hypertrophic or keloid, has not only an esthetic significance. Very often, they can cause great discomfort to patients, as well as functional limitations.

Pearls and Pitfalls

– The first step in the treatment of exuberant scars is their prevention through targeted intraoperative and postoperative measures.
– Conservative and surgical treatments for exuberant scars must be tailored to the patient and the characteristics of the lesion.
– In the treatment of keloids, surgery alone is often not resolutive and adjuvant treatments should be considered; complete keloid excision has shown higher recurrence rates than intralesional excision.

One of the best and straightforward ways to prevent and treat hypertrophic scars and keloids are occlusive dressings; these are used as a first-line therapy and require either silicone gel sheets or nonsilicone sheets.

Hsu et al. demonstrated that there was a statistical significance in the effectiveness of silicone (gel or sheets) in preventing hypertrophic scars and keloids [14].

At present, the treatment that guarantees higher rates of success is represented by prolonged massage and compression of the affected area. Assuming that collagen is the most abundant protein of the extracellular matrix and that the formation of hypertrophic scars is due to an excessive deposition of it, it has been demonstrated that the effect of the pressure therapy is related to its capability of decreasing collagen formation in the scar environment; RT-PCR studies demonstrated a reduction of major mRNA of type I and type III collagen accompanied by a

reduction of hydroxyproline following pressure application, assuming that it is related to collagen levels [15].

Massage therapy is certainly one of the mostly used prevention and treatment methods for hypertrophic scars. It seems to reduce scar height, pain, pruritus, and vascularization due to a mechanic effect and orientation of the collagen fibers. However, despite its wide use, the efficacy of this kind of technique still requires to be proven by controlled clinical trials to develop evidence-based guidelines to make these results generalizable [16].

The second line of treatment is based on intralesional corticosteroid injection (triamcinolone acetonide 10–40 mg/mL over intervals of 4–6 weeks). Corticosteroids work by suppressing abnormal scars through an immunosuppressive and anti-inflammatory effect and by inhibiting fibroblast and keratinocyte proliferation; injections are prolonged until the scar has flattened [17]. This treatment can be associated or not with cryosurgery monthly. Response rates vary from 50 to 100%, with a recurrence rate of 9–50% [18].

Fluorouracil is a chemotherapy drug that can be used in scar treatment in monotherapy or associated with corticosteroids. It works by inducing apoptosis of fibroblasts by acting intracellularly, being it a pyrimidine analog. Although it can be used in monotherapy, it has been demonstrated that combined therapy with corticosteroids is more effective [18]. It is possible to observe pain after injection, ulceration of the scar, and burning; it must not be used during pregnancy or in immunodeficient patients.

Suitable only for small scars, intralesional cryotherapy is now recognized as a valid therapeutic option. It is an evolution of simple cryosurgery, which is based on the insertion of liquid nitrogen into the lesion, reducing side effects and increasing the effectiveness of the therapy. Liquid nitrogen works by producing anoxia and necrosis of scar tissue, therefore producing a flattening of the scar. Among the main complications are pain (which is reduced compared to simple cryosurgery), edema of the treated areas, and temporary hypopigmentation [18].

Radiotherapy can be considered as an adjuvant therapy, in particularly resistant hypertrophic or keloid scars in combination with intralesional excision. Radiotherapy acts by inducing apoptosis of fibroblast and by reducing collagen synthesis at an absorbed dose of 15–30 Gy to be distributed in six sessions. The success rate reported is 25–88% [18]. This treatment should be avoided in patients under 12 years old and in pregnant women; the main complication is represented by radiation-induced cancers.

Histologic analyses suggest that fractional lasers induce scar remodeling, with a decrease in type I collagen and an increase in type III collagen, increasing pliability and decreasing thickness measured by ultrasounds; moreover, evidence suggests that if it is used immediately postoperatively, fractional laser treatment helps the distribution of drugs enhancing the bioavailability of topical drugs [19].

Surgery usually follows follow the medical treatment described above; this is particularly true in particular in children in whom it represents the last therapeutic option as the recurrence rate is very high (between 45% and 100%) [10]. On the contrary, surgery is the treatment of choice when hypertrophy is due to an incorrect orientation of the scar; in general, it is preferred to associate a complementary treatment following surgery (cortisone injections, massages, compression).

For what concerns keloids, there are no specific treatments for them. In clinical practice, the same aids used for the treatment of hypertrophic scars are used, but with great caution in this case. Surgery certainly plays a central role, although with very high recurrence rates; surgery can be associated with intralesional corticosteroid injection, with a lower recurrence rate when compared to surgical treatment alone. Both complete and intra-cicatricial excisions can be performed; the latter are usually preferred as they seem to partially reduce relapses. The principle is to leave 2–3 mm of keloid on each side of the lesion, in order not to affect healthy perilesional skin; this must be done in such a way as to minimize the tension of the wound. However, if possible, some authors also indicate complete excision of the keloid [20].

Key Point

Intralesional excision should be preferred for keloids. Unlike what one might think, the most "intuitive" treatment in this case is not the most correct. In fact, it is widely demonstrated that the complete excision of a keloid is associated with a very high recurrence rate, higher than that obtained with an intralesional excision.

Take-Home Message

1. Scarring is a complex process aimed at restoring tissue homeostasis following damage. The same type of injury can lead to different outcomes due to inter-individual but also intra-individual differences.
2. Wound healing consists of four different phases: hemostasis, inflammation, proliferation, and remodeling. From a didactic point of view, it is possible to differentiate the four phases as independent from each other; clinically, they overlap and continue in each other.
3. Factors influencing wound healing processes are both systemic and local/locoregional. Age, smoking, diabetes, infection, a lack of nutritional status, or the presence of hereditary pathologies are just some of the conditions that can alter the wound healing process.
4. Alterations in the normal healing process of wounds can result in pathological scarring; a collagen deposition in excess will result in a *hypertrophic scar* or a *keloid*, while its reduction will result in an *atrophic scar.*
5. The first treatment in subjects predisposed to the formation of pathological scars is prevention. It is necessary to avoid all procedures that are not strictly necessary and to take the necessary precautions in the event that these subjects have to be operated on.
6. Massage therapy is certainly one of the mostly used treatments for hypertrophic scars. It seems to reduce scar height, pain, pruritus, and vascularization due to a mechanic effect and orientation of the collagen fibers. However, in many cases, this is not sufficient, and intralesional infiltration of cortisone or alternative therapies are indicated.
7. Surgery represents the last resort considering the high risk of recurrence, especially for keloids. It is useful in cases where pathological scarring depends on factors that can be controlled with further surgery, such as the incorrect orientation of the collagen fibers.

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Complicated Wounds

3

Franco Bassetto, Carlotta Scarpa, and Federico Facchin

Background

Wounds characterized by an abnormal sequence of wound healing processes result in complications that determine the delay and development of chronic ulcers. The nature of the acute wound (trauma, surgery, bite, burn), the location, the size, the depth, and the type as well as the systemic status of patients impact the final outcome.

Limited vascularity in peripheral vascular disease, metabolic disease, immunosuppression, peripheral neuropathy, chronic medications, and connective tissue disease significantly impair wound healing. Furthermore, local factors such as unsteady tissue coverage, previous radiotherapy, and sustained pressure negatively impact the wound healing process. Inflammation, desiccation, and necrotic tissue overlap in the vicious cycle, limiting the correct evolution of tissue repair.

3.1 Introduction

A wound is considered "chronic" after 6–8 weeks of impaired healing and healing failure despite interventions [1].

Infection, necrosis, and osteomyelitis are the main complications affecting wounds. All open wounds are colonized with bacteria, which play a fundamental role in increasing and maintaining the vicious cycle at the base of healing failure. The quantitative and qualitative amount of microorganisms play a large role in wound evolution, with 10,000 colony-forming units of bacteria per gram as a limit between colonization and infection.

Chronic wounds, ulcers, or hard-to-heal wounds are defined as wounds that do not heal properly. They cause severe impacts on patients' quality of life and elevated costs of our society.

In particular, the economic burden for the healthcare system in the world has been calculated as the 1–3% of the total healthcare expenditure in developed countries, with annual costs in North America alone estimated at $25 billion [2].

It is currently estimated that at least 1–2% of inhabitants of developed countries will be affected by ulcerative lesions during their lifetime, with a higher incidence in elderly patients, especially over 80 years, or in younger patients with comorbidities such as arterial or venous vascular failure, diabetes, lymphedema, and neurological disorders such as medullar lesions.

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Table 3.1 History and physical examination that influence healing

Local	Systemic
Age	Malnutrition
Infection	Diabetes
Reduced blood flow	Steroids
Reduced venous drainage	Genetic causes
Neuropathy	Alcohol abuse
Foreign body	Smoking
Pressure	Immunosuppression
Edema	Connective tissue disorder
Irradiation	Chemotherapy

A wound, acute or chronic, should be evaluated in order to define its specific etiopathogenic causes. History and physical examination (including ankle brachial index) allow the physician to recognize local and systemic factors that influence healing (Table 3.1) [3].

3.2 Ulcers

3.2.1 Classification

Ulcers are characterized by a loss of continuity of skin surface that can progressively deepen, affecting subcutaneous tissues to involve muscles and bone tissue. They usually affect lower limbs and areas of chronic pressure as sacrum and ischium.

Skin ulcers can be classified into different categories depending on their etiopathogenesis: (1) arterial ulcers, (2) venous ulcers, (3) lymphatic stasis ulcers, (4) ulcers or pressure lesions—otherwise known as bedsore ulcers, (5) ulcers of neuropathic origin, (6) radiodermitic ulcers, (7) drug extravasation ulcers, and (8) post-traumatic ulcers.

3.2.2 Diagnosis

History and physical examination are fundamental to recognize the cause of the ulcer and to define the principle of treatment.

Laboratory tests that allow recognizing factors impairing wound healing are CBC, albumin, prealbumin, CRP, glucose level, and hemoglobin A1C. Additional diagnostic procedures are transcutaneous oxygen pressure ($tcPO_2$) measurements, Doppler US, and biopsy for microbiology and histopathology. X-rays allow bone evaluation to recognize its involvement or the presence of sharp edges.

Nonetheless, pictures and documentation of wound size, aspect, and infection should be part of patients' charts.

Additional imaging includes arteriography and magnetic resonance.

1. **Arterial ulcers**

   Arterial ulcers represent 5–10% of all ulcers; they are caused by insufficient tissue perfusion and ischemia due to reduced arterial flow. Other diseases such as diabetes or rheumatological diseases can overlap in the pathogenesis of these ulcers. The clinical history is characterized by rapid onset and evolution of the ulcers, which can lead to the forefoot or leg loss, in the most severe cases of vascular occlusion.

   Arterial ulcers are usually located in lower limbs in the areas of bone prominence of the foot, such as the peri-malleolar region. They can affect fingertips or interphalangeal joints such as the hand in patients suffering from rheumatoid arthritis and/or scleroderma. The lesions are well demarcated with the presence of necrotic tissue, with pale perilesional areas, easily subject to overinfection.

   This injury can worsen, involving underlying tissues such as tendons or bone (Fig. 3.1).

2. **Venous ulcers**

   Venous ulcers are the most common type of ulcers, classically localized to the lower limbs triggered by minor traumas and worsened due to insufficient return of retrograde venous flow, related to an incompetence of the venous valves or, more rarely, by a deficit in the calf muscle pump.

   The increase in venous pressure results in the deposition of pre-capillary fibrinogen with subsequent reduced oxygenation of tissues and leukocyte entrapment. The greater ease of adherence of cells to the vessel walls with the release of pro-inflammatory cytokines and chemotactic and free radicals finally brings to

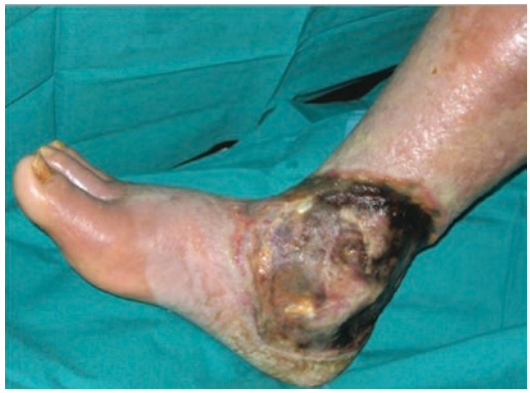


Fig. 3.1 Arterial ulcer

Table 3.2 CEAP classification 2020

C0	No visible or palpable signs of venous disease
C1	Telangiectasias or reticular veins
C2	Varicose veins
C2r	Recurrent varicose veins
C3	Edema
C4	Changes in skin and subcutaneous tissue secondary to chronic venous disease
C4a	Pigmentation or eczema
C4b	Lipodermatosclerosis or atrophie blanche
C4c	Corona phlebectatica
C5	Healed
C6	Active venous ulcer
C6r	Recurrent active venous ulcer

the formation of venous microthrombosis that definitely damages the microcirculation, resulting in increased intracapillary stasis.

Venous ulcers usually afflict the elderly in the distal leg region. They are characterized by irregular edges, fibrin abundance at the bottom of the wound, and hyperpigmented perilesional skin, colored typically by a brown/reddish pigment deposited. They can be divided into stages according to the Clinical-Etiology-Anatomy-Pathophysiology (CEAP) classification developed in 1993 and reported in the 2020 revision (Table 3.2) [4]. The clinical history of venous ulcers is characterized by a chronic and indolent course (Fig. 3.2).

3. **Lymphatic stasis ulcers**

Frequently associated with the previous one, this type of lesion is caused by an insufficient lymphatic vascular microcirculation of the lower limb and can be related to the presence of a pathology called lymphedema.

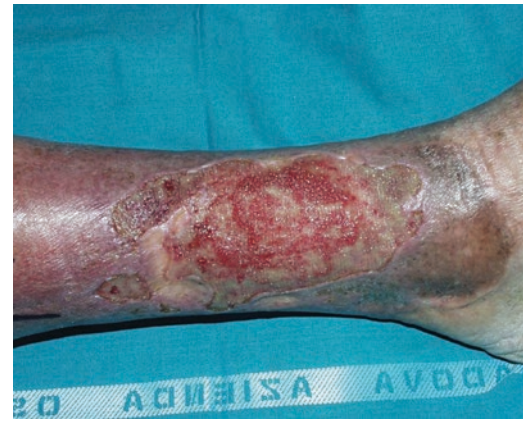


Fig. 3.2 Venous ulcer

Lymphatic ulcers present fibrinous bed with excessive exudate, irregular and sharp edges, and taut perilesional skin. They are usually associated with an important edema of the affected region. The risk of overinfection is very high and directly proportional to the amount of exudate present (Fig. 3.3).

4. **Ulcers/pressure lesions**

Better known as bedsore ulcers, these lesions occur more frequently in elderly bedridden patients or those affected by neurological disorders, such as paralytic patients. These lesions develop in areas that are typically near bone prominences, such as the sacrum, ischium, elbows, or heels. The mechanisms can be different: (1) skin pressure mechanism (just think of the plegic patient in a wheelchair), (2) clutch (mechanism that takes place, for example, at the time of personal hygiene or in the change of sheets), and (3) traction (mechanism that happens especially when the patient is moved to perform the dressings).

Such ulcers can also occur in areas where a urinary catheter or gastric nose tube is fed and is favored by the presence of moisture (e.g., the genital area for the use of the absorbent cloth). They are at high risk of bacterial overinfection, especially if located in the genital or sacral area.

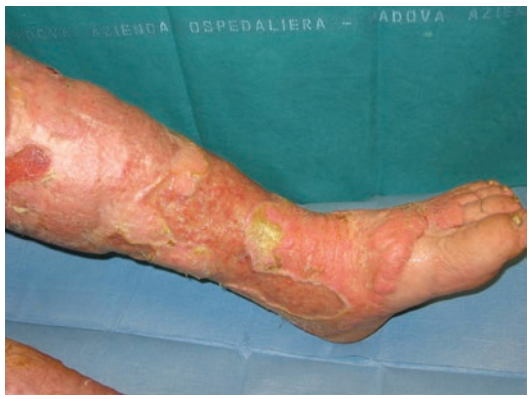


Fig. 3.3 Lymphatic ulcer

They can be divided into four stages, according to the european pressure ulcers advisory panel (EPUAP) classification, [5] depending on whether they affect the epidermis alone or deeper tissue from the dermis to the bone (Table 3.3). In the latter cases, the bone is not only exposed but also affected by an osteomyelitic process. It is shown in the classification provided in Table 3.3 (Fig. 3.4).

5. **Neuropathic ulcers**

   Typical diabetic patients will be addressed in the paragraph dedicated to the diabetic foot (Fig. 3.5).

6. **Radiodermitic ulcers**

   These ulcers stem from the characteristic picture of full-thickness necrosis, arteriosclerosis, and fibrosis, following the use of radiotherapy in the treatment of cancer. They can develop in any area treated with a high dose of radiation, typically lacking a strict temporal correlation. In fact, these lesions arise early or even years after the treatment, according to the dose administered (Fig. 3.6).

7. **Drug extravasation ulcers**

   More frequently visible at the level of the upper limbs, these lesions are caused by the extravasation of drugs or drugs that are administered intravenously and can therefore involve all skin and subcutaneous planes, causing a massive one depending on the amount and type of fluid extravasated. Characteristic is the absence of age with a higher incidence; such injuries can also affect pediatric patients due to their small veins and frequent movement that can displace iv lines (Fig. 3.7).

8. **Post-traumatic ulcers**

   More frequently acute, they can become chronic in the presence of comorbidities or complications such as infections. They can be caused by any trauma involving the skin.

Table 3.3 EPUAP classification

I	Nonblanchable erythema of intact skin
II	Partial-thickness skin loss involving epidermis, dermis, or both
III	Full-thickness skin loss involving damage to or necrosis of subcutaneous tissue that may extend down, but not through, underlying fascia
IV	Full-thickness skin loss with extensive destruction, tissue necrosis, or damage to muscle, bone, or supporting structures

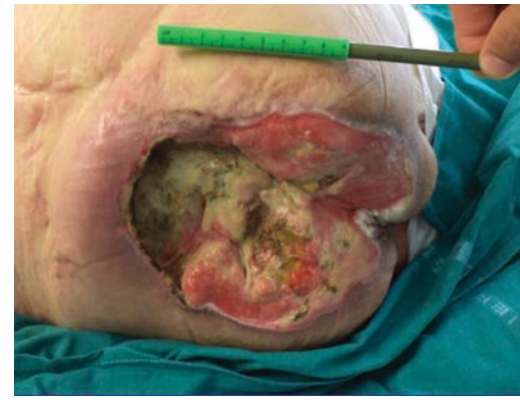


Fig. 3.4 Pressure ulcer

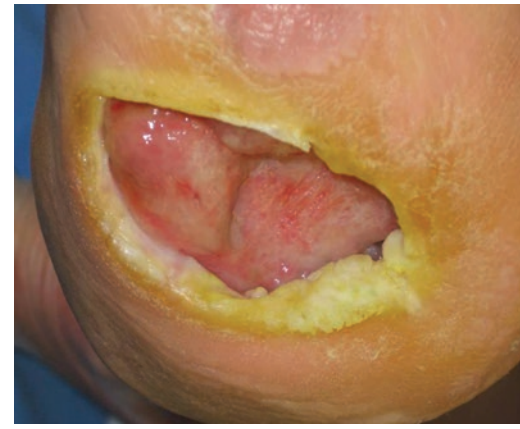


Fig. 3.5 Neuropathic ulcer

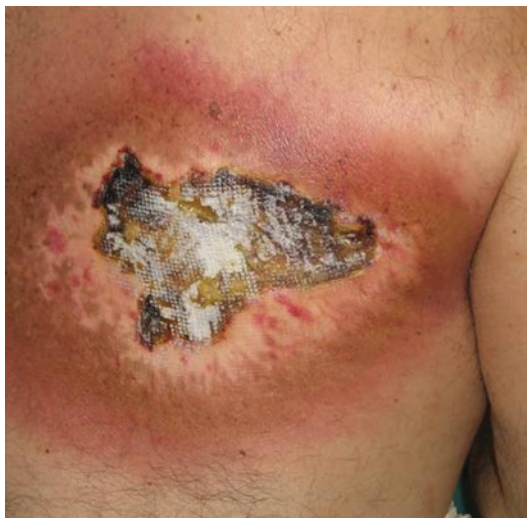


Fig. 3.6 Radiodermitic ulcer

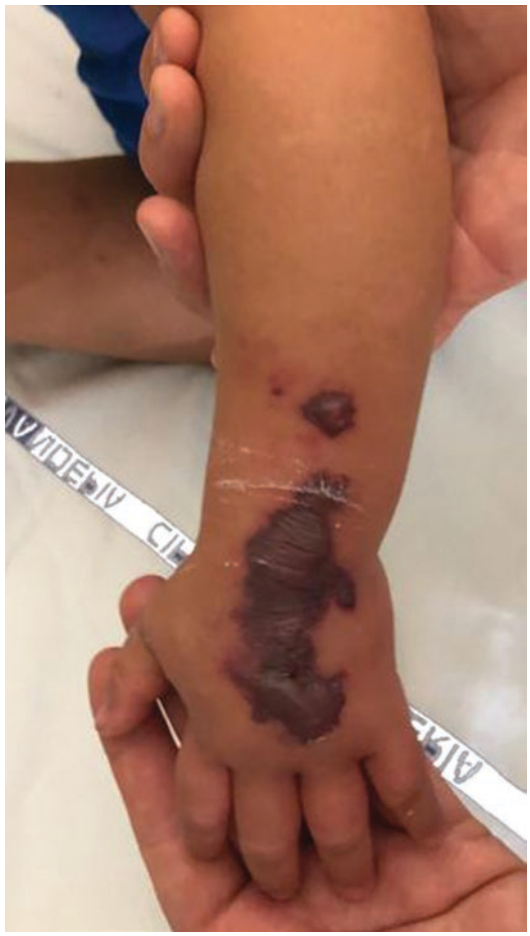


Fig. 3.7 Extravasation ulcer

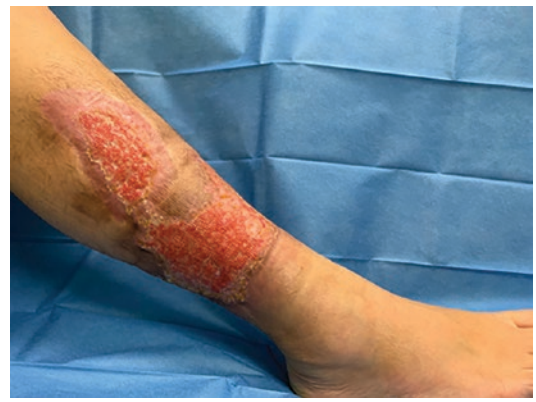


Fig. 3.8 Ulcer from a spider bite

Insect bites, such as the violin spider, are additional causes of traumatic/acute ulcers that can be responsible for massive necrosis of tissues due to the inoculation of toxins (Fig. 3.8).

3.3 The Diabetic Foot Etiology

The diabetic foot [6, 7] is a condition of progressive soft tissue and bone destruction of the normal physiology of the foot, usually starting as minor skin or nail lesion. It is due to sovrapposition of different pathogenic phenomena such as the arteriopathy of macro- and micro-circles, peripheral neuropathy, sensory, autonomic, and motor, and the presence of bone deformities.

Although diabetic foot affects more frequently the elderly and long-lasting carriers of diabetic patients, it is not possible to identify an age group definitely involved, nor a temporal correlation between the date of onset of ulceration and the underlying pathology.

Currently, it is estimated that at least 15% of the diabetic population will be affected over the lifetime by diabetic foot ulcers, and, even more worryingly, the risk of mortality at 5 years for diabetic patients suffering from the diabetic foot is 2.5 times higher than for patients who do not.

Characteristically visible at the sole of the foot, diabetic foot ulcers can worsen depending on the degree of arteriopathy and neuropathy, can involve the toes and the dorsal region, and progressively extend deeply or proximally to the lower limb.

Table 3.4 Texas diabetic foot classification

Stage	Grade			
	0	I	II	III
A (no infection or ischemia)	Pre- or post-ulcerative lesion completely epithelized	Superficial wound not involving tendon, capsule, or bone	Wound penetrating to tendon or capsule	Wound penetrating to bone or joint
B	Infection	Infection	Infection	Infection
C	Ischemia	Ischemia	Ischemia	Ischemia
D	Infection and Ischemia	Infection and Ischemia	Infection and Ischemia	Infection and Ischemia

The process of soft tissue necrosis can involve the subcutaneous tissues until bone, resulting in osteomyelitis. In addition, improper management of patients affected by diabetic foot can be associated with extensive progression to massive necrosis of tissues, infections which in severe cases can determine sepsis and patient death.

Charcot foot is the emblematic aspect of diabetic foot, which has become a bag of bones due to multiple stress fractures related to traumas that the patient does not notice due to the absence of algic sensation.

The diabetic foot can be classified into different stages of impairment depending on not only the ulcer but also the infectious and/or ischemic process, according to the Texas classification (Table 3.4; Fig. 3.9).

3.3.1 Diagnosis

Diagnostic tools are similar to ones used in chronic wounds. The neuropathic component of peripheral disease in diabetes requires a specific part of physical examination.

3.3.2 Possible Complications of Complicated Wounds

Of whatever origin they may be, patients affected by chronic ulcers can develop complications that do not allow or delay their healing with chronicization.

Infection is definitely the most frequent and common complication to all types of ulcers and diabetic foot and is also the most fearsome, being the main cause of hospitalization.

Other complications include complications "specific to the type of ulcers" such as ischemia in the affected area typical of the arterial vascular ulcer and which can also lead to the amputation of the patient's limb, or bone exposure resulting in osteomyelitis, especially for pressure ulcers.

In fact, the possibility that the natural contamination present at the bottom of an ulcer can turn into a real infectious episode is very high, especially in the patient suffering from comorbidities such as diabetes and obesity, and equally high is the possible mortality associated with it, reaching peaks of 42% to 5 years in patients suffering from the diabetic foot.

Bacteria are quickly able to colonize the ulcer; although most of them are commonly present on our skin and are part of the normal skin bacterial flora (see, for example, *Staphylococcus epidermidis* and/or *Staphylococcus aureus*), the absence of an epidermal barrier facilitates their entry and allows the colonization of other bacterial species; the presence of vascular insufficiency or comorbidity such as diabetes and the presence of the exuded can promote not only their multiplication but also and above all the establishment of the so-called biofilm or a glycoproteic barrier produced by the bacteria themselves and that prevents the effectiveness of traditional treatments.

The persistence of the infectious state can, in some cases, evolve into a much more fearsome framework and can lead to the death of the patient if not recognized in a timely manner: necrotizing fasciitis.

Initially characterized by the appearance of skin rash associated with edema and vesicles, this infectious complication involves the fascial region and the underlying areas, which can result in a massive tissue necrosis.

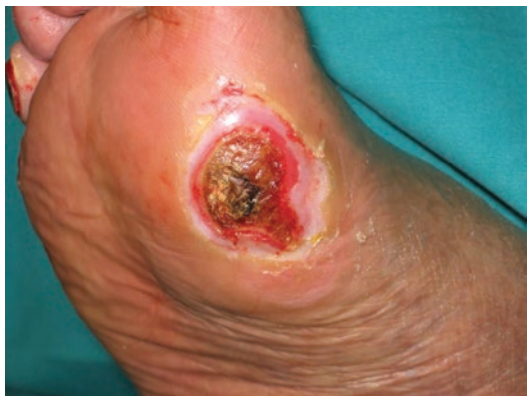
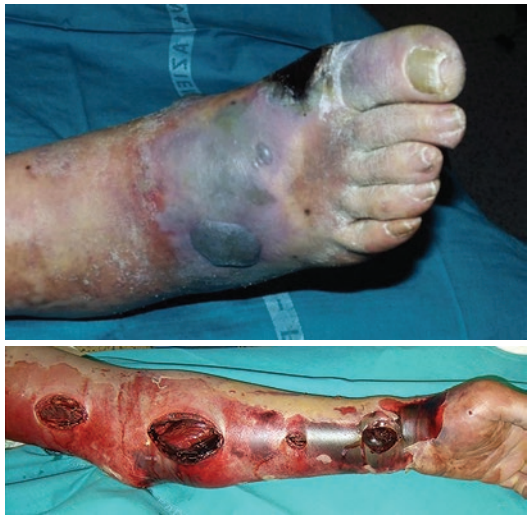


Fig. 3.9 Diabetic ulcer



Figs. 3.10 and 3.11 Necrotizing fasciitis

In order to avoid patient's death, fast diagnosis and treatment are mandatory. These last ones are based not only on clinical signs, but also on: 1) laboratory risk indicator for necrotizing fasciitis (LRINEC) score that analyze parameters (such as Hb, blood sugar, sodium, creatinine, leucocyte count, and PCR) to calculate the probability of the presence of fasciitis itself, 2) instrumental examinations such as TC, which will demonstrate the presence of a fascial thickening accompanied by gas bubbles and sometimes abscesses (Figs. 3.10 and 3.11).

3.3.3 Treatment of Complicated Wounds [8–14]

Patient education and prevention are the major intervention to limit complications. Ulcer's management is aimed at reverting the pathogenic cause of the disease. Therapeutic strategies tailored specifically to each wounded patient should address all systemic and local factors in order to improve healing potential. Multidisciplinary evaluation allows medical experts to merge therapeutic actions to restore normal physiology. The **TIME (Tissue, Inflammation/infection, Moisture, Edges)** approach consists in an ordered stepwise strategy to obtain wound closure or adequate wound bed preparation for reconstructive treatment.

Tissue consists in the assessment of the wound to determine the presence of necrotic tissue, foreign body, biofilm, and slough. Debridement is the main step of wound treatment removing necrotic slough and diminishing the infectious bioburden. It can be obtained surgically or gradually and conservatively. *Inflammation/infection* involves the management of hyperinflammatory state that negatively impacts wound healing. *Moisture imbalance* is aimed at addressing defects or excess of tissue hydration, which can limit cell survival. *Edges* are focused on treating and preserving the physiology of the skin surrounding the wounds.

Advanced dressing allows limiting the number of dressing changes, increasing the healing potential.

In addition to the topical treatments based on conservative debridement and advanced dressings, without lasting benefit in complicated wounds, surgical treatments are often mandatory to clean the wound bed and reduce the risk of infection. Debridement with a cold blade, with a hydrodebrider or an ultrasonic debrider, is the main step for the management of complicated wounds. Tissue defects can be reconstructed with skin grafts (with or without dermal substitutes), local or microsurgical flaps. Negative pressure wound therapy with or without instillation allows

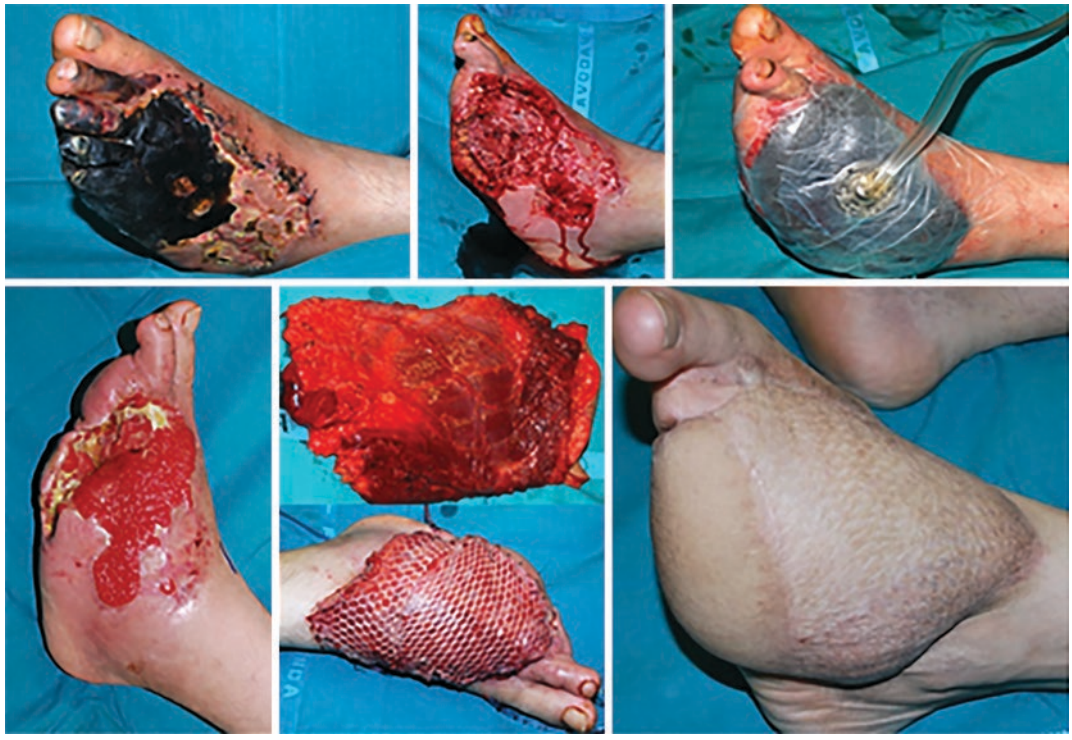


Fig. 3.12 Debridement, negative pressure therapy, and free flap coverage complicated diabetic foot

performing serial debridement, limiting or treating bacterial contaminations if necessary. In this case, the skin graft or flap surgery should be postponed and performed to obtain a valid bottom of the lesion (Fig. 3.12).

Alternatively, wound bed preparation techniques allow wound management to perform definitive reconstruction or improving local wound treatment. (1) Hyperbaric oxygen therapy is very useful, especially in cases where there is an initial tissue suffering and/or an infectious process. (2) Shock waves, vibrating acoustic waves that stimulate the production of VEGF with capillary formation, reduce the inflammatory state by limiting the ability of leucocytes to adhere to the vasal walls and stimulate fibroblasts to produce collagen. (3) Biofluorescence or the administration of blue LED light is associated with or not with chromophore gel that is tasked with stimulating the proliferation of fibroblasts and the consequent production of collagen, limiting bacterial charge by interacting with environmental oxygen, modulating inflammation by reducing TNF alpha and IL-6, and finally modulating growth factors such as VEGF or FGF (Fig. 3.13).

In the case of local infection extending beyond wounds as diffuse cellulitis or fasciitis, multidisciplinary management should include urgent surgical debridement with fasciotomy and subsequent antibiotic therapy (Fig. 3.14).

The amputation of the affected area, especially in cases of ischemia of the diabetic limb or foot, unfortunately still remains a possibility (Fig. 3.15).

3.4 Osteomyelitis [15–22]

Bone infection is one of the most severe complications in wounds. Pathogens attach the bone in the sessile-based organization of biofilm due to spreads from soft tissues (i.e., contiguous spread), direct implantation of an infectious during surgery, or penetrating trauma or hematogenous seeding.

Acute osteomyelitis occurs mainly in children and is of hematogenous origin. In adults, on the

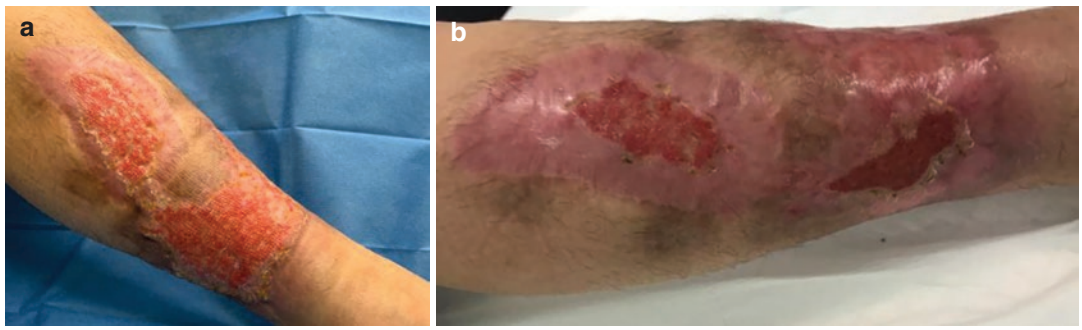


Fig. 3.13 (**a**) pre-fluorescent light energy treatment; (**b**) after 2 weeks of fluorescent light energy treatment

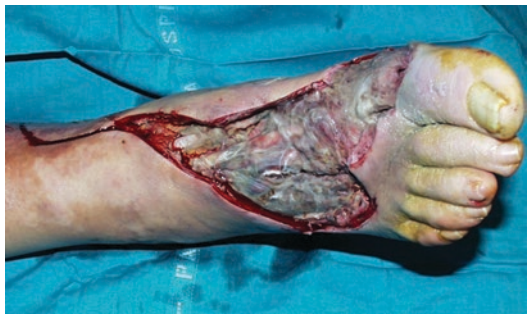


Fig. 3.14 Fasciotomies in necrotizing fasciitis

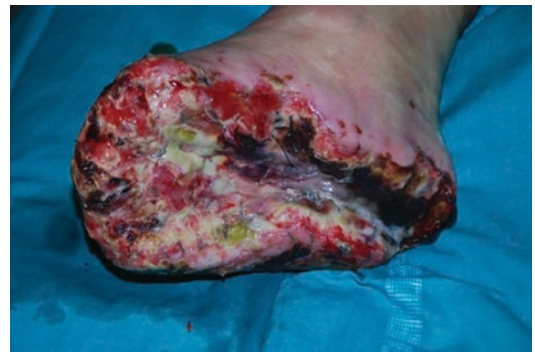


Fig. 3.15 Amputation

contrary, osteomyelitis is usually a subacute or chronic infection secondary to an open injury to bone and surrounding soft tissue. The presence of bone hardware used in fracture fixation or foot stabilization increases the risk of biofilm formation, the osteomyelitic process, and chronicization.

The staging system proposed by Cierny–Mader classification guides the management of osteomyelitis according to the anatomy of infection and patient condition. The first part of the system specifies four stages: type 1 involves medullary bone; type 2 or superficial involves the surfaces of bones and occurs in deep soft-tissue wounds and ulcers; type 3 or localized is an advanced local infection of bone and soft tissue that often results from a polymicrobially infected intramedullary rod or open fracture; and type 4 or diffuse osteomyelitis represents extensive disease involving multiple bony and soft tissue layers.

The second part of the Cierny–Mader classification system describes the physiologic status (host A, B, or C) of the host to define the candidability to surgery.

In chronic wounds, bone exposure at the base of a chronic, open wound is associated with bone infection and development of superficial osteomyelitis as in pressure sores or diabetic foot. The medullary contents are not involved.

On the other hand, osteomyelitis developed after bone fractures classified as localized, or diffuse osteomyelitis can cause chronic wounds and fistulization.

Patient diagnosis requires laboratory studies and imaging in order to define severity and to program surgical treatment. Complete blood count, erythrocyte sedimentation rate, and the C-reactive protein are the main lab tests needed.

Radiological studies useful in the diagnosis and defining osteomyelitis are conventional radiography, computed tomography, magnetic resonance, or nuclear imaging.

Magnetic resonance and positron emission tomography–computed tomography (PET-CT) are useful to confirm the suspect of osteomyelitis in suspected cases and to define the spread of bone

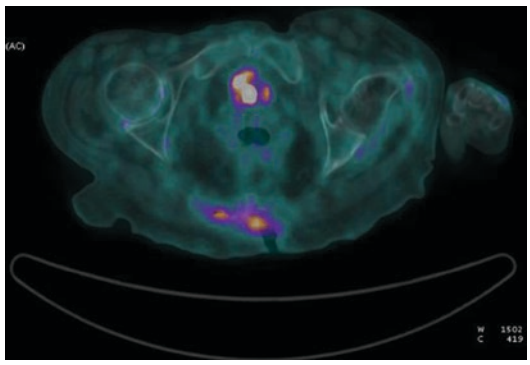


Fig. 3.16 Osteomyelitis in PET/CT

infection (Fig. 3.16). However, in chronic wounds with an exposed bone, they are not necessary and the main diagnostic aid is represented by tissue biopsy for microbiologic and histologic examination.

Multidisciplinary approaches, involving an orthopedic surgeon, an infective disease consultant, a plastic surgeon, a microbiologist, are fundamental for the treatment and radicalization of infective focus.

Osteomyelitis treatment is based on surgical debridement, systemic antibiotic therapy, and vascularized soft tissue coverage/repair (Fig. 3.17). Surgical removal of necrotic and demineralized bone should be aimed at obtaining a vital and bleeding bone as confirmed by the paprika sign. The need for bone stabilization should be evaluated preoperatively.

In the case of deficient peripheral vascularization and osteomyelitis, amputation represents the first choice in order to allow adequate soft tissue closure.

Prolonged antibiotic therapy is indicated to obtain pathogen eradication.

Key Points

- A wound is considered "chronic" after 6 to 8 weeks of impaired healing and healing failure despite interventions.
- Classification of different ulcers is based on etiology; different severity scales are applicable for different wounds.
- Single surgical debridement is not enough for cure.
- Correct treatment is based on a multidisciplinary approach.
- Prevention and early treatment are the most efficacious approach.

Pearls and Pitfalls

- Many different etiologic factors are usually associated and overlapped.
- Single surgical debridement is not enough for cure.
- Correct treatment is strongly dependent on specific and correct diagnosis.

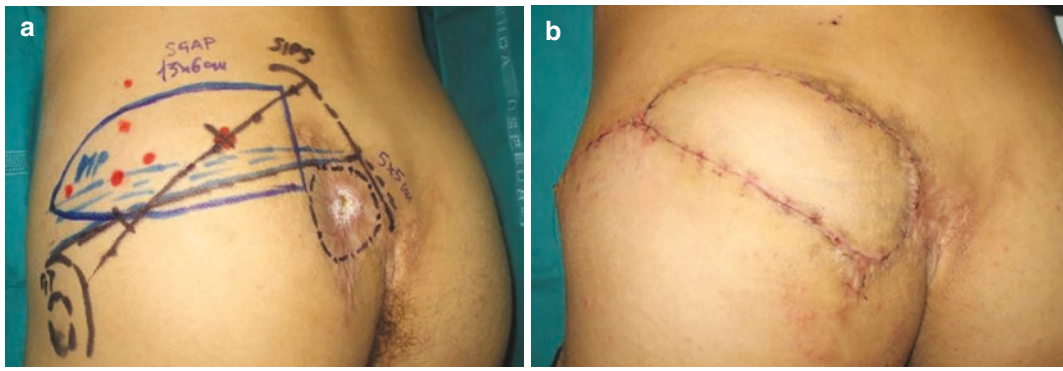


Fig. 3.17 (**a**) Preoperative marking of SGAP flap in pressure ulcer; (**b**) postoperative at 1 month

Tips and Tricks

- Correct treatment is based on a multidisciplinary approach.
- The role of history and physical examination is fundamental in evaluating each wound; further workup allows to define tailored treatment.
- Prevention and early treatment are the most efficacious approach.

Take-Home Message

- Systemic or local factors can compromise the normal process of healing, causing the formation of complicated wounds.
- A wound is considered "chronic" after 6 to 8 weeks of impaired healing and healing failure despite interventions.
- All open wounds are colonized with bacteria.
- Classification of different ulcers is based on etiology; different severity scales are applicable for different wounds.
- Treatment usually conservative.
- Osteomyelitis requires surgery and antibiotics.

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Suture Techniques

4

Michele Maruccia, Rossella Elia,
and Paolo Claudio Marannino

Background

The earliest reported sutures belong to ancient Egypt (3000 BC). Eyed needles were invented between 50,000 and 30,000 BC, while by 20,000 BC, bone needles became the gold standard unsurpassed until the Renaissance. African tribes used to ligate blood vessels with the help of tendons and suture the wounds using acacia thorns. North America used cautery. Indian physician Sushruta described in detail wound closure and suture materials around 500 BC. Roman physician Galen in the second century described gut sutures; the so-called "catgut" was manufactured during the tenth century by harvesting it from sheep intestines.

Briefly, the closure of wounds with the help of needle and thread has been practiced by humankind for several thousand years, and historically various suture materials have been used, from those derived from plant or animal materials to synthetic ones.

4.1 Introduction

The objectives of suturing are the following:

- To promote contact between the edges of the wound to achieve rapid healing.
- To give the wound resistance to tension.
- To limit residual dead spaces between the margins of the wound.
- To prevent complications, i.e., infection, hemorrhage, and tissue necrosis.
- To preserve the normal contour and shape of tissue.

Until the new fibrous tissue restores the physical-mechanical continuity of the tissue, the strength of the wound (or anastomosis) is completely dependent on the sutures. The "normal" level of healing is highly variable and poorly defined. It depends mainly on the level of perfusion and oxygenation of the tissue but also on the possible onset of phenomena that may delay healing (immune response of the patient, infections, critical physical condition, nutritional status, age, nature of the wound).

The suture materials must respect some basic principles, some of which are common to all implantable medical devices:

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- Biocompatible.
- Inert.
- Sterile.
- Ensuring maximum resistance in terms of wound support.
- Guaranteeing minimum trauma to the tissues.
- Minimizing the inflammatory response of the body.

4.2 General Principles

4.2.1 Handwashing and Patient Preparation

Hand hygiene forms the basis of antiseptic techniques aimed at reducing the incidence of nosocomial and surgical site infections (SSIs). The contaminated hands of health workers are known to result in nosocomial and surgical site infections, which lead to severe morbidity and mortality, prolonged hospital stay, and increased hospital costs.

Therefore, the aim of surgical handwashing is to clean up the colony-forming units (CFUs) of bacteria, prevent their transfer, or reduce the amount of permanent flora of the hands, which would ultimately prevent surgical wound contamination from microorganisms found on the hands of the surgical team.

According to a recent review [1], there is no firm evidence that one type of hand antisepsis is better than another in reducing SSIs. Chlorhexidine gluconate scrubs may reduce the number of CFUs on hands compared with povidone-iodine scrubs; however, the clinical relevance of this surrogate outcome is unclear. Alcohol rubs with additional antiseptic ingredients may reduce CFUs compared with aqueous scrubs. With regard to the duration of hand antisepsis, a 3-min initial scrub reduces CFUs on the hand compared with a 2-min scrub, but this is very low-quality evidence, and findings about a longer initial scrub and subsequent scrub durations are not consistent. It is also unclear whether nail picks and brushes have a different impact on the number of CFUs remaining in the hand (Videos 4.1 and 4.2).

Key Point

- The surgical hand and arm scrub procedure must be performed in the scrub suite before entry into the surgical suite/operating room.
- After scrubbing, you should hold up your arms to allow water to drip off your elbows.
- After scrubbing, dry with a sterile towel.
- Hold hands, forearms away from the body and higher than elbows until putting on sterile gown and gloves.

Preoperative shaving must be done immediately prior to the operation and with the least amount of skin injury possible; it makes the surgery, the suturing, and the dressing removal easier. Afterward, the skin at the incision site must be prepared; the same antiseptic agents used for hand scrubbing are available for preoperative preparation of the skin. The iodophors, alcohol-containing products, and chlorhexidine gluconate are the most commonly used agents. Washing with antiseptics is begun at the exact location where the incision will be made, moving outward in a circular motion. A "no touch" technique is used in which an area already washed is not returned to with the same sponge. In septic, infected operations, it starts from the periphery toward the planned area of the operation. After the skin preparation, the disinfected operating area must be isolated from the non-disinfected skin surfaces and body areas. The concept of local barrier protection has led to the development of a vast array of different techniques with the goal of preventing microbial spread from the patient into the surgical field. Ideal draping material should be impermeable to fluid, resistant to mechanical damage, and should remain in place during manipulation. The initial boundary should surround the planned incision site. An additional superficial layer extends to cover the body beyond the preparation site to minimize the risk of contamination and allow surgical personnel to maneuver while abiding by the aseptic technique.

4.2.2 Surgical Instruments

The majority of skin procedures may be performed with just a few key instruments: scalpel, forceps, needle holder, and scissors (Fig. 4.1).

The most commonly used *scalpel* blades are the #10 (curved cutting edge with an unsharpened back edge; a more traditional blade shape) and the #15 blade (a smaller version of the #10). The #10 blade is better for long, straight incisions. The smaller #15 blade is well suited for short, tortuous incisions and is suitable for most plastic surgery procedures. In general, the scalpel is held between the thumb and index finger with the middle finger supporting the handle from below, also called the "pencil grip." The most effective method of making the incision is to begin with the tip of the blade, for accuracy, and then to use the sharpest portion of the belly of the blade for the incision, with completion of the cut utilizing the tip once again.

The *forceps* are available with or without teeth. The forceps with teeth are preferable for picking up tissue rather than by using the atraumatic style of forceps. All of these pick-ups must be handled gently to avoid tissue crush injury and are best used as retractors, rather than as grasping forceps. The forceps should be held so one arm is an extension of the thumb and the other is an extension of the index finger. The base of the forceps should rest on the dorsal surface of the web space between the thumb and

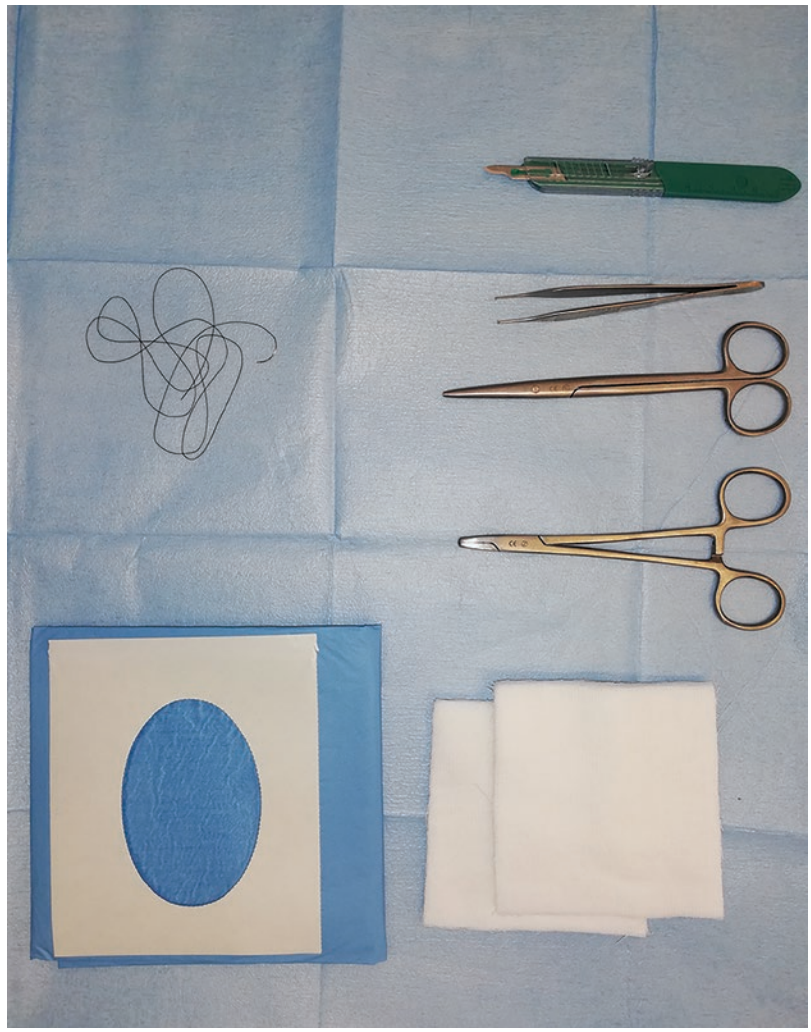

Fig. 4.1 Essential surgical instruments and equipment

index finger. During suturing, the forceps allow the surgeon to create counter traction and control the position of the skin edge to facilitate passage of the needle perpendicularly through the skin. The forceps should also be used to grasp the needle when repositioning it in the needle holder. You should never touch the needle with your fingers.

Scissors are sharp tools as well as scalpels; they differ in shape, length, strength, and angle. They are formed by two articulated branches whose front part has the shape cutting edge and the back portion, the ring handle. Scissors are generally held with the thumb slightly in one ring and the ring finger in the other. The index finger stabilizes the instrument by resting on the shaft. The cut is generally performed with the scissors in the vertical position to ensure the total vision of what is being sectioned, and never horizontally, of the scissors because you cannot see the portion underneath that is dissected. The tips of a scissor must always face upward and never downward. The four main functions of scissors are for cutting tissue, dissecting/undermining, suture removal, and bandage removal. The fine Metzenbaum scissors are commonly used for dissection purposes and may be used to cut lighter capsules and small fibrous tissue connections. The sturdier Mayo scissors are used to cut ligaments, larger fibrous bands, and thick capsular tissues. Stitch or suture scissors may be straight or curved but are usually blunt to prevent damage to adjacent tissues during the suture cutting process.

Needle holders, or needle drivers, come in a variety of styles and sizes. The selection of a needle holder from this wide choice of instruments depends upon the nature of the procedure and the operator's preference. They should be comfortable as well as functional. There are several techniques for holding the needle holder. The most common method is to place the thumb and ring finger slightly into the instrument's rings. This allows them to pronate and supinate and to open and close the jaws of the needle holder. Avoid inserting the fingers far into the rings of the instrument since this will tie up the fingers and impede mobility. Some surgeons do not put their fingers into the rings at all and simply grasp the rings and body of the needle holder in the palm of their hand.

Tips and Tricks
When holding instruments

- Use three-point control: have three points of contact between hands, instrument to increase precision.
- Extend the index finger along the instrument to provide extra control and stability.
- Place only fingertips through handle loops: rotation comes from the wrist; you can achieve greater control, and it is quicker to pick up, put down.

4.2.3 Tissue Handling

The general principle of tissue handling is very simple: be gentle at all times. This involves the initial approach of injecting the skin and deeper layers, marking the skin incision, draping the surgical area, making the incision, and the careful use of retractors and other surgical instruments used during the procedure. Keeping the tissue layers moist during the procedure is very important, and the use of frequent cool sterile flush and suction is encouraged.

Lidocaine is the most frequently used infiltrative local anesthetic. For diffuse infiltration, several factors can reduce injection discomfort: slow injection rate, use of small-bore needles (27-gauge or higher), room-temperature injection fluid, and injection with the use of small-volume syringes. During infiltration, the surgeon must avoid intravascular injection. This complication can be minimized by frequent aspiration during the introduction of the local anesthetic.

Whether the surgeon is completing a primary wound closure or transferring a local flap, attention should be directed toward the details of wound approximation. Wound closure often begins with the placement of subcutaneous sutures. Proper eversion of the skin at the margin of the wound is required for accurate place-

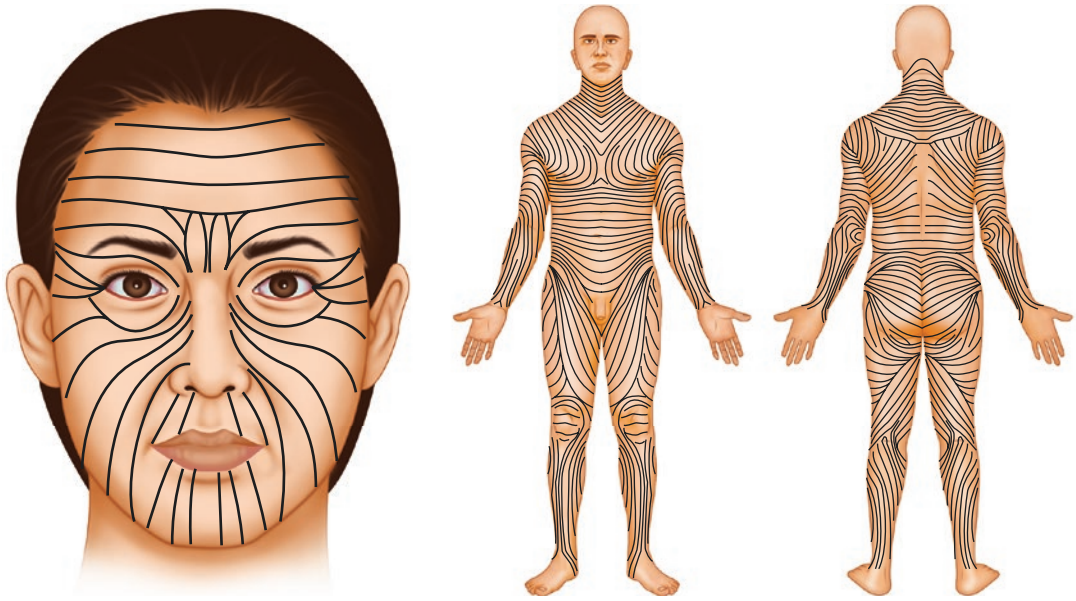

Fig. 4.2 Orientation of Langer's lines throughout the body

ment of these sutures. Soft-tissue dissection is an essential component of wound closure. Proper technique includes a uniform undermining of the skin for primary wound closure. Dermal sutures provide most of the strength in wound closure, limiting scar stretching after skin sutures are removed. Wound repair should be performed with the least wound closure tension necessary to approximate the wound margins (Video 4.3).

4.2.4 Incision Placement and Planning

Skin tension lines, also known as Langer's lines or lines of cleavage, are linear clefts in the skin that indicate the direction of orientation of the underlying collagen fibers. At the same time, they run parallel to the principal muscle fibers below the skin. The principle is that if the skin is disrupted parallel to the long axis of the fibers, the wound tends to reapproximate. Conversely, if the wound crosses the long axis of the fibers perpendicularly, they are disrupted in a manner that causes the wound to gape open; therefore, greater tension is required to close the wound. Lacerations that run parallel to these lines naturally reapproximate the skin edges. Lacerations that run at right angles to the tension lines tend to gape apart. Figure 4.2 illustrates the typical orientation of Langer's lines throughout the body.

4.3 Closure Materials

4.3.1 Sutures

The ideal characteristics of suture material include (1) good tensile strength, (2) good knot security, (3) minimal tissue reactivity, (4) optimal handling and workability, (5) ability to resist bacterial contamination, and (6) favorable absorption profile.

Suture threads can be classified according to different criteria (Fig. 4.3).

Classification on the basis of origin:

- Natural: these are sutures manufactured from raw materials of natural origin (vegetable or animal), e.g., silk and catgut.
- Synthetic: These are sutures produced from polymerization of molecules or compounds of chemical origin.

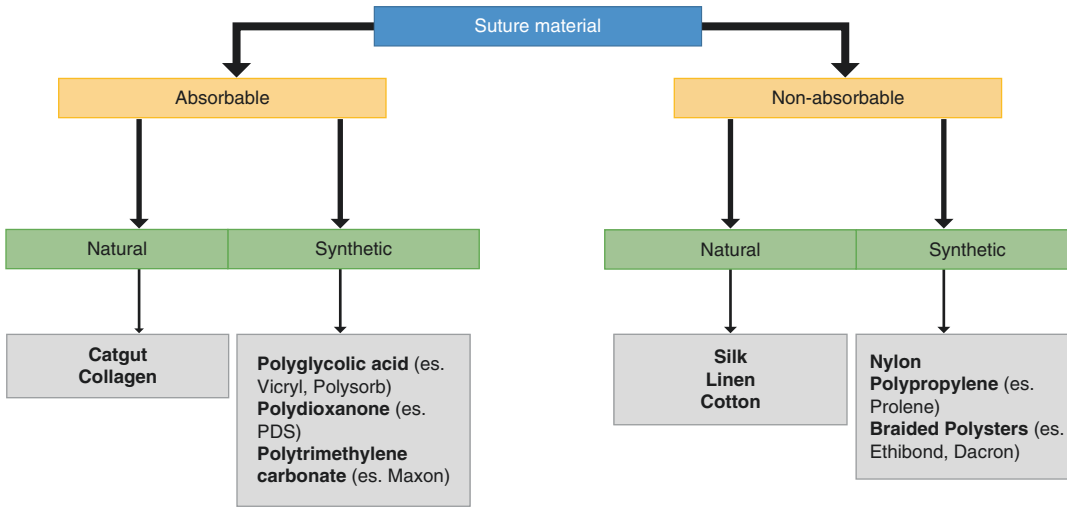

Fig. 4.3 Classification of suture threads

Classification on the basis of the number of threads:

- Braided: they are sutures composed of several thinly wound monofilaments around a central core (GRAINED) or twisted around themselves (PORTS).
- Monofilament: they are sutures made up of a single monofilament that makes them compose the structure.
- Barbed: the presence of micro blades on the surface of the wire and the exclusive terminal retention ring allows a suture to be carried out without knots, ensuring a safe, effective and fast closure.

Characteristically, multifilament suture material (e.g., silk) tends to be easier to handle and tie, and knots in multifilament material are less likely to slip. On the other hand, monofilament materials (e.g., nylon or Prolene) are less traumatic since they glide through tissues with less friction, and they may be associated with lower rates of infection. Since monofilament materials are more likely to slip, one generally ties knots with five or six "throws" when using monofilament materials (in contrast to three throws with silk). Despite the greater number of knots required, monofilament materials such as nylon are generally preferred for skin closure because they stimulate less tissue reaction, are less traumatic, may have less likelihood of infection, and provide a better cosmetic result [2].

Classification on the basis of absorbability

- Absorbable.
- Nonabsorbable.

Absorbable sutures lose their ability to give over time mechanical wound support. As a result, they are metabolized according to different mechanisms and "absorbed" by the body. Nonabsorbable sutures maintain permanently or over a long period of time the ability to mechanically support the wound edges. They can undergo a slow and gradual metabolization that, however, does not compromise their mechanical characteristics over time.

The original absorbable suture materials were plain and chromic "catgut," which actually consisted of processed collagen derived from the submucosa of animal intestines. Plain gut is broken down enzymatically after about 7 days. Chromic gut is collagen treated with chromium salts to delay breakdown. Chromic gut typically loses its strength after 2–3 weeks and is completely digested after about 3 months. Now there are many synthetic absorbable materials made from polymers (e.g., Vicryl and Monocryl). These materials are broken down nonenzymatically by

Table 4.1 Commonly used absorbable and nonabsorbable sutures

Suture	N. Threads	Tensile strength	Knot security	Tissue reactivity	Application
Absorbable sutures					
Polyglycolic acid (Dexon®)	Braided	20% at 21 days	Good	Low	Subcutaneous high tension closure, vessel ligation
Polyglactin (Vicryl®, Polysorb®)	Braided	75% at 14 days 50% at 21 days	Good	Low	Subcutaneous high tension closure, vessel ligation
Polydioxanone (PDS II®)	Monofilament	70% at 14 days 50% at 30 days	Poor	Low	High tension subcutaneous contaminated tissue
Poliglecaprone 25 (Monocryl®)	Monofilament	50–60% at 7 days	Good	Minimal	Subcuticular/skin closure
Glycomer 631 (Biosyn®)	Monofilament	75% at 14 days 40% at 21 days	Good	Minimal	Subcutaneous suture and cutaneous suture
Nonabsorbable sutures					
Silk	Braided	None in 365 days	Good	Moderate	Skin closure
Nylon (i.e., Ethilon®)	Monofilament	Decreases 20% per year	Fair–good	Low	Skin closure
Polypropylene (Prolene®, Surgipro®, Surgilene®)	Monofilament	Extended	Poor	Minimal	Running intradermal suture, skin closure
Polyester (Dacron®, Ethibond®)	Braided	Indefinitely	Good	Minimal	Tendon suture, mucosal surfaces

hydrolysis; water penetrates the suture filaments and causes the breakdown of the polymer chain. As a result, synthetic absorbables tend to evoke less tissue reaction than plain or chromic gut.

Table 4.1 summarizes the properties of the most common suture threads used in plastic surgery.

Pearls and Pitfalls

Absorbable sutures are used primarily as buried sutures to close the dermis and subcutaneous tissue and to reduce wound tension.

Nonabsorbable sutures are characterized by their resistance to degradation by living tissues, and they are most useful in percutaneous closure.

In adults with clean wounds of the face or neck, there is no difference in long-term cosmetic results of repairs with permanent or absorbable suture material. We prefer absorbable sutures, as they do not have to be removed, saving the surgeon time and lessening patient anxiety and discomfort [3].

4.3.2 Needles

The surgical needle allows the placement of the suture within the tissue, carrying the material through with minimal residual trauma. The ideal surgical needle should be rigid enough to resist distortion, yet flexible enough to bend before breaking, be as slim as possible to minimize trauma, sharp enough to penetrate tissue with minimal resistance, and be stable within a needle holder to permit accurate placement.

Surgical needles are composed of the following:

- The swaged end connects the needle to the suture.
- The needle body or shaft is the region grasped by the needle holder. Needle bodies can be round, cutting, or reverse cutting:
  - Round bodied needles are used in friable tissue such as liver and kidney.
  - Cutting needles are triangular in shape, have three cutting edges to penetrate tough tissue such as the skin, and have a cutting surface on the concave edge.
  - Reverse cutting needles have a cutting surface on the convex edge, are ideal for tough

tissue such as tendon or subcuticular sutures, and have a reduced risk of cutting through tissue.

- The needle point acts to pierce the tissue, beginning at the maximal point of the body and running to the end of the needle, and can be either sharp or blunt:
  - Blunt needles are used for abdominal wall closure and in friable tissue and can potentially reduce the risk of blood-borne virus infection from needlestick injuries.
  - Sharp needles pierce and spread tissues with minimal cutting and are used in areas where leakage must be prevented.

The needle shape varies in their curvature and are described as the proportion of a circle completed—the ¼, 3/8, ½, and 5/8 are the most common curvatures used. Different curvatures are required depending on the access to the area to suture.

Key Point

Suture classification as per the United States Pharmacopeia (USP) is based on the diameter of any given suture material necessary to produce a certain tensile strength. In general, the higher suture number indicates a lower cross-sectional diameter of the suture. Since the USP baseline rating for suture is "0," as suture diameter decreases, "0 s" or numbers followed by "0 s" are added, i.e., 4–0 is of lesser diameter than 2–0. Suture strength ratings above "0" increase in numeric order, i.e., $1 < 2 < 3$, etc.

4.3.3 Alternative to Suturing

- Staples allow rapid wound closure. In addition, there is a minimal inflammatory reaction.
- Glue—cyanoacrylates (Histacryl and Dermabond) are biodegradable adhesives that polymerize on contact—there is roughly 1 min available for fine adjustment of the edges. It should not be allowed to get inside the wound as it is cytotoxic. Glue is particularly useful for simple lacerations in children.
- Steristrips—they are easy to apply but are not as strong as sutures and will fall off when wet. It is important to avoid placing them under tension, particularly in the elderly with thin skin; traction dermatitis and even blistering can result. They are usually used over intradermal sutures as external reinforcements.

4.4 Basic Suture Techniques

Key Point

1. The needle should be grasped at approximately two-thirds from the point.
2. The needle should enter the tissues perpendicular to the tissue surface.
3. The needle should be passed through the tissues along its curvature.
4. The suture should be passed at an equal distance from the incision on both sides.
5. Size of suture "bite" and interval between bites should be equal in length, proportional to the thickness of tissue being approximated.
6. The sutures should be tied only to approximate the tissues, not to blanch. A simple apposition of the edges is sufficient as postoperative edema will increase tension and ischemia may result.
7. The knot should never lie on the incision line.
8. Suture is foreign body: use minimal size and the amount of suture necessary to close wound.
9. As a general rule, the distance between simple interrupted stitches should equal their length.

4.4.1 Simple Interrupted Suture

The most commonly used and most versatile suture in cutaneous surgery is the simple interrupted suture. This suture is placed by inserting the needle perpendicular to the epidermis, traversing the epidermis and the full thickness of the dermis, and exiting perpendicular to the epidermis on the opposite side of the wound. The two sides of the stitch should be symmetrically placed in terms of depth and width. In general, the suture should have a flask-shaped configuration; that is, the stitch should be wider at its base (dermal side) than at its superficial portion (epidermal side). The eversion of the margins is essential to decrease the likelihood of creating a depressed scar as the wound retracts during healing (Fig. 4.4).

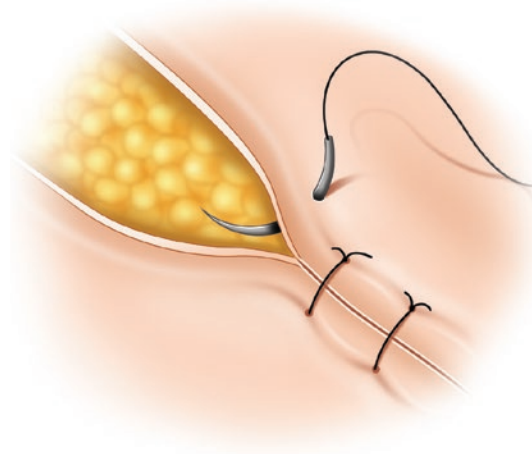

Fig. 4.4 Simple interrupted suture

Tips and Tricks

How to knot a tie.

The square knot is traditionally used. First, the tip of the needle holder is rotated clockwise around the long end of the suture for two complete turns. The tip of the needle holder is used to grasp the short end of the suture. The short end of the suture is pulled through the loops of the long end by crossing the hands so that the two ends of the suture are on opposite sides of the suture line. The needle holder is rotated counterclockwise once around the long end of the suture. The short end is then grasped with the needle holder tip and pulled through the loop again. Depending on the surgeon's preference, one or two additional throws may be added. Properly squaring successive ties is important. In other words, each tie must be laid down perfectly parallel to the previous tie.

4.4.2 Simple Running Suture

The suture is started by placing a simple interrupted stitch, which is tied but not cut. A series of simple sutures are placed in succession,

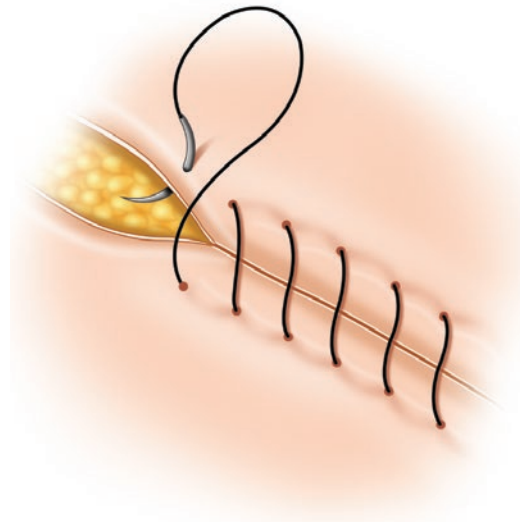

Fig. 4.5 Simple running suture

without the suture material being tied or cut after each pass. The line of stitches is completed by tying a knot after the last pass at the end of the suture line (Fig. 4.5). A simple running suture may be either locked or left unlocked. The first knot of a running locked suture is tied as in a traditional running suture and may be locked by passing the needle through the loop preceding it as each stitch is placed. This suture is also known as the baseball stitch because of the final appearance of the running locked suture line.

4.4.3 Vertical Mattress Suture

A vertical mattress suture is a variation of a simple interrupted suture. It consists of a simple interrupted stitch placed wide and deep into the wound edge and a second more superficial interrupted stitch placed closer to the wound edge and in the opposite direction. This kind of suture ensures good hemostasis (decreasing dead space) and eversion of skin margins. It is useful for skin closure of the scalp and articular surfaces (Fig. 4.6). The half-buried vertical mattress suture is a modification of a vertical mattress suture: the needle penetrates the skin to the level of the deep part of the dermis on one side of the wound, takes a bite in the deep part of the dermis on the opposite side without exiting the skin, crosses back to the original side, and finally exits the skin. Entry and exit points thus are kept on one side of the wound.

4.4.4 Horizontal Mattress Suture

A horizontal mattress suture is placed by entering the skin 5 mm to 1 cm from the wound edge. The suture is passed deep in the dermis to the opposite side of the suture line and exits the skin equidistant from the wound edge. The needle reenters the skin on the same side of the suture line 5 mm to 1 cm lateral of the exit point. The stitch is passed deep to the opposite side of the wound, where it exits the skin; the knot is then tied. A half-buried horizontal suture exits with the same principle explained above.

4.4.5 Intradermal Suture

This technique involves a horizontally placed serpentine continuous suture within the dermal layer (Fig. 4.7). Apposition of the skin is maintained by longitudinal tension of the suture along the incision. The ends are often taped to prevent slippage. Because the suture never penetrates the epidermis, there are no external suture marks.

4.4.6 Deep Closure

"Dead space," which is an open cavity in the internal recesses of the incision, can serve as a reservoir for hematoma and microorganisms, prevent accurate wound closure, and impair wound healing. Properly placed deep sutures should not only eliminate dead space in the depths of the wound but also relieve tension from the cutaneous suture line, thereby minimizing the postoperative widening of the wound [4].

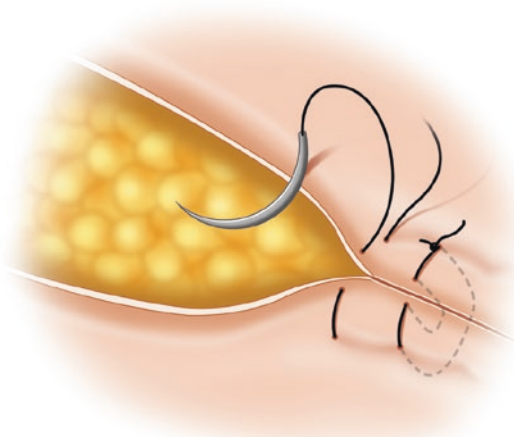

Fig. 4.6 Vertical mattress suture

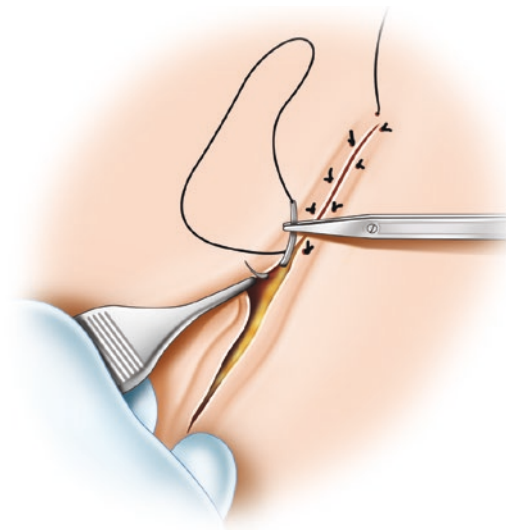

Fig. 4.7 Intradermic suture

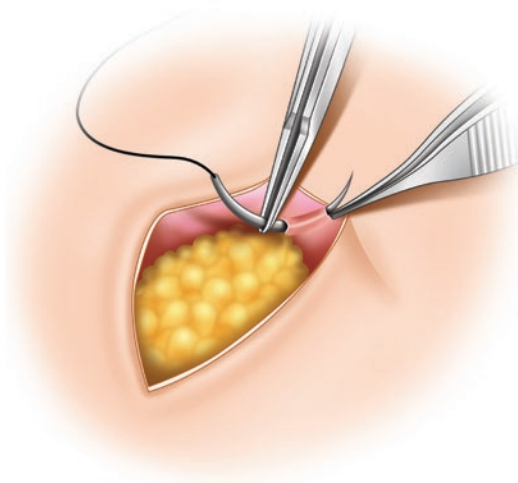

Fig. 4.8 Subcutaneous suture

For deep closure, absorbable sutures are popular. The knots of the subcutaneous sutures are usually buried to avoid interference with skin closure and decrease the risk of postoperative erosion of the knot through the wound surface (Fig. 4.8). To ensure that the knot does in fact assume the desired buried position in the depths of the wound, the surgeon must be sure that both ends of the suture are on the same side of the loop before tying the suture and must then pull the ends of the suture in a direction along the length of the incision while tightening the knot.

4.5 Postoperative Dressing

After completion of wound closure, a surgical dressing is usually applied. Most wounds should be covered with an antibiotic ointment and a nonadhesive dressing immediately after laceration repair. Limited evidence from one trial suggests that antibiotic ointments such as topical bacitracin zinc or combination ointments containing neomycin sulfate, bacitracin zinc, and polymyxin B sulfate significantly reduce the rates of wound infection when compared to a petroleum ointment control (5–6% versus 18%, respectively) [5]. Small crossover trials indicate that occlusion of the wound increases the speed of reepithelialization although complete healing appears to occur at about the same time when compared to uncovered wounds [6].

One of the main considerations is the risk for postoperative hematoma formation. If this is a concern, a compression-type dressing should be planned. A compressive dressing is also necessary when covering a skin graft to optimize grafts' taking (moulage) (Video 4.4).

When a skin defect is left open to heal by secondary intention, several strategies may be employed to hasten the healing process. Foremost is providing a moist healing environment.

Limited evidence is available to guide the timing of bathing after suture placement [7, 8]. Patients with nonabsorbable sutures (e.g., nylon, polypropylene sutures) may be allowed to shower or wash the wound with soap and water without risking increased rates of infection or disruption of the wound. Although not well studied, prolonged soaking of nonabsorbable stitches, including swimming in chlorinated water, should be avoided because of the theoretical risk of premature loss of suture tensile strength with wound dehiscence.

Suture removal varies according to the body areas (Table 4.2).

Table 4.2 Skin suture size and removal time according to different body areas

Body area	Size	Removal time
Face	5-0/6-0	6 days
Scalp	3-0	10–14 days
Chest/abdomen/back	2-0 to 4-0	10–14 days
Limbs	3-0	10–14 days
Hands	4-0 or 5-0	10–14 days
Nailbed	6-0 absorbable suture	Absorbable

Take-Home Message

- The aim of all suturing techniques is to approximate wound edges without gaps or tension.
- The final result is determined by basic surgical principles, i.e., good quality wound edges, clean debrided wound, and good apposition without tension, rather than the material per se.
- The ideal suture material should be easy to handle, have high tensile strength, and have no tissue reaction.
- A variety of suture materials is available for soft tissue surgery. The selection of a particular type is dependent on the physical characteristics of the material.

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Further Reading

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Dressings and Dermal Substitutes

5

Gabriele Delia, Lorenzo Gasco,
and Francesco Stagno d'Alcontres

Background

Wounds are an ideal environment for the proliferation of bacteria. For wounds, we intend both simple de-epithelialization and more complex injuries involving the entire tegument and exposing deep tissue. This occurs when sterility is lacking and when the wound is closed for the first time due to intra- or postoperative contamination. This has been proven to be a constant condition in chronic wounds or when healing occurs for the second time. Although there can be many factors that cause the chronicity of wounds, from genetic to metabolic factors, the formation of bacterial biofilm plays a key role. Bacterial biofilm has been proven to make wounds chronic, even more than other factors such as acute infections. The microenvironment of chronic wounds is characterized by an imbalance between factors promoting healing and factors preventing it such as chronic inflammation. In particular, the presence of necrotic tissue, fibrin, and exudate promotes the adhesion of different bacteria, which typically colonize chronic wounds.

5.1 Introduction

The most important difficulty in the tissue regeneration process and the healing of chronic wounds is the formation of bacterial biofilm. This consists of micro-bacterial colonies, which adhere to the tissues (living and nonliving) and extracellular matrix. The latter is composed of polysaccharides made from gelling agents, proteins, some of which have enzymatic activity, and extracellular DNA. The extracellular matrix has a number of functions, including protecting colonies from external agents (antibiotics and disinfectants), creating a hypoxic environment by identifying the most resistant colonies, and capturing proteins with enzymatic activity, which metabolize antimicrobials and reduce their effectiveness. In these particular circumstances, the inflammatory process begins to feed itself in a vicious circle. In such an environment, characterized by the prevalence of polymorphonuclear granulocytes as far as immune cells are concerned, there are phagocytes, which attempt to eliminate the bacteria found in colonies. This action is inhibited by biofilm and extracellular matrix surrounding the colonies. This leads to an "ineffective phagocytosis" with consequent degranulation and accumulation of pro-inflammatory factors, which cause direct damage to the host tissues. It has been demonstrated that some species of bacteria such as *Staphylococcus aureus* and methicillin-resistant *Staphylococcus* can result in macro-

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phages from an M1 form to an inactive M2 form. These phenomena are at the basis of chronic inflammation, which can be seen in almost all "difficult wounds" [1].

Healing is more difficult to achieve when bacterial colonization involves four or more different species, especially with anaerobic species. These species are found in the deepest part of biofilm, where oxygen concentration is lower. The bacterial species that most frequently colonize this type of wound are *S. aureus*, *Pseudomonas aeruginosa*, *Staphylococcus epidermidis*, *Serratia marcescens*, *Streptococcus*, and *Enterococcus* spp. Combinations of the above-mentioned species coexist within the microenvironment and perform a synergistic action (exchange of genes involved in antibiotic resistance). Everything that has just been described from a microbiological and molecular point of view must be taken into account in clinical practice. Unfortunately, there is no gold standard diagnostic test to demonstrate the presence of biofilm. The commonly used culture buffer is exposed to several risks such as contamination and difficulty in collecting a suitable sample. The presence of bacterial biofilm is therefore thought to be in all wounds that do not respond to standard treatments despite the patient's general condition. Plastic surgeons have the responsibility of carrying out good surgical procedures, such as wound cleansing and disinfection, without damaging the host tissues and eliminating bacterial colonies efficiently. In such cases, dressings are not only a physical barrier to external agents but also a means of hydrating and absorbing exudates, conveying active ingredients and promoting the production of granulation tissue [2].

5.2 Standard Dressings

Sterile gauze and bandages are used in clinical practice because they are easy to handle and to find and affordable. They are useful in covering surgical incisions and in dressing minor traumas (where there is no contamination or severe tissue necrosis). They protect from external agents but do not alter the natural history of the disease. When removed, they can damage granulation tissue by adhering firmly to the wound as they are dry dressings.

5.3 Hydrogel

Hydrogel has a three-dimensional structure consisting of water-insoluble hydrophilic substances, which therefore have the capacity to absorb it from the surrounding environment by eliminating secretions. Advantages of this type of dressing are the high moisturizing effect that promotes the autolytic cleansing of the necrotic tissue and the faster passage of the cells from the edges toward the center of the wound. Being these dressings also transparent, they allow doctors to supervise the wound more often. The deterioration of this "three-dimensional structure" is quite slow, allowing the absorption of active substances such as silver, which maintain their pharmacological properties longer. Silver has in fact an antibacterial effect. Indications for hydrogel application are surgical wounds, burns, radiodermatitis, pressure ulcers, and all those wounds with minimal-to-moderate exudate.

5.4 Hydrocolloids and Hydrofibers

Hydrocolloids and hydrofibers are made of a variety of substances such as pectin and carboxymethyl cellulose. These dressings gelify when in contact with the exudate absorbing it. Therefore, they are ideal for the treatment of wounds with moderate amounts of exudate. The same action mechanism is found in hydrofibers. These are mainly made of cross-linked fibers of carboxymethyl-cellulose that are also used in the case of loss of substances in deep wounds. They keep the microenvironment hydrated, becoming a sort of gel. This is a fundamental condition for tissue regeneration (Fig. 5.1).

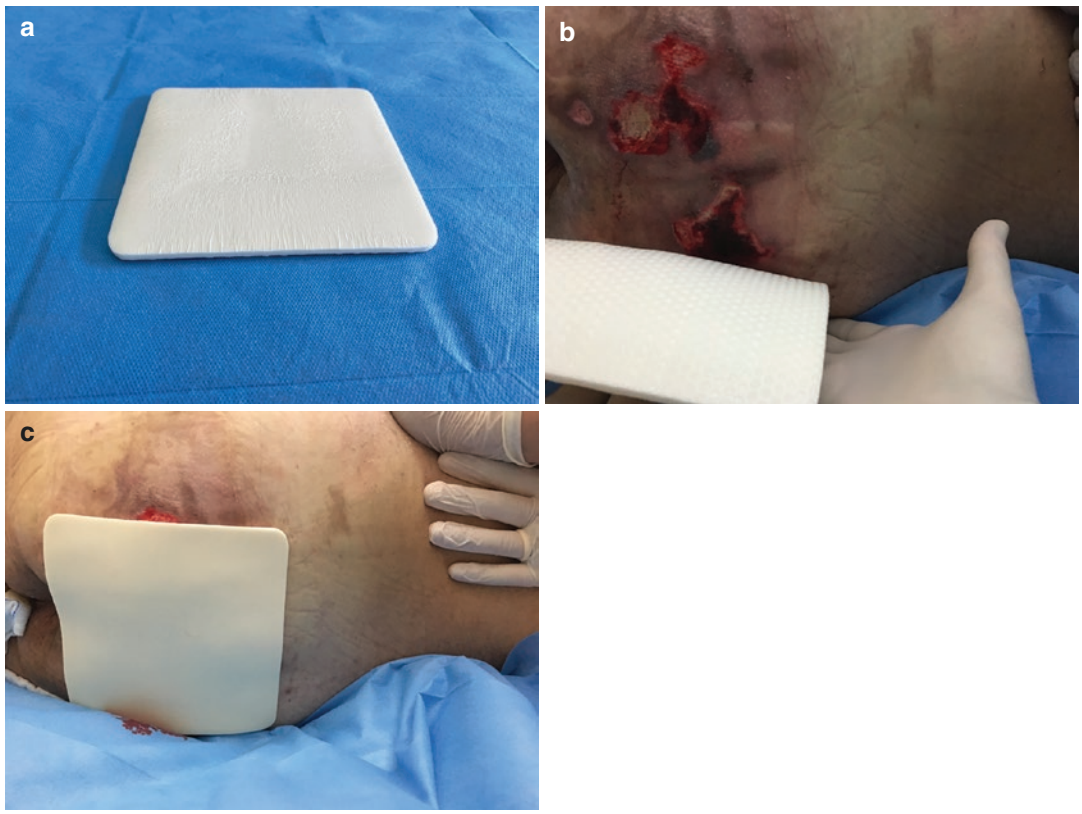

Fig. 5.1 (**a**) Hydrocolloid dressing. (**b**) Sacral pressure ulcer. The European Pressure Ulcer Advisory Panel (EPUAP) and The National Pressure Ulcer Advisory Panel (NPUAP) guidelines recommend the usage of hydrocolloids for the management of pressure ulcers. (**c**) Hydrocolloid dressing application on the pressure ulcer

5.5 Sodium Alginate

Sodium alginate comes from brown seaweed. It is made of fibers that can be cut and shaped to fit the wound. When it comes in contact with the exudate, it gelifies and is able to neutralize a large amount of secretion. For this same reason, sodium alginate is particularly recommended in the dressing of wounds with high amounts of exudate, both infected and not infected. It has been recently advised to combine it with bioglass and deferoxamine to promote regeneration in diabetic ulcers with promising results.

5.5.1 Foams

Foams are semipermeable, hydrophilic, or hydrophobic dressings of polyurethane base or silicone, with good absorbing capacity. These substances protect from both a thermal and mechanical point of view and also maintain the right level of humidity at the wound site. They can be used as additional dressings, which fit well into deep wounds and avoid damaging the wound itself when removed. This is because they do not adhere tightly to the surface. These dressings can also be combined with antibacterial agents, such as usnic acid, a metabolite of some species of lichens, with strong antibiofilm activity.

5.6 Film Dressings

Film dressings present a structure consisting of transparent polyurethane and micropores, allowing oxygen, carbon dioxide, and water vapor to pass through the dressing. They do not allow the passage of secretions and bacteria, keeping the

microenvironment well isolated. Clearly, these characteristics give these protections good autolytic properties and can be used for superficial wounds during reepithelialization.

Key Point
Bacterial biofilm delays wound healing. Surgical debridement removes necrotic tissue and, at the same time, eliminates bacterial colonies. The dressing hydrates, absorbs exudates, delivers active ingredients, and promotes the formation of granulation tissue.

5.7 Advanced Dressings and Wound Types

Having listed and described the main dressings available on the market and used in clinical practice, it is fundamental to underline a very important issue: the choice of the correct dressing according to the type of wound to be treated. Only the surgeon is capable of choosing the right dressing. In doing that, he has first carried out both a good general objective examination (diabetes mellitus, vasculopathy, obesity, smoking habit, autoimmune diseases) and a local one (characteristics of the lesion, painfulness, evolution, etc.). Diabetic ulcers are characterized by a lack of oxygenation and regeneration in a chronic inflammatory phase. They can be therefore treated with foams enriched with silver ions, hydrofibers, dressings enriched with hyaluronic acid, and nonadhesive dressings in order not to damage the soft layer of granulation tissue that is slowly growing.

Pressure ulcers are characterized by chronic pressure alteration of the tissues at the level of bone protrusions. In these wounds, foams are indicated, in particular those made of silicon multilayers. Polyurethane foams are recommended thanks to their active substances, like silver, which have an antibacterial effect. Some of these dressings have been developed especially for this type of wound, as they are shaped to fit different body sites (e.g., made in the shape of a cast of the sacral area). During the initial stages (always bearing in mind the importance of taking action on the treatment of the patient with pressure-relieving devices as well as frequent mobilization), it is preferred to use films that regulate gas exchange and have mild autolytic properties.

Burns are another form of chronic injuries that the plastic surgeon has to deal with on a daily basis. These wounds are characterized by abundant exudation and demarcation of necrotic tissue in the acute and subacute phase with extreme tendency to infection. Depending on the stages of development of the burns, different dressings are recommended: from very moist and occlusive ones to hydrofiber with silver ions. Viscose-rayon gauze soaked in petrolatum, which makes them highly nonadherent, can help reduce pain during removal, especially in the case of extensive burns.

Venous ulcers, on the other hand, are characterized by abundant necrotic tissue and moderate exudate on the wound surface, which promotes bacterial infection and chronic inflammation. Suitable for this type of lesion are alginates, hydrocolloids (also with a fat-colloid matrix that blends with hydrocolloids) that can prevent bacterial infection and promote wound healing, as well as improving the venous stasis of the lower limbs.

Lastly, radiodermatitis represents a particular type of lesion, where a reduction of cell proliferation and collagen production can be seen. They often have a de-epithelialized area, which does not tend to heal. Film dressings are therefore recommended. These lesions must be treated by keeping them isolated from the external environment (pathogenic bacteria), removing the thin layer of fibrin that covers them and protecting the regenerated fragile tissue.

Partial-thickness grafts taken with a dermatome from different areas of the body raise the problem of dressings in donor areas. This area causes discomfort to the patient like strong pain for the first few days. Many researchers have tried to identify a type of dressing that can be better used, although differing opinions remain. It

appears that a more wet dressing promotes a faster reepithelialization and a dry medication reduces pain. Another method of reducing a patient's pain is to avoid changing the first dressing and let it detach from the wound when healing has occurred. In the meantime, it is necessary to monitor the wound until it heals completely.

5.7.1 Tie-Over Dressings

Tie-over dressings are dressings often used in plastic surgery due to the extensive use of full or partial-thickness grafts in reconstructive surgery. The technique involves fixing, with suture threads applied around the graft, a pressure bandage consisting of gauze or cotton with the aim of obtaining constant immobilization and compression on the graft itself. This is particularly important during the first few days when the graft is kept alive by gases and molecules present in the exudate. Afterward, it is revascularized by the vessels from the bed of the recipient site. It is therefore essential, at this stage, that the graft remains still, which is why the pressure bandage is generally removed on the fifth postoperative day. Recently, experts have suggested that pressure bandages can be replaced by other pressure dressings, which increase patient comfort with the same effectiveness [3]. However, it must be considered that this is the best choice for areas with a particular anatomical shape such as ears, nose, and eyelids. Furthermore, with the intraoperative application of pressure bandages, hematomas and liquid formations are avoided (e.g., after the excision of large neoformations in richly vascularized areas, like the scalp, or after removal of auricular cartilage) [4].

Key Point
It is of fundamental importance to choose the right dressing according to the type of difficult wounds you want to treat. It is the task of the plastic surgeon to give precise indications to the team regarding the management of wound healing.

5.8 Dermal Substitutes

The ideal dermal substitute should provide protection against infections and fluid loss (essential, for example, in the case of burns) while recreating a stable matrix that can be integrated into the host tissue through the synthesis of the dermal layer. It is also important that the immunocompatibility guaranteed by the absence of cells and antigens is identified as nonself. The greatest advantage of these materials is the formation of tissue similar to the human dermis, with its elastic structure very different from scar tissue. Another crucial characteristic is the simplicity of these substitutes when they are handled and the resistance that they have toward the mechanical forces to which they are subjected. There are currently many dermal substitutes that can be used in clinical practice, each with its own particular characteristics. First of all, they can be divided into two large groups: those used for temporary wound coverage and those used for wound healing [5, 6].

The first group includes biological derivatives, which are made from humans or animals. The most frequently used treatments consist of sterilization processes using ethylene oxide or γ rays. This is done in order to eliminate all microorganisms present in the material minimizing the possibility of transmitting diseases to the host. This risk, although very low, cannot be eliminated. These aggressive procedures sometimes alter the dermal matrix, reducing the quality of the product significantly. Dermal substitutes, belonging to the first group, are used as biological dressings and removed after 12–21 days. This is because they contain allogeneic cellular residues that cause rejection by the host [7].

Gammagraft™ (Promethean Lifesciences, Inc.), for example, is made of γ irradiated human skin, and it is used as a biological dressing, which promotes healing of the recipient site until it is removed. E-Z Derm™ Porcine Xenograft (Brennen Medical, LLC) is a xenomaterial of porcine origin. It is generally surgically removed after about 10 days when partial-thickness skin graft is performed. Some biological derivatives act as grafts and are kept in place because they

undergo special processes to completely remove the antigenic component.

Alloderm® (KCI/Life Cell©) comes from human skin and is treated with minimally invasive processes that make its structure virtually identical to the human dermis. Thanks to the removal of the epidermis at the basal membrane level and the subsequent removal of all antigenic cells, this substitute is indicated for the reconstruction of skin in any body area.

Glyaderm® (Euro Skin Bank) and Epiflex® (DIZC, German Institute for Cell and Tissue Replacement) have similar characteristics. Synthetic biological derivatives (second group) are made up of purified biological molecules that are inserted into a matrix synthesized in laboratories. Collagen is the most widely used biological molecule. Through laboratory processes, collagen obtains a three-dimensional structure with pores. The advantage of a matrix synthesized in laboratories is of course the zero immunogen power, even if a slight immunogenicity of collagen has been demonstrated. The matrix contains fibronectin, vitronectin, and RGD sequences, which are recognized by the host cell integrins that begin to colonize the implanted material. Following the adhesion phase, the fibroblasts and keratinocytes in the host begin to secrete metalloproteinases, which result in remodeling and reshaping the matrix. Timing is here a fundamental concept because the matrix must remain in place to be incorporated into the host. In fact, if it were resorbed too quickly, it would have no time to be colonized, vascularized, and integrated. This is why collagen has been cross-linked to different degrees. However, this process can cause excessive resistance for the matrix to be reabsorbed, leading to chronic inflammation and the development of fibrosis and scar tissue. Adding other molecules, such as glycosaminoglycans, can be useful in overcoming these problems because it causes reabsorption resistance and can be adjusted to obtain a balance between resorption and colonization, modifying the amount and type of molecules added. An example that demonstrates the importance of the molecules added to the extracellular matrix is the comparison between the two most widely used dermal substitutes: Integra® and Matriderm®.

Integra contains chondroitin-6-phosphate, which slows down the process of reshaping and vascularization of the dermal substitute, bringing it to full taking after about three weeks. This generally involves a two-step procedure; i.e., after the dermal substitute has been implanted, it is necessary to wait three weeks and then partial-thickness skin graft is carried out [8].

In the case of Matriderm, which contains collagen/elastin, the remodeling process is much faster, allowing the application of this dermal substitute together with partial-thickness skin grafts.

Today Integra® Bi-Layer and Single-Layer (Integra Lifesciences) is the most widely applied dermal substitute. It consists of biodegradable bovine collagen polymerized with glycosaminoglycans. Its matrix is composed of type I collagen and chondroitin-6-phosphate, whose function has been described above. It is available on the market in two formats: a "double layer" of 2 mm covered with a silicone film, which is placed on the wound for about 21 days and then covered with a partial-thickness skin graft; the other one is the "single layer" of 1 mm not covered with silicone on which the skin graft can be placed at the same time of the dermal substitute. This is indicated for large wounds with bone exposure, extensive burns, and all those conditions in which a simple skin graft would not be enough to cover deep tissues. It is certainly an extremely effective dermal substitute, but it is characterized by acellularity and is therefore highly subject to bacterial infections. In order to overcome this, it is crucial to have an adequate surgical debridement and an implant on a sterile field, as well as silicone coating until the skin graft is performed.

Matriderm® Bi-Layer and Single-Layer (Dr. Suwelack Skin & Health Care AG) is a dermal matrix consisting of bovine collagen fibrils of types I, III, and V derived from nuchal ligament with the addition of elastin, whose structure is maintained intact. This matrix is porous like the one of Integra. The instructions are similar to those listed above; the only difference being that this type of dermal substitute cannot be dressed with disinfectants or iodine-based ointments because they tend to alter its structure.

Renoskin® (Perouse Plastie) has the same characteristics.

Pelnac® (Gunze LTD) is an artificial dermal matrix of porcine origin formed by a three-dimensional structure of atelocollagen covered with a silicone film. It should be used with care in patients with allergic diathesis (asthma, urticaria, etc.), which has become very common in Europe recently. It has shorter taking time compared to Integra, and during this phase, it almost seems to melt (be aware of differential diagnosis with infection).

Hyalomatrix® PA (Fidia Advanced Biopolymers S.R.L.) is a matrix of avian origin, consisting of an active layer and a semipermeable silicone film. The first layer is made up of an esterified derivative of hyaluronic acid, which promotes dermal regeneration, while the silicone foil controls fluid loss. It is recommended as a temporary dressing, therefore used in skin losses involving a large percentage of body surface area.

Apligraf® (Organogenesis, Inc.) is the only biological dermal substitute made from neonatal fibroblast cultures embedded in a type I bovine collagen matrix. It is suitable for all the conditions listed above including second-degree burn and higher.

Oasis® Wound Matrix—Oasis® Burn Matrix (Healthpoint) is an acellular biological matrix composed of collagen and submucosa obtained from the small intestine of pigs. It is not recommended in third-degree burns.

Veloderm® (BTC SRL) is the only dermal substitute of vegetable origin consisting of a particular microcrystalline cellulose with low polymerization and a high level of crystallinity. It has been proven that it is extremely useful as a temporary dressing in wounds and burns (up to the second degree deep) because it helps contain massive fluid loss and allows you to overcome acute phases. It can be used as a dressing on donor areas of partial-thickness skin graft. This can possibly lead to pain reduction.

The third group consists of synthetic derivatives, which are not molecules found in nature and in human tissue. While this, on the one hand, facilitates industrial production by eliminating the purification and the elimination of antigenic molecules, on the other hand, it raises the opposite problem. These molecules are recognized as nonself in particular conditions, leading scientists to insert biomimetic protein molecules to "deceive" the cells of the immune system and prevent a "foreign body" type reaction. Therefore, it is useful to stress that the action of the dermal substitute is similar to a scale that sees on one plate the ability of the host cells to degrade the matrix and on the other the capacity of the host cells to integrate within the matrix itself. If the balance is not perfect, there will be either reabsorption of the matrix without colonization by the host tissues or a foreign body reaction with scar tissue formation [9].

The main synthetic substitutes currently used in clinical practice are listed below.

Dermagraft® (Advanced Biohealing) is composed of polygalactin and human fibroblasts; Dermagen® (Genevrier) is composed of glycosaminoglycans, collagen, and chitin; Biobrane® (Smith & Nephew) consists of a silicone film and a nylon that traps the clots and makes the substitute adhere to the wound until reepithelialization; and Suprathel® (PolyMedics Innovations GmgH (PMI) consists of a resorbable membrane of D,L-polylactide. The indications, with small variations between one substitute and another, remain the same: traumatic wounds after stabilization and good surgical debridement, first- and second-degree burns, and, for some, third-degree burns, chronic ulcers after accurate surgical debridement (Figs. 5.2 and 5.3).

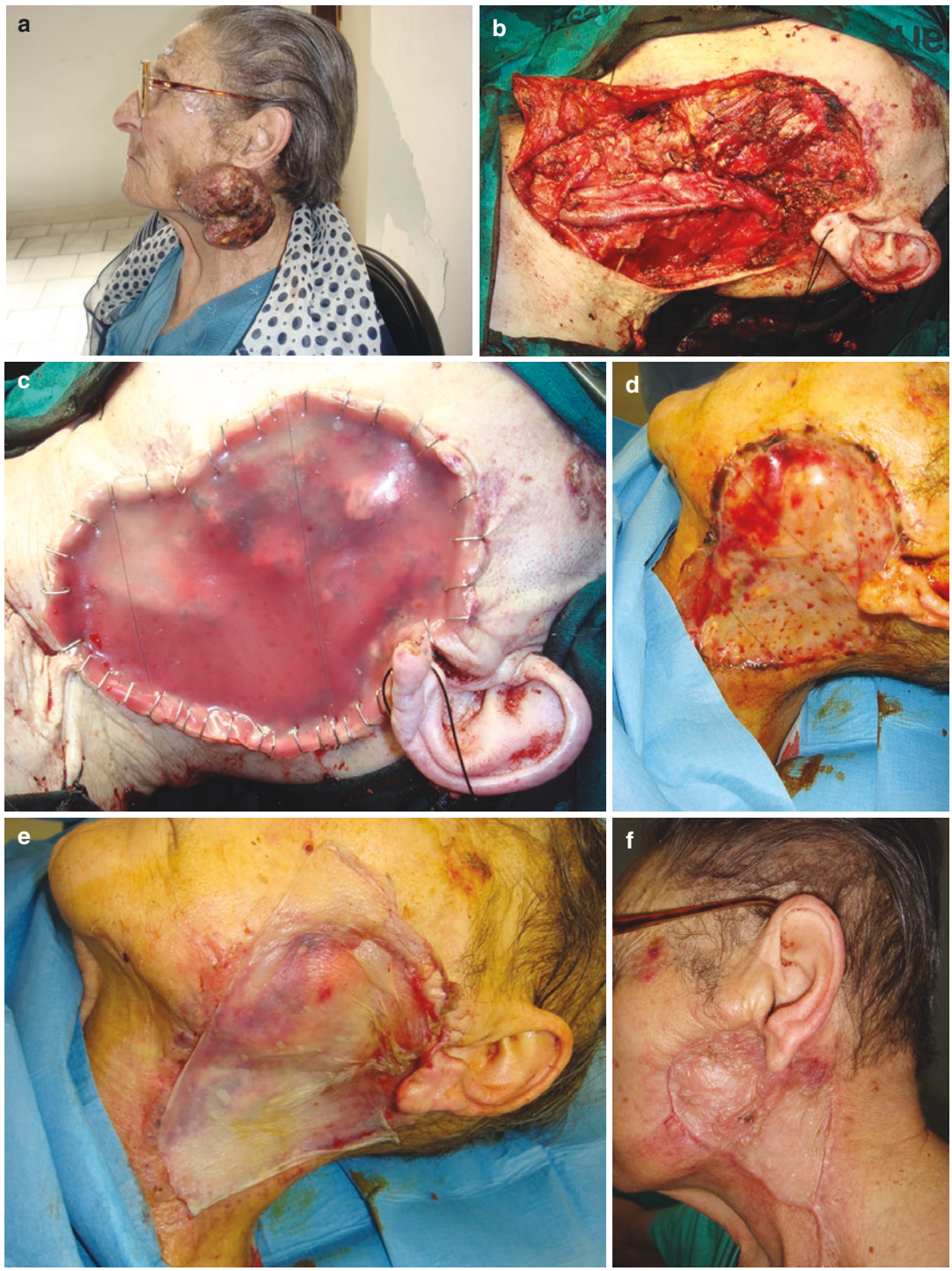

Fig. 5.2 (**a**) Left laterocervical sarcoma. (**b**) Tumor excision with laterocervical lymphadenectomy. (**c**) Application of dermal substitute. (**d**) Three weeks after dermal substitute application and removal of the silicone lamina. (**e**) Partial-thickness skin graft application. (**f**) 1-month postoperative follow-up

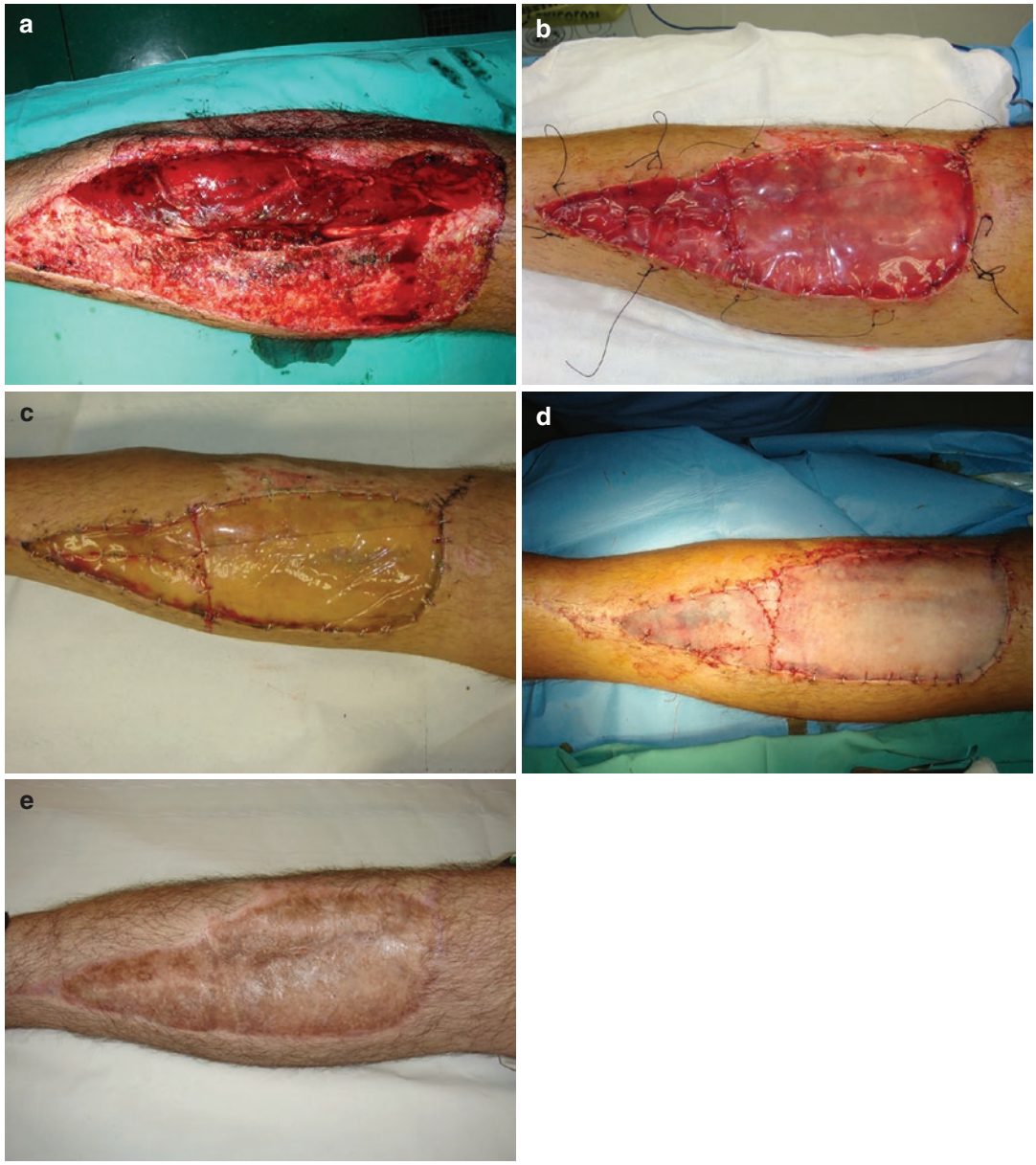

Fig. 5.3 (**a**) Trauma of the posterior surface of the left leg with skin degloving. (**b**) Debridement and dermal substitute application. (**c**) Three weeks after dermal substitute application with silicone layer. (**d**) Partial-thickness skin graft application. (**e**) 1-month postoperative follow-up

Pearls and Pitfalls

Some indications of a possible requirement for a dermal substitute are

- Burns.
- Deep wound.
- Wound with periosteal exposure.
- Vessels or nerves exposure.
- Diabetic foot ulcers.
- Pedicle flap exposure.

Key Point

An ideal dermal substitute should provide wound protection against infection and fluid loss while recreating a stable matrix that can be integrated into the host tissue through dermal neosynthesis. Key features are absence of cells and antigens recognized as nonself, manageability, and resistance to the mechanical forces to which they are subjected.

Tips and Tricks

- Remember to rule out signs of infection before applying a dermal substitute to the wound bed.
- Remember that not all dressings are the same and must be selected according to the patient and the characteristics of the wound.
- Remember that before applying an advanced dressing, it is important that the wound bed is well cleansed.

Take-Home Message

- Nowadays, bioengineering and research on biomaterials have reached significant goals, allowing physicians to face dramatic situations that in the past could not have been tackled (polytraumatized burns involving a large part of the body surface).
- The new perspectives see researchers focused on the development of the "perfect dermal substitute" that not only can successfully integrate into the host tissue but also leads to the formation of a dermis equal to the human one, for elasticity and resistance, and gradually less and less similar to scar tissue.

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Grafts in Plastic Surgery

6

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Background

A graft is defined as a free tissue transfer from one body area to another, with total vascular and anatomic deconnection from the donor site (the area from which the graft is harvested). Grafting represents a fundamental technique in the armamentarium of the plastic surgeon and is one of the most ancient witnesses of plastic surgery practice. Full-thickness skin grafts harvested from the gluteal region were used for nasal reconstruction in criminals that had undergone punitive amputation. The Italian Giuseppe Baronio (1750–1811) performed and published the first skin graft in a lamb in his milestone publication "*Degli Innesti Animali*." Only in 1817, when Sir Astley Cooper used a skin graft from a man's amputated thumb to provide coverage for the remaining stump, grafts began to slowly gain popularity in Europe. Other important contributions have been the introduction of split-thickness skin grafts by Leopold Ollier, the concept of wound bed preparation for skin graft by Carl Thiersch, and the introduction of innovative surgical instruments by surgeons like Ricardo Finochietto, Martin Douglas Humby, and Earl Padgett, which led to the development of dermatomes (Fig. 6.1).

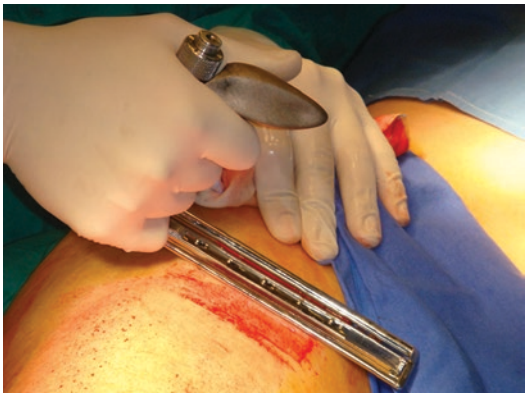

Fig. 6.1 Harvesting of a split-thickness skin graft with a manual dermatome

6.1 Introduction

Grafts, yesterday and today, respond to the need to restore the physical, and therefore psychic, integrity of the human body, injured from burns, surgical resections, congenital defects, asymme-

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try, traumas, or merely to fulfill esthetical needs. Almost every tissue of the body can be harvested and grafted, completely or partially, in different ways, alone or together with other tissues. The results strictly depend on the cultural background and technical mastery of the surgeon performing the procedure. The comprehension of physiology and anatomy behind grafting surgery is fundamental to reach the best outcome.

6.2 Graft Classification

Grafts can be classified according to a variety of features [1]. Based on its antigenic characteristics, a graft can be classified as

- Autograft: the donor and the recipient subjects are the same person.
- Homograft: donor and recipient subjects belong to the same species (e.g., *Homo sapiens*). Homografts can be further divided into *isografts* (different subjects with identical genetic heritage such as congenital twins) and *allografts* (subjects different genetically but belonging to the same animal species) (Fig. 6.2).
- Xenografts (or heterografts): when the donor and the recipient subjects do not come from the same species (e.g., pig, horse, bovine).
- Given the possibility to harvest and graft tissues from a donor site not necessarily corresponding to the recipient site, a further classification can be performed based on the similarities between the two sites:
  - Isotopic graft: the donor and recipient sites match both for anatomy and tissue type (e.g., lower limb skin to cover a skin defect of the arm).
  - Orthotopic graft: the donor and recipient sites are anatomically different but provide the same type of grafted tissue (e.g., rib cartilage to reconstruct or remodel septal nasal cartilage).
  - Heterotopic graft: the donor and the recipient sites are different both in terms of anatomy and tissue type (e.g., ear cartilage to reconstruct the tarsal plate of the eyelid).
- Since grafts can be composed of one or more tissue types, they can be further classified into
  - *Simple*: the graft is made up of only one specific tissue (e.g., skin graft, bone graft, mucosal graft).
  - *Composite*: the graft is made up of two or more tissues (e.g., dermo-adipose graft, chondromucosal graft).

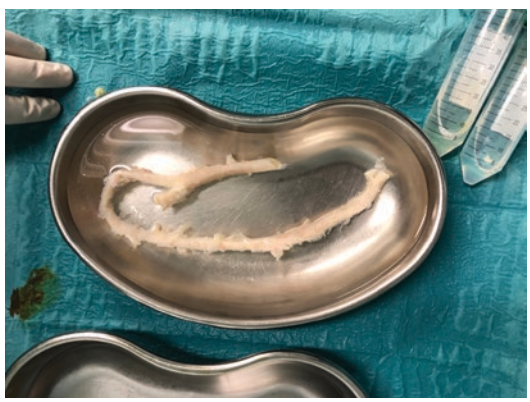

Fig. 6.2 Femoral artery homograft used for the reconstruction of vascular defects

Key Point
Grafts can be classified according to antigenic characteristics, correspondence between donor and recipient sites, and tissue composition.

6.3 Physiology of Revascularization

Historically, graft take is related to secondary intention healing of wound beds (granulation, contraction, and reepithelialization), and it is divided into three phases: imbibition (0–48 h), inosculation (48–72 h), and revascularization (>96 h). Nowadays, modern in vivo models have improved our knowledge of graft take mechanisms, underlining the importance, for graft survival, of the metabolic activity of the graft at the time of placement and the vascularity of the donor site [2]. Although graft take mechanisms have been largely discussed in the literature mainly for skin grafts, the process can be considered similar for other kinds of tissues (e.g., fat tissue).

6.3.1 Phase 1: Imbibition

Huebscher in 1888 and Goldmann in 1894 firstly theorized that, before revascularization, the graft is

nourished by O_2 and metabolites within the host fluid from the wound bed [3, 4]. This phase, which is called "imbibition," may vary in duration, depending mainly on the characteristics of the recipient site (vascularity of wound bed), and lasts up to several days. This mechanism is commonly believed to be responsible for graft survival in this ischemic period, which lasts from graft harvesting to the revascularization phase, and is characterized by anaerobic metabolism [5–7]. The term "serum imbibition", introduced by Converse in 1969, refers to the changes in graft weight, as it grows to up to 40% of the initial weight within the first 24 h and decreases until it reaches a final weight gain of 5% 1 week after grafting [8].

Along with other authors, Converse rejected the theory that plasma circulation gives metabolic supply to the graft, being the serum only a moisturizing element for the graft [9, 10]. "Serum imbibition" would allow the graft vessels to remain patent and the creation of a connection between graft and recipient sites through serum fibrinogen bridges.

6.3.2 Phase 2: Revascularization

Different studies have demonstrated that, after 48–72 h, there is a growth of 10–11 μm diameter vessels in the fibrine interface between graft and recipient site [11]. Different theories have been proposed to explain graft revascularization, including *anastomoses (inosculation)* between wound bed capillaries and graft native vessels, and *angiogenesis* (or neovascularization) from the recipient site to the graft, with new vessels replacing graft native vessels [12–17]. The best evidence nowadays supports the theory of endothelial cell proliferation from the recipient site to the graft tissue, using the preexistent vascular network of the graft itself, while in the graft, the endothelial cells gradually degenerate [14, 15, 18–20]. An in vivo model, developed by Lindenblatt in 2010, supports this theory, suggesting the role of angiogenesis as a primary factor in graft revascularization through the fibrine interface between the skin graft and the wound bed, leading to reperfusion of graft native circulation [21–23]. A study by Calcagni et al. in 2011, based on a crossover wild-type/green fluorescent protein (WT/GFP) skin transplantation model, was designed in order to clarify the unanswered questions about graft revascularization and to establish the origin of the skin graft vasculature [24]. The data indicated a replacement rate of graft native vascular network close to 100% at the periphery of the graft vs. 50–60% at the center of the graft, suggesting heterogeneous mechanisms involved in graft revascularization and a centripetal vascular replacement pattern.

6.3.3 Phase 3: Maturation

Skin grafts may take up to 1 year to be fully integrated, being this process variable in duration according to underlying clinical conditions and to the etiology of the defect that led to graft reconstruction. During the first 4 days after grafting, the epidermis of a skin graft doubles in thickness due to the nuclear and cytoplasmic swelling of epidermal cells, cellular migration to the surface of the graft, and an increased cellular turnover, which lasts until 4 weeks after grafting [25, 26]. The cross-linking process between collagen fibers in the wound interface allows the extracellular matrix to develop resistance to mechanical insults. Within 5 months after skin grafting, in a full-thickness skin graft, 85% of native skin collagen is replaced, but the percentage decreases to 50% in split-thickness skin grafts [27, 28]. Nonnative skin graft fibroblasts convert into myofibroblasts developing alpha-smooth-muscle actin (alpha-SMA) fibers, which exert contractile forces on the extracellular matrix determining wound contraction. Scars from skin grafts continue to modify for several years, and scar management may be required, especially in burn victims or children.

Key Point
The physiologic process of graft take can be divided into three phases: *imbibition*, responsible for initial graft survival; *revascularization*, which brings new blood supply to the graft; and *maturation*, which determines complete tissue integration.

6.4 Complications in the Grafting Process

Any fluid in the interface between the graft and the recipient site may cause graft take failure: hematoma, seroma, edema, and collection of pus due to graft infection are common complications that may easily interfere with the grafting process. In general, the experienced surgeon uses technical artifices, according to the different types of grafts, to avoid that fluid collection causes graft failure. These include accurate hemostasis, antisepsis, infiltration of a solution with adrenaline in the receiving site during fat grafting, skin fenestration in case of skin grafts, and administration of i.v. corticosteroids in the case of vessel grafts to reduce the edema. Delayed healing and wound dehiscence, eventually requiring surgical revision, may occur, especially in diabetic patients [29]. The loss of connections between a graft and its recipient site is one of the main concerns during grafting procedures; for this reason, an adequate fixation and stabilization of the graft, along with correct therapeutic indications, is still the best way to avoid the disruption of the fragile vessels in the graft–recipient site interface. As the maturation process proceeds over months or years, scar contracture may cause concerns to the patients and require surgical revision. Finally, in terms of esthetic outcome, as skin color is variable among different anatomic areas, concerns may derive from different pigmentation and the consequent "patch-like" effect in skin graft procedures.

6.5 Skin Graft

The skin, which is the largest organ in the human body accounting for 15% of its total weight, has a complex three-dimensional multilayered structure. The epidermis and the dermis are the two main components of the skin. The epidermis is the outermost layer, and it is further divided into five layers (from superficial to deep): *stratum corneum*, *stratum lucidum*, *stratum granulosum*, *stratum spinosum*, and *stratum basale*. The epidermis ranges a lot in thickness among different body areas, from 50 μm in the eyelid to 1 mm in the glabrous skin of the foot, with an average thickness of 100 μm. The dermis provides the mechanical features of the skin. It is composed mainly of collagen and elastin fibers, ground substance, eccrine and apocrine sweat glands, and pilosebaceous follicles. The upper part of the dermis is called *papillar dermis*, which has an undulating interface with the epidermis, allowing a solid connection between the two layers (papillar structure). It contains blood vessels and nerve fibers. The deeper part is the *reticular dermis,* rich in type I collagenous fibers, which provide strength and stability to the skin structure.

Skin grafts are composed of the epidermis and a variable amount of dermis. A full-thickness skin graft (Wolfe–Krause) includes all the dermis layers. Split-thickness skin grafts (STSG) are further divided into thin (120–300 μm, Thiersch–Ollier), medium (300–460 μm, Blair–Brown), and thick (460–760 μm, Padgett).

The surgeon should perform an accurate evaluation prior to graft harvesting, including the amount of skin needed, the characteristics of the recipient site, the possibility of a re-harvesting procedure, and the long-term esthetic impact.

The full-thickness skin graft provides an excellent functional and esthetic outcome as it contains intact accessory skin structures and it presents a lower tendency to hypo- or hyperpigmentation, compared to STSGs. On the other hand, full-thickness skin grafts are very limited in availability, as a primary closure must be achieved at the donor site, which means that only body areas with surrounding loose skin are suitable for this type of skin graft harvesting. Areas that are particularly useful for full-thickness skin graft harvest are the pre- and postauricular areas, clavicular skin, inner arm, and inguinal region, among others. Despite a greater amount of primary contraction, full-thickness skin graft should always be considered for joint surfaces because of a lower amount of secondary contraction, which occurs in STSGs. Of course, due to its thickness, full-thickness graft take is more difficult than STSG take.

A split-thickness skin graft is the best option when a large skin defect has to be covered or

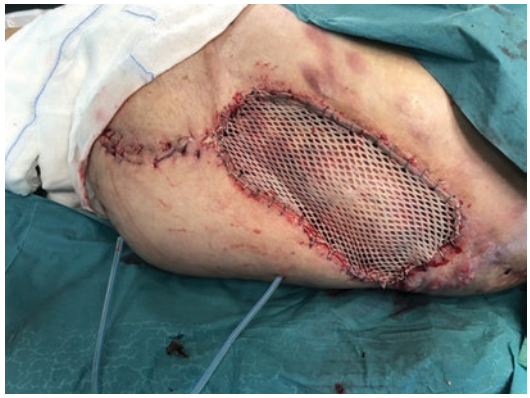

Fig. 6.3 A meshed split-thickness skin graft used for the coverage of a large skin defect

when the surgeon considers the possibility of a re-harvesting procedure, such as in burns patients who present a great imbalance between skin defect and healthy skin availability. In these patients, the possibility of increasing the size of the STSG should be considered by the surgeon. In fact, STGS can be meshed (meshed graft) through a 11 blade or with a proper instrument called mesher, increasing its size up to six times (Fig. 6.3). Meshed grafts present a net-like structure and are very helpful to cover irregular surfaces. The gaps created within this kind of grafts are filled by keratinocytes deriving from the surrounding skin stripes. Anyway, hypergranulation may be observed through the gaps, often leading to cobblestone-like skin deformities, hence undermining the esthetic outcome of this procedure. With regard to donor sites, hidden areas are preferred (e.g., thigh or gluteus). The donor site of STSG heals by secondary intention. The chosen dressings vary according to the surgeon's preference, and other factors such as cost, availability, and patient profile affect the decision. The advantages, disadvantages, and possible indications of full-thickness skin grafts and thin and thick STSGs are listed in Table 6.1.

Key Point
The most important goal in skin graft surgery is to ensure a clean, firm, and lasting adhesion between the graft and the donor site.

During full-thickness skin graft harvest, the surgeon should be careful not to harvest the graft with the underlying fat tissue. If the fat tissue is present in some areas of the graft, it should be carefully removed, as fat necrosis may interfere with graft take. During graft manipulation, skin hooks or anatomic forceps should be used. When the graft is not immediately placed after harvest, it must be wrapped in a sterile gauze soaked in saline solution. The graft is then fixed to the perilesional skin with circumferential sutures; both nonabsorbable or absorbable sutures can be used for this purpose. In the case of large areas to be covered, several meshed grafts can be easily and quickly placed by using stapler points. A very large graft may also require stitches in its central areas to ensure better fixation and tighter adhesion to the recipient site. The importance of fenestration of the graft to avoid fluid accumulation has already been discussed. When possible, a tie-over medication is performed; it consists of fixing the dressings over the graft by suturing it directly to the skin. In particular situations, both fixation of the graft and fluid removal can be successfully achieved through a vacuum-assisted device. Compressive dressings should be maintained until 6–7 days after grafting.

6.5.1 Adnexa Grafts

Cutaneous adnexa can be transferred as grafts as well, and, among these procedures, hair transplantation (HT) is the most famous and requested. Hair loss is one of the most popular distressing issues among the male and female population, being the most common etiology androgenic alopecia (AGA). Although several nonsurgical treatments are currently available, HT has gained popularity over the years due to the advancement in its safety and effectiveness [30]. The major donor site for hair harvesting is commonly represented by the mid-occipital region, between the upper and lower occipital protuberances, where there are usually 65–85 follicular units (FU) per cm2 [31]. One of the main limitations in HT surgery is represented by the limited donor site area, which determines the maximum number of FU

Table 6.1 Advantages, disadvantages, and possible indications of full-thickness skin grafts and thin and thick STSGs (split-thickness skin grafts)

	Advantages	Disadvantages	Indications
FTSG	– Optimal skin quality and esthetic outcome – No secondary contraction	– Low availability – Lower rate of graft take	– Facial defects – Joint surfaces
Thin STSG	– Optimal graft take – Faster donor site reepithelization – Possibility of meshing – Possibility of reharvesting	– Great amount of secondary contraction – Poor esthetic outcome – High risk of hyper- or hypo-pigmentation	– Burn wounds – Chronic and acute wounds with an adequate wound bed
Thick STSG	– Good graft take – Slower donor site reepithelization – Possibility of meshing – Possibility of reharvesting – Greater structural stability (compared to thin STSG)	– Secondary contraction – Poor esthetic outcome – Risk of hyper- or hypo-pigmentation	

that it is possible to harvest. Harvesting more than 15–20 FU per cm2 is not recommended, but, when needed, other parts of the body may be used as additional donor sites, like the parietal scalp, the submental region, and the chest [32].

The two types of HT commonly performed are follicular unit transplantation (FUT) and follicular unit extraction (FUE), the latter representing today the most common approach [33, 34].

The implantation process is the same independently from the harvesting technique used, as recipient sites for FU are created in a random and irregular pattern under magnification using 19–21 gauge needles or flat-edged blades. Given the great amount of blood flow along the scalp, complications are rare. When performing hair transplantation, proper patient selection and evaluation, along with a correct surgical technique, are essential to obtain safe and satisfactory outcomes.

Tips and Tricks: FUT and FUE

In the FUT technique, a strip of tissue is removed from the occipital region. A beveled incision is made, parallel to the existing follicles, about 5 mm in depth, not beyond the subcutaneous tissue. The donor strip gets dissected off the occipital fascia and aponeurotic galea, and the excess of subcutaneous tissue is removed from the donor strip, leaving 2 mm of fat beneath the FU as a safety margin. The donor site is closed by a direct suture.

FUE harvesting time is longer than FUT. This process, when performed manually, includes the use of a sharp punch oriented at the center of the hair follicle and with the same angle and advanced for 4 mm. At this point, the FU is gently removed through delicate forceps in an atraumatic fashion. Robotic devices have been recently developed to improve the precision and speed of FUE harvesting.

6.6 Dermal Graft

Dermal regeneration is very limited in the human skin. Full-thickness skin defects heal by secondary intention with the formation of a scar tissue covered by fragile and dry skin that can be easily ulcerated with minimum friction. For this reason, dermal substitutes are commonly used for deep tissue reconstruction before skin grafting procedures.

Autologous dermal grafts have long been indicated in abdominal wall reinforcement for treating incisional or muscular abdominal hernia. They can be harvested manually like a skin graft,

after de-epithelialization, or by dermatome, when larger grafts are needed. When the dermatome is used, the procedure comprehends harvesting a thin layered skin graft, followed by the deeper harvest of the dermis. The skin graft is then used to cover the donor site while the deeper layer is transferred to the receiving area. Nevertheless, with the advent of dermal substitutes and synthetic meshes, autologous dermal grafts are no longer commonly performed.

Dermal substitutes are widely used in burn injuries, oncological resections for skin cancer, to cover exposed structures such as tendons and nerves and to improve functional and esthetic outcomes.

Dermal substitutes are applied to a vascularized wound bed with the aim of forming a collagen matrix that can be repopulated by blood vessels and cells. These substitutes are very sensitive to infection during intake; for this reason, they need particular care. In most cases, dermal substitutes can regenerate a well-vascularized dermis in 2–3 weeks, and the area can be easily covered with a skin graft once the silicon sheet that frequently covers the dermal substitute is removed (Fig. 6.4). The first commercially available dermal substitute was a bovine-derived collagen type I cross-linked matrix with glycosaminoglycans, obtained by processing bovine tendons. It is covered by a silicone sheet that temporarily substitutes the missing epidermis. Another commonly used dermal substitute is a bovine-derived collagen matrix with noncross-linked collagen fibers of types I, III, and V coated with elastin fibers. Furthermore, newly designed alternative compositions of these dermal substitutes can be placed and covered with skin grafts in the same surgery, saving time and reducing costs derived from dressings and multiple procedures. Other dermal substitutes and their characteristics are listed in Table 6.2.

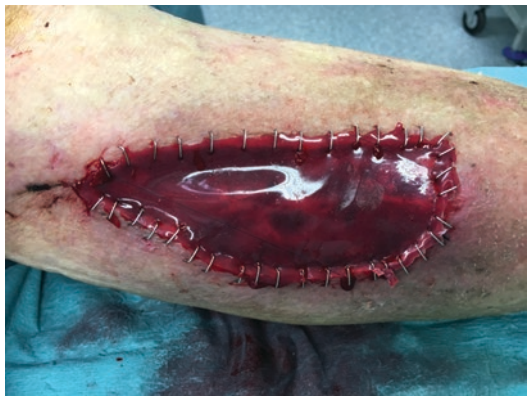

Fig. 6.4 A bovine-derived dermal substitute used for the reconstruction of a full-thickness defect derived from skin cancer oncological excision in the lower limb. The translucency of the regenerative matrix is given by the silicon sheet that covers it, which will be removed during the second-stage surgery prior to skin grafting

The abovementioned dermal substitutes are permanent, but, when a temporal coverage is needed for large wounds, dermal allografts or xenografts may be used. These types of grafts are eventually rejected by the recipient, but they may adhere and provide a regeneration template in patients with large burn injuries. After 2–3 weeks, they can be removed and the residual vascularized wound bed can be covered with autologous skin grafts.

6.7 Fat Graft

Adipose tissue is composed of large lipid-laden adipocytes, adipose stem cells (ASCs) or preadipocytes, and various stromal vascular cells such as fibroblasts, immune cells, and vascular endothelial cells. Autologous fat graft is characterized by numerous beneficial characteristics, including the fat filling capacity and the presence of adipose tissue bioactive factors (ASCs). Due to the simplicity of the procedure, its low costs, and the low donor site morbidity, fat grafting is a very useful tool in the plastic surgeon armamentarium.

Autologous fat grafting has been used successfully for the treatment of facial aging, breast augmentation and reconstruction, breast implant-related complications, radiation damage, traumatic or congenital deformities, chronic wounds, burn injuries, malformations, and other pathologies characterized by tissue dystrophy.

To date, a standardized technique has not been universally adopted, as numerous studies showed satisfying results using different methodologies.

Table 6.2 Permanent and temporary dermal skin substitutes

Product	Tissue	Origin
Integra® (Integra Lifesciences)	Bovine tendon type I collagen and glycosaminoglycans on a silicone sheet	Xenogenic
MatriDerm® (MedSkin Solutions)	Bovine acellular noncross-linked, coated with elastin	Xenogenic
EZ Derm® (Mölnlycke Health Care)	Porcine aldehyde cross-linked dermal collagen	Xenogenic
Alloderm® (LifeCell Corporation)	Human acellular lyophilized cadaver dermis	Allogenic
Dermagraft® (organogenesis)	Human fibroblasts on polyglycolic—polylactic acid mesh	Allogenic
Allograft—Composite	Cryopreserved cadaveric skin	Allogenic
Apligraf®—Composite (organogenesis)	Neonatal human fibroblasts in bovine type I collagen or neonatal human keratinocytes	Allogenic/ xenogenic

However, the ASPS Fat Graft Task Force published in 2009 evidence-based guidelines for autologous fat grafting. The three major steps identified in fat grafting are harvest from the donor site, fat processing, and inoculation at the recipient site.

The choice of donor site depends on the desires of the patient and the accessibility of fat during surgery. The abdomen, "love handles," posterior hip, lateral thighs, and medial thighs (in thin patients) are often chosen as donor sites. The local anesthetic solution should consist of 0.2% lidocaine with 1:200,000 epinephrine, and the quantity of solution to infiltrate should be as much as the amount of fat tissue required. Approximately 10 min after infiltration, the harvesting procedure can be performed. Viable fat tissue is commonly obtained by syringe aspiration or liposuction, minimizing as much as possible the level of invasiveness, thus maximizing tissue viability (Fig. 6.5) [35]. These characteristics are commonly achieved by using a 3–4 mm blunt cannula on a syringe or a closed suction system exerting no less than −0.83 atm pressure during aspiration [36].

Once the fat is harvested, it can be processed with several methods such as washing, centrifugation (less than 3000 rpm), decantation, or concentration (Fig. 6.6). No scientific evidence supports the superiority of one technique over the other [37]. However, it is acknowledged that contamination, exposure to air, and mechanical damage should be avoided during this process in

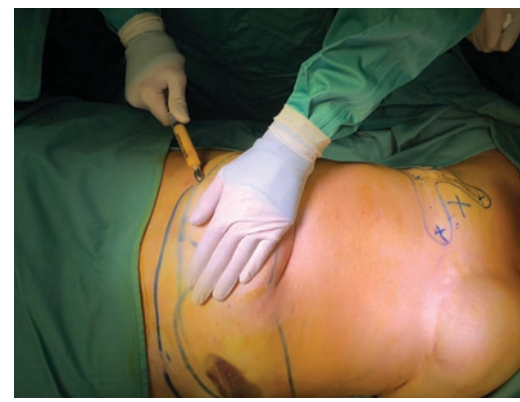

Fig. 6.5 Harvesting of abdominal fat during a fat grafting procedure for the correction of residual asymmetry after breast reconstruction

Fig. 6.6 Fat decantation after harvesting. The separation of fat components is noted: blood and fluids locate on the lower part of the syringe, while the upper part is mainly composed of fat

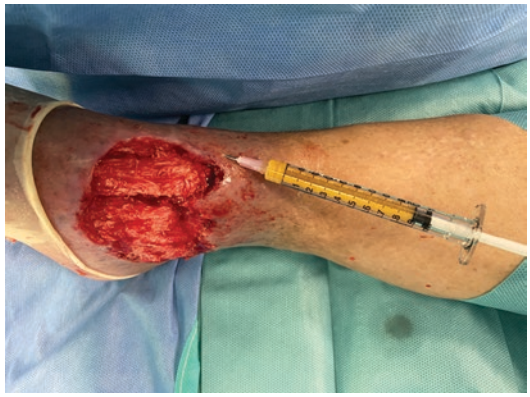

Fig. 6.7 Fat grafting during a regenerative surgery procedure. Fat is grafted in small aliquots into the perilesional skin to enhance the healing of a radiodermitic ulcer of the lower limb

order to maximize fat tissue viability [36]. Once adipocytes are separated from blood and damaged adipocytes via the abovementioned methods, they can be transferred to 1-cc syringes and grafted at the recipient site. Fat is injected subcutaneously with blunt-tipped cannulas or needles (Fig. 6.7). Mechanical damage of the tissue must also be minimized during this process. For this reason, the injection should be performed serially over multiple tissue planes, using a 2.5-mm blunt-tipped infusion cannula (or a similar blunt needle) with a slow rate (0.5–1 cc/s) of fat introduction for minimizing the shear stress exerted on the adipocytes.

Key Point
Maximizing the contact surface area of the fatty parcel with the surrounding tissue is the major concern during fat transfer procedures. In fact, this optimizes the blood supply to the newly grafted fat minimizing the quote of cellular necrosis. Transferring large globules of fat has proven to cause central necrosis of the transferred tissue, with suboptimal results caused by tissue resorption and loss of volume.

Key Point
Coleman's lipostructure technique.

This widely used technique for lipostructure consists of gentle harvesting of the fat, centrifugation up to 3000 rpm to remove nonviable components, and injection of the fat in small aliquots. This ensures maximizing the contact surface area of the fatty parcel, hence reducing the quote of adipose tissue necrosis [38].

6.7.1 Bone Graft

Bone reconstruction can be performed using autografts, allografts, xenografts, bone substitutes, or implants. *Autologous bone grafts* are indicated for reconstructing small defects due to the obvious lack of great donor sites in the human body and to the morbidity determined by large bone harvests. Common indications for the use of bone grafts are bony defects derived from trauma, oncological resection and congenital pathologies, fractures nonunion, and contour deformities (less common). Graft incorporation in the receiving site consists of graft resorption and replacement by vascular ingrowth and new bone apposition [39]. Many factors affect bone graft incorporation and remodeling: the type of graft (e.g., autogenous/allogeneic, vascularized/nonvascularized); the osteoinductive, osteoconductive, and osseointegrative characteristics of the graft; the molecular and mechanical environment of the surgical site (compression stimulates while traction reduces bone growth); the contact between the graft and recipient bed (stable contact prevents bone resorption); and patients' characteristics and comorbidities. Typical donor sites for bone grafts include fibula, tibial crest, rib, calvarium bone, and iliac crest; grafts can be fashioned including cancellous bone, cortical bone, or both with different clinical applications (Table 6.3). The use of allogeneic bone grafts for reconstruction of large bony defects can be

Table 6.3 Common characteristics of cancellous and cortical bone grafts

Characteristic	Cancellous bone grafts	Cortical bone grafts
Immediate strength and support	Low	High
Osteogenic properties	High	Low
Incorporation	2 weeks	1–2 months
Maximum length	6 cm	12 cm

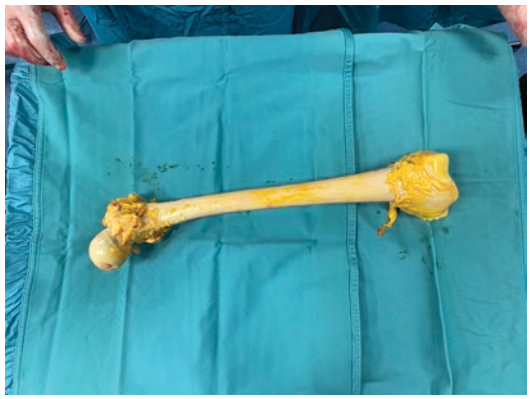

Fig. 6.8 Cadaveric bank femoris prepared for allogenic bone grafting in skeletal limb reconstruction

indicated in some cases (Fig. 6.8). Methods for bone preservation and sterilization have improved during the last decades and allow to obtain acellular scaffolds that are mainly repopulated by ingrowth of recipient mesenchymal cells. Disadvantages of this technique are the antigenicity of the graft and the lack of osteogenic properties in the prepared allografts. The combined approach consisting of allogenic bone grafts and autogenous vascularized/nonvascularized bone grafts can overcome most of the limitations with good and promising results [40].

6.8 Cartilage Graft

Cartilage grafts are widely utilized isotopically in ear and nose reconstruction and heterotopically for tarsal eyelid reconstruction. Graft intake is not predictable, as grafted tissue may exhibit various amounts of resorption, and it is exposed to infection due to the avascularity that intrinsically characterizes cartilaginous tissues. Commonly used donor sites include auricular, nasal, and rib cartilages. Auricular cartilage is the most versatile graft because of its adaptability to be contoured into different shapes. Moreover, it can be harvested under local anesthesia using retro auricular incisions, with low morbidity of the donor site. Auricular cartilage grafts are often used for ear, nasal, tarsal, and nipple reconstruction (Fig. 6.9). Nasal cartilage grafts can be obtained from the septum, and they can be harvested simply as cartilage or as composite chondromucosal grafts for eyelid reconstruction. Rib cartilage is the best option when a large amount of cartilage is needed. For this reason, the costal cartilage graft is often used as a cartilage framework for total ear reconstruction and for the reconstruction of the nose and the nipple, in septorhinoplasties, and in tracheal reconstruction [41].

6.9 Vascular Graft

Vascular grafts may be utilized isotopically or, less commonly, heterotopically for conjunctival reconstruction.

They are particularly useful for microsurgical anastomoses when a deficit of vessel length, size mismatch, and tension over the pedicle are encountered during surgery (Fig. 6.10). There seems to be an association between interposition vein grafting and free-flap complications, but results are still controversial [42, 43]. Commonly used vein grafts are the great or the lesser saphenous vein, the cephalic vein, the volar forearm vein, and the dorsal foot vein.

Arterial grafts present fewer disadvantages when used for the reconstruction of vascular deficits, mostly due to their structural characteristics. Common donor sites are the subscapular artery and its ramifications, the anterior and posterior interosseous arteries, the radial or ulnar arteries, the deep or superficial inferior epigastric arteries, the dorsalis pedis artery, and the descending branch of the lateral circumflex femoral artery (LCFA).

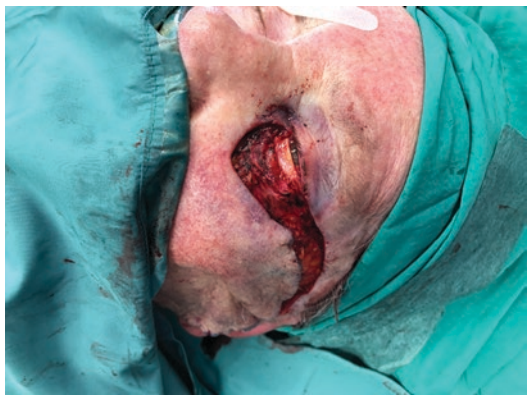

Fig. 6.9 Inset of a cartilage graft for reconstruction of the inferior eyelid tarsum. The cartilage is harvested from the concha of the homolateral ear and sutured to the residual tarsum. A Mustardè flap is then prepared for the reconstruction of the skin defect

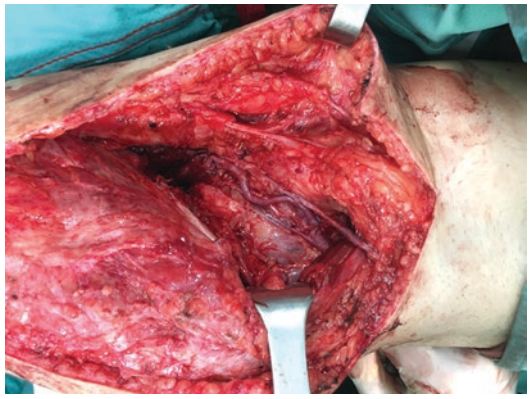

Fig. 6.10 Saphenous vein graft for the reconstruction of a vascular defect in a microsurgical case. The vein may be used for the reconstruction of both arterial and venous defects

6.10 Nerve Graft

When reconstructing nerve defects, nerves can be transferred as a simple graft or together with a vascular pedicle, as a vascularized nerve graft. It is recommended to use a free vascularized nerve graft when the gap distance between proximal and distal ends is greater than 6 cm. For gaps smaller than 6 cm, it has been demonstrated that conventional grafts are equivalent to free vascularized grafts in terms of functional recovery [44]. When a nerve graft is used, all neuronal

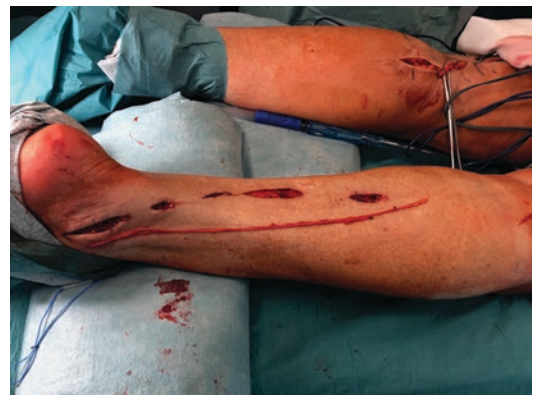

Fig. 6.11 Sural nerve graft harvested from the right leg. Four small incisions are used for dissecting the length of the nerve needed. Long nerve grafts can be harvested from this anatomical area

cells included in the graft and in the distal end of the injured nerve degenerate. The nerve graft, mostly composed of glial supportive cells, guides axon regeneration toward the distal end. The sural nerve is the most commonly used graft as it can reconstruct long nervous defects and because its harvest causes low sensitive donor site morbidity (Fig. 6.11). Other nerves, such as the branch from the obturator nerve to the gracilis and the distal anterior interosseous nerve, are less commonly used. When possible, donor nerves close to the defect should be evaluated for functional transfer if the resulting benefit is greater than the functional loss of the donor site. Biological and synthetic conduits have been used for addressing peripheral nerve gaps due to their ability to induce nerve growth. Biological conduits commonly include bone, artery, and vein with or without muscle graft filling. Biodegradable synthetic conduits include polyglycolic acid polymers [45]. Acellular human processed nerve allografts (ANAs) may be used for nerve reconstruction. They are composed of epineurium, fascicles, endoneural tubes, and laminin. With these characteristics, ANAs act as 3D scaffolds that are repopulated by recipient cells similarly to autologous grafts. Nevertheless, autografts have been demonstrated superior to ANAs and conduits, and the latter resulted inferior to ANAs [46]. Transplanting Schwann cells into ANAs in vitro has proved to improve functional regeneration,

reaching results of functionality similar to the use of autografts [47].

6.11 Fascial and Tendon Graft

The use of fascial grafts is related to their ability to reinforce, sustain, or substitute damaged structures. For their structural characteristics, fascial grafts are commonly used to achieve symmetry in static procedures in facial paralysis surgery, alone or as an adjunct to dynamic procedures. With these indications, they can be anchored to the labial commissure to open the oral orifice or to the tarsum for closing the eyelid rim. Moreover, they can be used for the correction of palpebral ptosis by suspending the upper ptotic eyelid to the frontalis muscle. The preferred donor site for harvesting fascial grafts is the tensor fascia latae or the deep temporal fascia. For this purpose, a surgical instrument called "fasciotome" has been developed to minimize the donor site morbidity derived from an open approach, which usually comprehends a wide incision and exposure of tissues, allowing graft harvest through two small skin incisions. Tendons may be used for the same indications of fascial grafts. Palmaris longus, plantaris, or extensor digitorum longus tendons are commonly used for grafting because of their low donor site morbidity.

6.12 Tissue Engineering

Regenerative surgery is considered an interdisciplinary setting of research, and its clinical application is aimed at repairing, substituting, or regenerating cells, organs, and tissues in order to restore altered structures or functions. Tissue engineering consists of the creation "ex vivo" of biological substitutes, overcoming most of the limitations of natural and synthetic biomaterials. Numerous attempts in recreating human tissues have been made over the years; only a few are briefly summarized in this section.

Commercial products currently available for the treatment of **skin and mucosal defects** are divided into three categories: acellular products, cellular products, and growth factor products. Acellular products, such as collagen and decellularized matrices or fibrin, are constructed using a combination of synthetic and natural materials without cells. These products promote wound healing by improving the wound microenvironment, which facilitates endogenous tissue healing, and providing temporary wound coverage. Cellular products are commonly composed of cultured keratinocytes with synthetic scaffolds. Some products are composed of a combination of fibroblasts, keratinocytes, and scaffolds. Recently keratinocytes, fibroblasts, and melanocytes were utilized to recreate the structure of the physiological skin [48]. Similarly, with the aid of cell cultures, it has been possible to recreate a layered mucosa that has been clinically utilized for treating vaginal deficits such as those of Mayer–Rokitansky syndrome or gender reassignment surgery. *Growth factor products*, such as platelet-derived factors, which are the most studied at the moment, are soluble factors that promote healing by stimulating the regeneration of resident cells. Although all of these devices hold promise, none has been able to mimic the healing capacity of native skin.

Autologous fat grafting allows isolation of large amounts of fat-derived stem cells. Plastic surgeons have investigated cells harvested in lipoaspirates as cell sources for bioengineered tissues. Adipocytes are harvested from the lipoaspirate and expanded on three-dimensional scaffolds with the aim of recreating volumetric material to address deep defects. Studies examined the expansion of the fat-derived stem cells ex vivo with their reimplantation and demonstrated improved volume retention than traditional aspirates. Nevertheless, tissue-engineered fat is still experimental.

With regard to bone grafting, most of the studied devices use synthetic polymer and processed biologic materials to provide acellular osteoconductive scaffolds with and without osteoinductive ligands. A human decellularized bone allograft with bone morphogenetic protein 2 has been developed to promote osteoinduction and osteoconduction. New studies are evaluating the feasibility of ex vivo constructs with endothelial

cells and hMSCs. Although these devices show promise, they are still experimental.

For **cartilage** reconstruction, commercial products have been developed using implantation of isolated or cultured cells. Autologous chondrocytes have been harvested, expanded ex vivo, and reimplanted in cartilaginous lesions. Different techniques have been developed both utilizing scaffolds or not. Scaffolds investigated are hydrogels, decellularized xenogenic matrices, microfiber meshes, and 3D-printed scaffolds, which can be natural (collagen or hyaluronic acid) or synthetic molecules. Clinical indications for these products include reconstruction of articular surfaces and ear and tracheal reconstruction.

Tissue-engineered **blood vessels** may provide alternatives to autologous tissue bypasses, usually utilized for coronary artery bypass grafting and peripheral transplantation in microsurgery, and actually represent a promising therapeutic option. In the last few decades, tissue-engineered vascular grafts showed a quick development: while large-diameter (>6 mm) artificial blood vessels have been successfully used in clinical settings, small-diameter grafts (<6 mm), such as the inguinal artery and coronary artery transplantation, failed to achieve satisfactory patency. In fact, the low blood velocity in small-diameter vessels may enhance blood thrombosis capacity and intimal hyperplasia impairing graft success. Recently, polyurethane and fibrin scaffolds have been used, jointly with MSCs, in preclinical and clinical studies showing good promise [49, 50].

Reconstruction of peripheral **nerve defects** with tissue-engineered nerve scaffolds is an exciting field of research and holds potential for near-future clinical application. However, neovascularization of the graft and nerve regeneration are scarce for large nerve defects. Polyurethane copolymer scaffolds, studied in "in vivo" models, showed good Schwann cell compatibility and rapid vascularization, restoring nerve conduction and function [51]. Adipose-derived stem cells (ASCs), thanks to their capacity to differentiate, among others, in Schwann cells, have been used with different nerve conduits, such as hydrogels or silk fibers, and have proved to promote nerve regeneration [52].

Pearls and Pitfalls

- Hematoma, seroma, edema, and infection are common complications that may easily cause graft take failure. Technical artifices such as accurate hemostasis, antisepsis, fenestration of skin grafts, and administration of i.v. corticosteroids can be used to avoid graft failure.
- Since full-thickness skin grafts provide an excellent functional and esthetic outcome but are very limited in availability, a split-thickness skin graft is the best option when a large skin defect has to be covered.
- Due to the fragility of fat cells, mechanical damage of the tissue must be minimized both during fat graft harvest and injection.
- Combining the use of allogenic bone grafts with autogenous vascularized/nonvascularized bone grafts is a promising approach that can overcome most of the limitations of traditional bone grafting with good results.
- Vein grafts need particular care during harvesting and setting. In particular, it is important to avoid manipulating the vein excessively during harvest and to perform graft dilatation prior to anastomose, to make sure the graft is positioned according to anterograde flow (due to the presence of valves), to use a vein with a smaller caliber than artery, as vein dilatation under arterial pressure is common, and to carefully select the length of the graft to avoid kinking of the pedicle.
- In the case of nerve grafting, it is recommended to use a conventional nerve graft when the gap distance between proximal and distal stumps is smaller than 6 cm. For gaps greater than 6 cm, free vascularized nerve grafts are indicated.
- To harvest a fascial graft, a "fasciotome" can be used to minimize the donor site morbidity derived from an open approach, allowing graft harvest through two small skin incisions.

Take-Home Message

- A graft is defined as a **free tissue transfer** from one body area to another, with **total vascular and anatomic deconnection** from the donor site.
- The **graft take process** is a **complex biologic process**, and its main phases can be distinguished in **imbibition** and **revascularization**. The understanding of the physiology of revascularization guides the surgical technique and clinical management of grafts.
- Mastering grafting techniques depends mainly on the **type of graft**, the **recipient sites**, and the **structural needs** of the reconstructed area. **Optimizing vascularity and stability** of the connection between the graft and the recipient site appears to be the main concern in graft surgery.
- The tissues most used as grafts in plastic surgery are **skin and adnexa, dermal tissue, fat, bone, cartilage, blood vessels, nerves, fascia**, and **tendons.**
- **Tissue engineering** has demonstrated promising results for creating artificial grafts in a laboratory setting, but only a few could be clinically translated with success.

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Further Reading

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7 History of Reconstructive Microsurgery: From Myth to Reality

Isao Koshima

Key Point

Since 1960, many micro-reconstructive techniques have originated from the Orient, beginning with finger replantation, free flaps, perforator flaps, nerve flap, super-microsurgery, lymphatic anastomosis, vascularized nerve transplantation, etc. World's first free DIEP flap and head and neck/limb reconstruction methods using ALT flaps have also been established in Japan. Popularization of perforator flaps did not become popular in Japan but rapidly spread to the world through live surgery and cadaver study at the first ever International Course on Perforator Flaps (June 1997, Belgian Ghent University). Now, nano-microsurgery is emerging. These surgical techniques and concepts have greatly developed the surgical field. With this technique, Allogenic organ transplantation, bone reconstruction, skull base surgery, nerve surgery, advanced hand surgery, lymphatic surgery, etc. will be developed in a short period of time.

Tips and Tricks

Looking back on history, new concepts and treatments are advocated by revolutionary youth. The more effective it is, the more pressure from authorities and academic societies will be applied, and many concepts are destined to disappear. However, the effective concept and treatment method that remain in history are destined to spread to the world in a short period of time due to the stronger the suppression pressure from the surroundings, the more it burns and the explosion occurs mainly among young people.

Pearls and Pitfalls

Revolutionary innovators who continue to launch new concepts are often oppressed, alienated, and disappeared from academic societies and authorities. They must always be prepared to avoid this. The leaders of microsurgery and perforator flaps continued to grow because of their excellent advocates and the formation of a society such as a perforator course of young groups to train their professionals.

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Take-Home Message

The history of microsurgery is shifting from standard microsurgery to super-microsurgery and nano-microsurgery. Behind the history of the evolution of surgical techniques were young innovators with delicate chopstick culture techniques in the Orient as well as the development of surgical instruments and microscopes, as well as a professor boss who supported them.

Background

The 1960s can be said to be a very important age for plastic reconstructive surgery. In 1962, Jacobson, a thoracic vascular surgeon at Vermont University in the United States, developed an animal-experimental microvascular anastomosis (microsurgery) using a German Zeiss microscope and ophthalmic surgical instruments. In addition, since there was no successor to microsurgery in thoracic vascular surgery, Jacobson's technique was limited to experiments, and microsurgery in thoracic vascular surgery would disappear. At that time, young surgeons (Tatsuki Katsumura, Okayama University; Nomoto, Nagasaki University) from Japan studied abroad to learn this technique and returned to Japan, but they could not apply it clinically because of no microscope and instruments. It was applied clinically with a technique that was completed independently in Japan.

In 1963, Chen in Shanghai succeeded replantation of a complete amputation of the wrist for the first time in the world. At that time, the microscope had not yet been introduced in China, so the operation was performed using a large loupe for machine work. In 1964, at the Venezuelan naval hospital, the allogenic hand of a young man who died that day was successfully transplanted to a young man who lost his hand in an explosion. This was the world's first transplant of the allogenic hand. Unfortunately, after the operation, a young doctor (Goldwyn, the former editor of J plast reconstr Surgery), a subordinate of McMurray in the Plastic surgery of Harvard university, who was a member of the team of world's most advanced kidney transplant, performed immunosuppressive therapy; however, two weeks later, necrosis occurred by rejection (this news was published in the March 9, 1964 issue of Medical Tribune).

In plastic surgery, Harry J. Buncke, California University, reported successful replantation of the thumb and index fingers of a monkey. However, this was not the level of the finger, but near the wrist, because the fingers were amputated obliquely and radial artery was anastomosed at the level of the wrist joint. In the United States, it is reported as the first success of experimental finger replantation.

7.1 Introduction

In plastic surgery, in addition to the conventional surgery for congenital anomalies and burn and cleft lip, reconstructive surgery and cosmetic surgery have recently developed significantly, and now there are three major pillars: plastic, reconstructive, and cosmetic surgeries. New concepts and techniques of plastic surgery influenced a wide area of surgery.

The allogenic organ transfer was originated from allogenic skin graft and renal transplantation in plastic surgery in the middle of the twentieth century, and it can be said that the history of plastic surgery had a great influence on the current surgical operation. However, like many history books, most of the history of plastic surgery has been written by Western authors, and the history of things that started in the Orient, such as microsurgery, is far from true. This paper describes the true historical anecdote of microsurgical reconstruction from Japan.

In Japan, vascular anastomosis began in the 1960s using a microscope made in Japan. In 1965, Tamai of the Nara Medical University Orthopedic Surgery succeeded in completely cutting and re-planting the thumb for the first time in the world [1]. Behind this feat was the presence of the world's latest anastomotic needles and surgical microscopes. His teacher, Professor Onchi, visited Jacobson at the University of Vermont shortly before, and a finger artery anastomosis was performed using the latest Ethicon micro-anastomosis needle that had been brought back to Nara Medical University. Onchi's passion was hot, and he bought the latest expensive Zeiss microscope at Nara Medical University ahead of other universities and was preparing for the world's first feat. Due to the achievements of Onchi and Tamai, many young followers in Japan appeared, and from around this time, the foundation for Japan to lead the reconstruction technique using microsurgery was laid. Also, from that time on, the competition began to occur in the field of plastic surgery as to who would be the first in the world to perform flap transfer and free flap using microsurgery. Finally, in 1973, Daniel and Taylor reported the world's first successful case of transplanting a free groin flap for a skin soft-tissue defect in the ankle joint and performing vascular anastomosis [2].

Daniel was sent from McGill University in Canada to train under O'Brien in Melbourne, Australia, which was at the forefront of microsurgery. Although he was still in his twenties, the surgery seemed to be so good that he could perform vascular anastomosis after a short training.

7.2 History on Free Flap Transfers in Japan

In Japan, in 1971, Harii of Tokyo Police Hospital succeeded in the world's first supercharged chest wall flap in the field of plastic surgery, and in 1972, free superficial temporal artery flap and skull for bald hair due to burn scars. Successful free omentum transfer for exposed deep burn ulcers was also achieved. Behind the feat of Harii, there was a great deal of support from his teacher, Director Seiichi Omori. In 1993, Ueba of Kyoto University Orthopedic Surgery also succeeded in the world's first free vascularized fibula transfer. At that time, it was very difficult for Japanese people to submit a treatise in English.

In the early 1968, Tamai reported the effectiveness of vascularized muscle transfer in dogs. In 1976, Ikuta of Hiroshima University reported for the first time in the world a dynamic reconstruction technique in which the muscles of the forearm of a boy with Volkmann contracture were reconstructed by a pectoralis major muscle transplant with a neurovascular pedicle. The transplanted pectoralis major muscle began to move with the forearm, the fingers began to move, and the function of the hand was restored. Behind Ikuta's feat was the enthusiastic support of his teacher, Professor Kenya Tsuge. At the same time, Kubo of Hiroshima University Orthopedic Surgery reported in his experiment that muscles normally recovered with an electron microscopic approach. In the same year (1976), Harii succeeded in voluntarily reconstructing established facial palsy by transplanting gracilis muscle with a neurovascular pattern from the thigh for old facial nerve paralysis. In this way, microsurgery pioneers Tamai, Harii, Ikuta, and Ueba played an active role at the forefront of the world in the early 1970s, and as a result, became the foundation of Japan's development ahead of the world for 30 years to this day.

7.3 Introducing Perforator Flap and Fighting Against Traditional Microsurgery by the Authority

In 1984, Song in China reported anterolateral thigh flap (ALT flap) and anteromedial thigh flap (AMT flap) [3]. The flap as large as 30 cm in length can be supplied by only one perforator with less than 1 mm in diameter. That being the feature, they reported it as a septocutaneous perforator flap. While as a nutrient vessel, it surpassed the common sense in its thinness.

In 1986, Koshima applied island ALT flap to the reconstruction of genital defect, followed by

Lin in 1988. In 1989, Koshima reconstructed wide loss of lower jaw with combined vascularized iliac bone flap and ALT flap. Based on such clinical cases, the anatomy of its nourishing blood vessels was reported by Xu [4] and Koshima [5] in the late 1980s. In 1989, a deep inferior epigastric perforator flap (DIEP flap) was reported by Koshima [6] (Fig. 7.1a, b). And accordingly, the basic concept of the perforator flap was set up.

In 1993, a series of head and neck reconstructions with ALT flap was reported by Koshima [7] (Fig. 7.2a, b). Afterward, Kimura and Kimata established its validity by applying ALT flap to head and neck reconstruction.

From 2000, head and neck reconstruction with such ALT flap became popular in the world (Figs. 7.3 and 7.4). Until now, according to Wei in Taiwan and Yu in Anderson Cancer Center, ALT has been the primary choice in head and neck reconstruction.

Moreover, from the middle of 1990, the DIEP flap had become the first choice for and was widely applied in minimally invasive breast reconstruction in Europe and the United States, replacing the traditional rectus abdominis musculocutaneous flap. In 1997, the workshop on perforator flap was started in Europe; later on, the thoracodorsal artery perforator flap (TAP flap) was presented by Angrigiani in Argentina in 1996 [8]. Together with TAP flap pedicled with intermuscular capillary [9, 10], ALT flap, and DIEP flap, the three flaps are started to be shown on live surgery of the international perforator training session. Until now, more than 5000 learners have learned the elevation of such flaps, which are then being applied worldwide.

TAP flap was initially reported in 1995 by Angrigiani in Argentina as a new flap pedicled by a thick thoracodorsal artery perforator to replace the latissimus dorsi musle flap [8]. In my opinion, per-

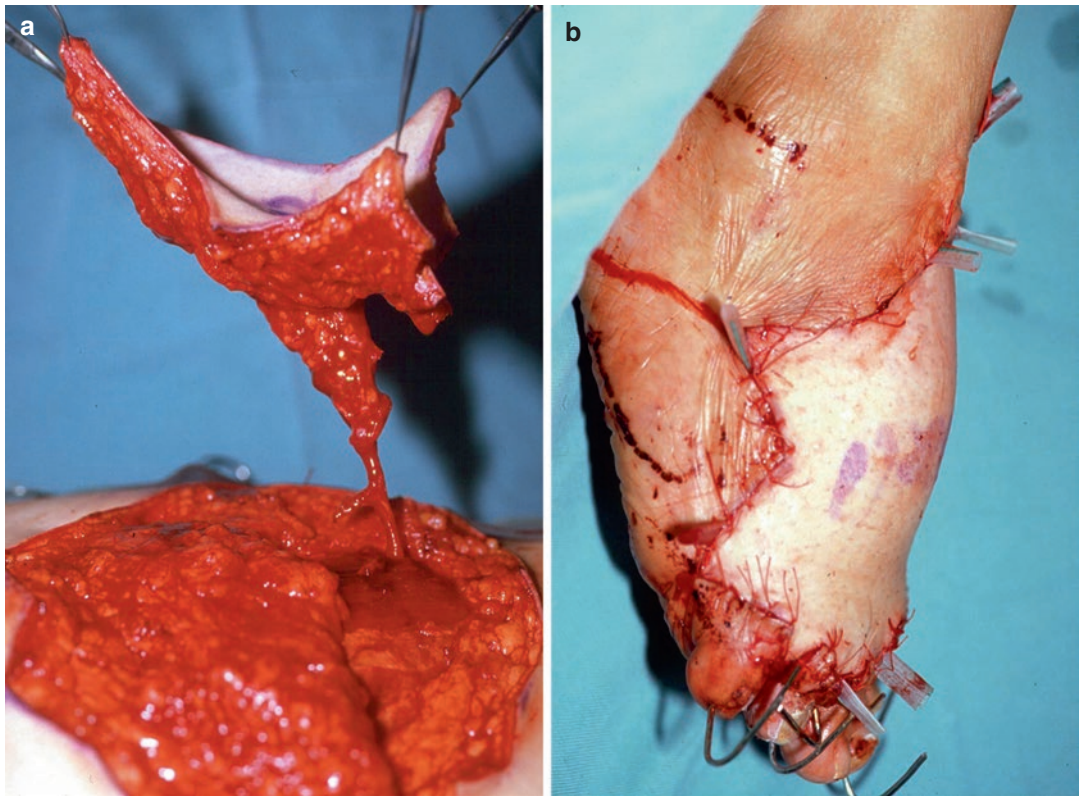

Fig. 7.1 (**a** and **b**) The world's first case of a free DIEP flap (surgery on 1987.12.25., Koshima I, et al. J Reconstr Microsurg, 7: 313–316.1991)

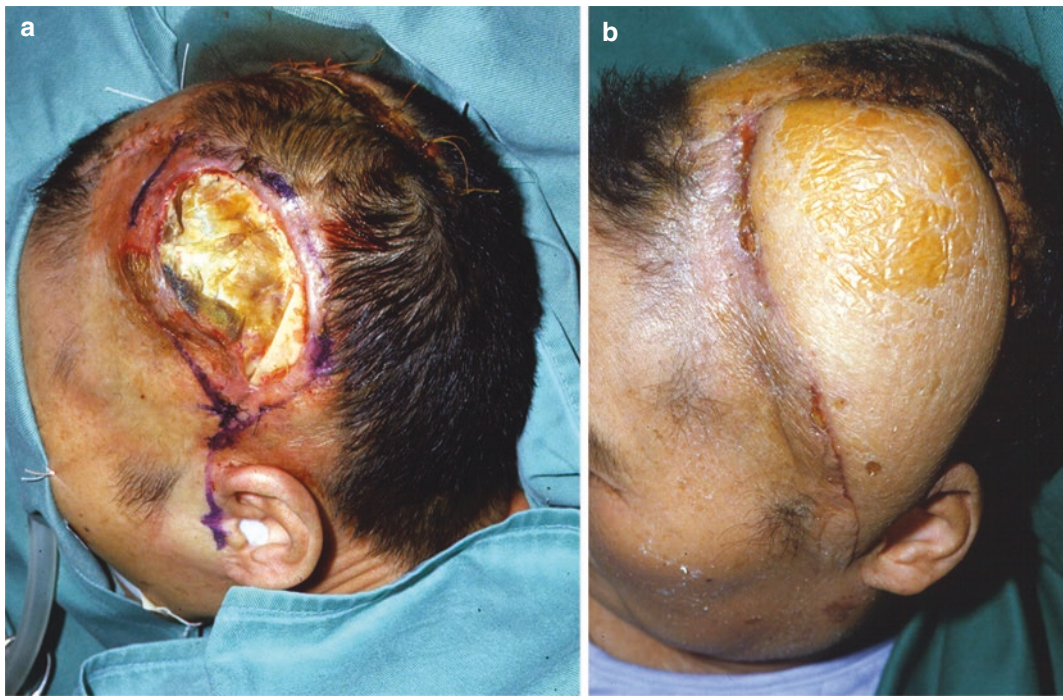

Fig. 7.2 (**a** and **b**) The world's first case of head and neck reconstruction using ALT flap.. After this, head and neck reconstruction with the ALT flap was established (surgery on 1985.9.27. Koshima et al., Jap J of Plast Reconstr Surg. 6: 260–267, 1986)

forator as thick as 0.8 mm in diameter is usually absent. Thus, currently, it is not popularly applied. However, according to my experience, the thin capillary perforator (diverged from descending lateral branch of a thoracodorsal artery) can support the big flap [9, 10]. To elevate the flap in 30 min for application, a new capillary perforator flap is believed to be the most popular free flap in clinical use.

Since around 1987, the idea of a perforator flap is that a huge flap can live only with a perforator flap of about 0.5 mm without inserting muscle or fascia with a conventional myocutaneous flap or fascia flap. The DIEP flap [6] was devised from this concept, and minimally invasive flap transfer that does not include muscle and fascia as much as possible begins. Initially, various perforator flaps were not easily understood not only in Japan but also overseas, and they overturned the conventional surgical techniques, so there were many criticisms from authorities in each area, especially in Japan. Koshima of Japan, Allen of the United States, and Blondeel of Belgium played a central role in the first international perforator flap in June 1997 with the intention of having young reconstructive surgeons around the world master of the perforator flap procedure. A flap training course was launched (Figs. 7.5 and 7.6). In this workshop, we actually exhibited live surgery and had them experience the raising of a skin flap using a fresh cadaver. Many young reconstructive surgeons learned the perforator flap in a short period of time during this course. The response was great, and then the perforator flap spread mainly in Europe. In the workshop, live surgery such as ALT flap and posterior tibial perforator propeller flap (Koshima), DIEP flap ((Allen), GAP flap (Blondeel), and lymph venous anastomosis (Koshima) was demonstrated for the first time in Europe. This will be the 25th time until 2019, and the number of participants is 200 to 600 each time, and more than 5000 audiences have been attended so far. Unfortunately, in Japan, there is always strong resistance from authoritative doctors and aca-

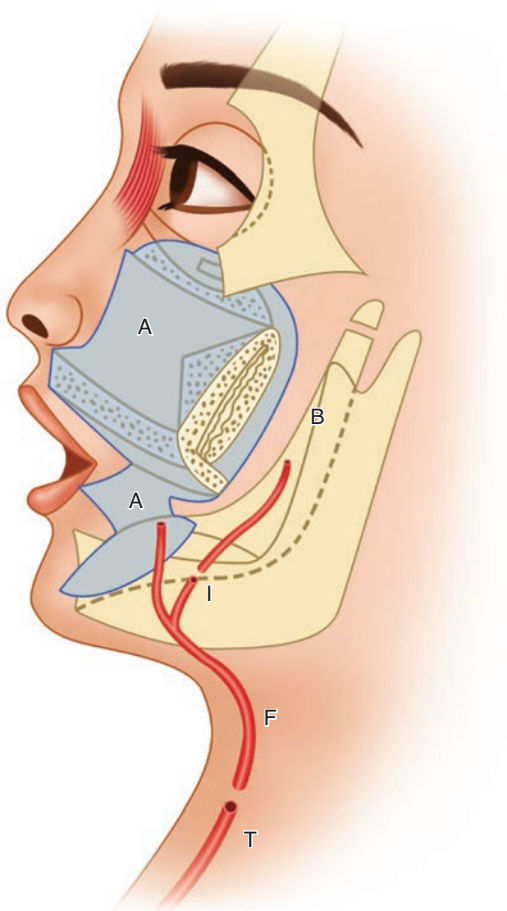

Fig. 7.3 Schema of chimera-type combined tissue transfer for complex facial defect using ALT flap (reprinted with permission from [7])

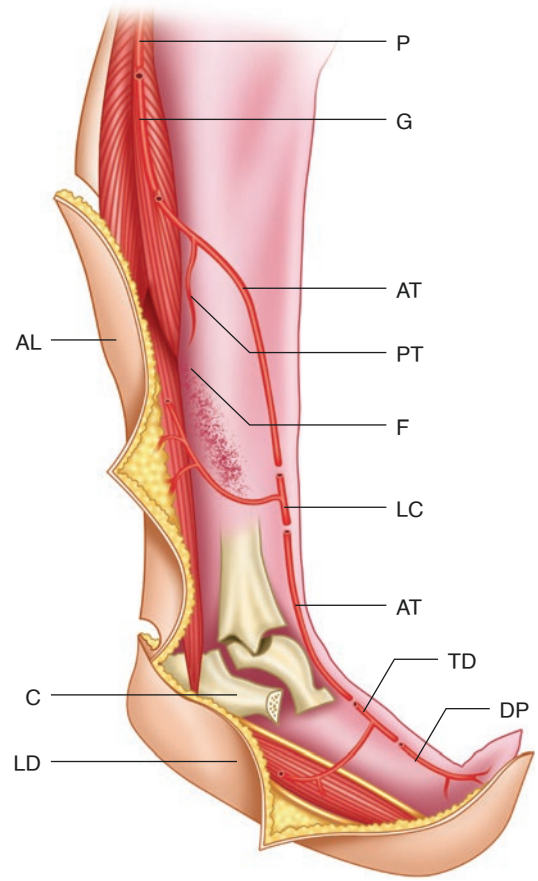

Fig. 7.4 Chimera reconstruction of the complex defect in lower limb using a flow-through ALT flap (reprinted with permission from [7]). P, popliteal artery; G, saphenous vein graft; AT, anterior tibial artery; PT, posterior tibial artery (obstructed); F, fascia lata (Achilles tendon repair); LC, lateral circumflex femoral artery; AL, anterolateral fasciocutaneous flap; C, calcaneus bone; LD, latissimus dorsi musculocutaneous flap TD, thoracodorsal artery; DP, dorsalis pedis artery

demic societies to new techniques and new concepts, and it was about 20 years after success in Japan that this flap became widespread after Europe and the United States.

In addition, super (supra)-microsurgery (super-microneurovascular anastomosis named by Koshima) initially started with microvascular anastomosis of about 1 mm by replanting the fingertips, but then 0.3 mm to 0.5 mm. New replantations and tissue transplants using microneurovascular anastomosis are being developed. At the same time, with the development of perforator flaps, it became common knowledge from around 1990 that a conventional large flap could live with a single pedicle of 0.5 mm, and today, tissue transfer and nerve turnover flap by anastomosing nerve fascicles. Reconstruction methods for nerve defects by nerve flap are becoming widespread.

7.4 History on Nerve Flap

The origin of the report on vascularized nerve transfer is the report on pedicled nerve transfer by Strange in 1947 [11]. Strange transferred the ulnar nerve to the median nerve in two stages as a pedicled nerve transfer. The first report of vascularized free nerve transfer was made by Taylor in

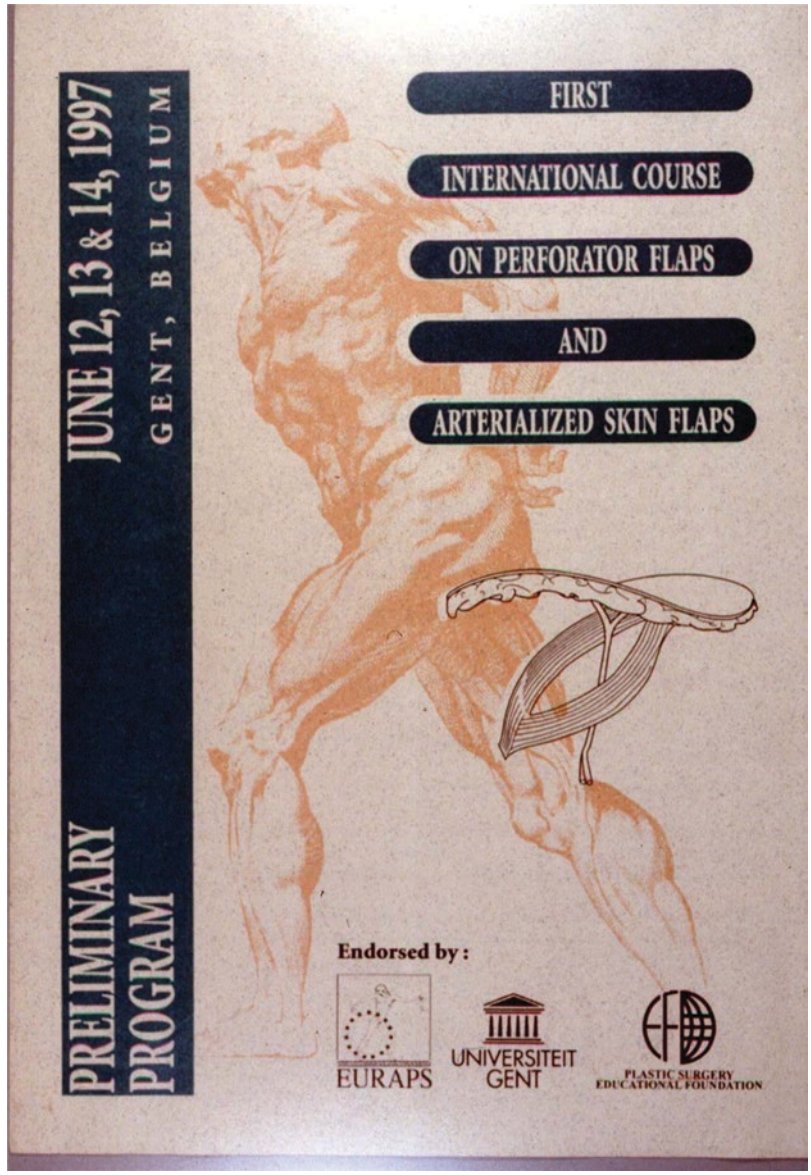

Fig. 7.5 Program of the first International Course on Perforator Flap and Venous Flap (June 1997, Belgium-Ghent University)

Melbourne in 1976 [12]. He performed a vascularized nerve transfer of the radial nerve with the radial arteries and veins as the vascular pedicle to the defect of the median nerve. After that, although vascularized nerve transfer has theoretical advantages over conventional nerve graft, there is no suitable transplanted nerve for vascularized nerve transfer, and there are technical difficulties over conventional methods. It did not reach the general public because no clear clinical comparison was made. According to an experimental study of vascularized nerve transfer of the sciatic nerve of rats by Koshima et al. [13–15], vascularized nerve transfer was performed to a transplant bed surrounded by scars, compared with the conventional method. In the experimental model, early regeneration of axons and high density of large-diameter sciatic nerves have been demonstrated, and the excellence of vascularized nerve transfer has been recognized. In addition, Rose performed vascularized nerve transfer of the deep peroneal nerve in cases of finger nerve injury and gained excellent sensory recovery, and regained interest in vascularized

Fig. 7.6 Faculty members of the first International Course on Perforator Flap. Koshima (Japan), Allen (United States), Blondeel (Belgium), Show (UCLA), Webster (Scotland), Monstrey (Belgium), Konraad (Belgium), and others participated. Live surgeries (DIEP flap, ALT flap, GAP flap) were demonstrated (June 1997, University of Belgium-Ghent)

nerve transfer [16]. When transplanting a thin nerve to the main nerve of the upper limb, it is necessary to fold it into multiple pieces and transplant it as a cable graft. The clinical application was limited because it was bent and impaired the blood circulation of each nerve piece, and the functional donor loss after sacrificing these nerves was not negligible. Bonney reported a vascularized nerve transfer of the ulnar nerve, a method that is performed only under specific conditions of brachial plexus withdrawal injury, where the ulnar nerve is a widely used transplanted nerve for nerve reconstruction of the upper limbs. Therefore, the development of vascularized nerve transfer of the sural nerve, which is mostly used as a transfer nerve by the conventional method, has begun. After that, since the donor site of the vascularized nerve flap having arteries and veins is clinically restricted, the arterial nerve feeds the graft by arterial blood circulation using the nerve graft having only the arterial system or the venous system. Nanosurgical nerve flap transfer (presented Japanese Society Reconstr Microsurg, Nov. 27, 2020.), which needs anastomosis of 0.1 mm feeding vessels in nerve flaps, has also begun to be performed.

7.5 Surgery for Lymphedema

Microscopic lymphatic vein anastomosis method.

In 1976, Melbourne plastic surgeon O'Brien reported excellent results after microscopic lymphatic venous anastomosis (LVA) [17–19]. Yamada's report is cited in his first treatise [20].

O'Brien is a pioneer in plastic reconstructive surgery who developed new tissue transplants one after another from the 1970s to the 1980s using microvascular anastomosis as well as lymphedema treatment. He then devoted his life to the development and dissemination of surgical treatment for lymphedema for 20 years. This method was also used in Japan in the 1970s, but the postoperative improvement rate was not as high as expected. Therefore, there were few followers. I often heard lectures on O'Brien's lymphedema at the International Society of Microsurgery in the 1980s and 1990s. His last lecture was in Vienna, but it was the most impressive. He had been treating lymphedema so much, but no one had followed lymphedema surgery. He cried and said that this was the hardest thing for him. He died after that, but unfortunately, the technique disappeared in the world. Currently, a new supermicroanastomosis technique is spreading all over the world, within Japan as the transmission base. The background to this is that the real supermicrovascular anastomosis was completed in Japan from around 1990, and the introduction of new fundamental knowledge about the dynamic function of the lymphatic vessel was more effective to popularize the technique of LVA [20].

Supermicro lymph venular anastomosis (LVA) [21–24].

The difference from the Yamada and O'Brien is that the lymphatic vessels are perfused into the venous system by anastomosing the lymph vessels just below the dermis with a needle of 0.3–0.8 mm caliber size.

Vascularized lymph channel transfer (VL transfer) with vascular pedicle [25].

In 2004, the first (VL transfer) of severe lymphedema of the lower limbs for which LVA was ineffective was performed at the University of Tokyo, and 16 years later, it is currently completely cured [25]. This procedure has been used for LVA-ineffective severe lymphedema for the past 16 years and has been shown to be very effective in about 30%. This method has already been lectured and demonstrated internationally. For patients with severe lymphedema that has passed for a long time, the lymp channel flap with prdicle vessels is collected from the healthy side with feeding vessels attached to the normal lymphatic vessels. This is transplanted to the affected limb, and lymphatic fluid is guided to the venous system by transfer of VL flap with normal function. In the case of hemilateral lower limb edema, a lymphatic vessel having a dynamic function in the contralateral first metatarsal region is transplanted to the inguinal region of the affected limb [25]. In cases of bilateral lower limb edema, lymphatic vessels are collected from the axilla and transplanted into the inguinal region. Since the smooth muscle of the VL flap is transplanted alive, the pumping function of the lymphatic vessels is restored and the lymphatic system is expected to have a perfusion effect. It is used for severe lymphedema, and some cases have begun to be completely cured.

7.6 Nano-Microsurgery

In 2017, Koshima moved from the University of Tokyo to the International Center for Lymphedema of Hiroshima University Hospital and developed surgical instruments to perform a finer microvascular anastomosis of 0.1 mm. By using this device and a 1.5–1.0 mm long needle of 40–30 μm, the vascular anastomosis for 0.1 mm diameter became possible. Now a new era of nanosurgery has been started. Reconstructive surgery expected from the introduction of this procedure includes artificial anatomical changes (lymphatic vessel bypass, motor and sensory nerve bypasses), anastomosis of nerve fibers (terminal branches), and cell membrane incision to prevent diseases (prophylactic bypass surgery). Now we can change or modify human anatomy. New operations such as nanosurgical anastomosis and vascularized cellular transfer with feeding vessels are conceivable.

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Evolution of Soft Tissue Flaps Over Time

8

Geoffrey G. Hallock

Background

Most laypersons and even our medical colleagues without hesitation think that the realm of the plastic surgeon is as a cosmetic surgeon. This in a sense is correct in that the movement of body tissues anywhere for any reason by the truly aesthetic practitioner is really also a basic essential characteristic within our reconstructive domain. Even a rhytidectomy or "facelift" could be considered an advancement flap! Taken from the Dutch word "flappen" [1], roughly translated, the word "flap" refers to any hunk of tissue that has an intrinsic blood supply that will maintain its viability. Thus, a flap in addition to skin could be composed of vascularized bone, tendon, nerve, viscera, etc. The history of all such diverse flaps has already been cataloged appropriately by Dr. Koshima in the first chapter. But how they have evolved over the past millennia and why, will best here be shown concentrating on soft tissue flaps only.

8.1 Introduction

Evolution marks the changes in characteristics of a biological entity over time. To put things into the proper perspective, remember that the planet Earth is some 4.5 billion years old ± a few years! The anatomically modern human is said to be the last extant evidence of the genus Homo, which diverged from the Pan genus of the chimpanzee and bonobos—who are our DNA closet relatives still living—some four million years ago [2]. Subsequently traced from *Homo habilis* then followed by *Homo erectus* some two million years later, *Homo sapiens* finally arrived into this world only about 200,000–400,000 years ago. Exactly what "time" is can be equally misunderstood, even if a nonrelativistic discrete measurement like a "year"; and normally is conceived to always proceed in one direction—onward! But a study of the evolution of flaps requires that instead we must now go "back to the future."

Just as the evolution of *H. sapiens* was never in a straight lineage, with many divergences from and hybridizations with other concurrent species [3], so too has been the progression of flaps. To state quite simplistically the cause of this meandering, this course has long been separated into the dichotomy of the anatomists and that of the surgeons, whose paths seem to have run parallel to each other with only occasional intersections [4]. The surgeons struck first, their success [or failure] relying solely on empiri-

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Fig. 8.1 Oblique median forehead flap for two-stage repair of nasal tip

cism and geometric tissue rearrangements as convenient. The first recorded evidence of the use of flaps can be traced to the forehead flap (Fig. 8.1), circa 700 B.C., commonly used to replace the tip of the nose that often had been removed as a corporal punishment as still done in some parts of this world today. Although credit often is given to Susruta Samhita, the Kanghiara family from the Kangra District of the Northern India state of Himachal Pradesh may instead deserve this recognition, as secretly such cutaneous flaps had been used there since 1000 B.C. [5]! More than 2 millennia later, Gaspara Tagliocozzi [1597], often as he displayed in his Teatro Anatomico [anatomic theater] at the University of Bologna (Fig. 8.2), improved the Sicilian method of nasal reconstruction by cutting parallel slits in the skin over the biceps muscle to delay a bipedicled flap, one that remained attached to the arm only at both ends [6]. After a few weeks, the skin was raised to be retained only at its most distal connection on the arm, which allowed the rest to be placed upon the nasal defect itself. Only after another few arduous weeks to allow neovascularization or new blood vessel growth into the arm skin from the nose itself, the flap could be finally separated from the arm to complete the nasal repair.

In both the Indian and Italian methods of nasal reconstruction, the middle portion of the transferred flap, which allowed reach to the defect, was always left open to the air, a technique today called an *interpolation* flap. Both of these flaps, as were all of that time period, had no anatomically identified blood supply, and so were called by many "random flaps," which they were.

Key Point

In the beginning, most flaps were skin flaps designed by the individual surgeon depending on what problem needed to be solved. If the flap pattern worked, often some geometrical variation, the format could then be repeated with some reliability. These were called "random flaps," since cut at random independent of any known blood supply, and often said to be nourished by a "subdermal plexus" of vessels. Today, the proven existence of an intradermal plexus most likely is the true basis of circulation to these random flaps.

Fig. 8.2 The anatomic theatre of Gaspara Tagliocozzi today at the University of Bologna

That is not to say that the source of circulation to the muscles and skin of the body was unknown. Quain [1844] [7] knew long ago the arterial anatomy of the human body as rendered in his numerous lithographs that proved to be quite accurate (Fig. 8.3). The young medical student, Carl Manchot [1889] [8] at Kaiser Wilhelm University in Strassburg, in the highly competitive atmosphere of the day, temporarily discontinued his studies to complete cadaver dissections that unveiled the circulation to the skin to be either large arteries appearing in the fissures between muscles [now called "septocutaneous"] or by perforators through the muscles ["musculocutaneous perforators"]. With the advantage of radiography, Salmon [1936] [9] further documented the interconnections of "Les artères perforantes, musculo-cutanées," which consistently supplied specific anatomical skin territories as Manchot also had predicted. Unfortunately, these anatomi-

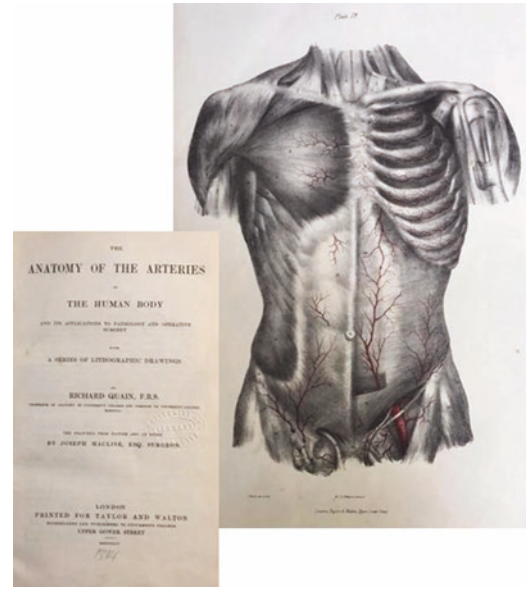

Fig. 8.3 Quain's elements of anatomy/edited by Edward Albert Schäfer and George Dancer Thane (public domain)

cal works, as were many others, were hidden from the surgeons of the English-speaking world until recently [10, 11]. For that matter, the German physiologist Spalteholz [1893] [12] was also presumably unaware of Manchot's publication, when he concluded that the primary circulation to the skin was either by direct cutaneous arteries or reinforced by small indirect vessels that emerge through the deep fascia as spent terminal branches, which had first supplied the deeper tissues and that most often muscle—in fact retrospectively corroborating the findings of Manchot and then later Salmon!

Key Point
Whenever one thinks that their personal discovery is a new revelation that will change the course of reconstructive surgery, it is prudent to investigate the literature as probably someone else had already conceived that idea, although perhaps not in the same language.

Unaware of these revelations by the anatomists, the Italian surgeon Tansini [1896] [13] personally in his cadaver laboratories solved a problem of reliably closing mastectomy wounds by transfer of tissues available nearby from the axillary region. He discovered there a large "scapular circumflex" blood vessel that coursed directly to the skin, but to be safe kept attached the latissimus dorsi muscle to thereby conceive the *musculocutaneous flap* (Fig. 8.4). Soon afterward but now almost a century ago, Esser [1917] [14] in virtual anonymity raised flaps supplied by a palpable artery of the face, trunk, or even groin that he could feel with his finger. He called these "biological flaps" or "artery flaps," which were connected to the body only by their bare vascular pedicle, known now as "island" flaps [15]. Esser did emphasize that inclusion of a nearby vein was as important if not more so than the artery, if venous congestion was to be avoided [15]—a problem still difficult to overcome with cutaneous flaps even today! Another contemporary, the Italian surgeon Pieri [1918] [16], was also well aware that discrete vessels pierced the subcutaneous tissue to vascularize the skin, and by rumor, it is said he placed in a drawing all the cutaneous perforators of the body, with suggestions of how flaps could be designed to incorporate them!

The trench warfare of the First Great War soon overwhelmed the nascent plastic surgery specialty as did the onslaught of the tubed pedicle flap (Fig. 8.5), persuasively disseminated worldwide by the New Zealander Gillies (17). This was a reasonable, if not naturally occurring event, by surgically closing side-to-side the raw undersurface of the unepithelialized open pedicle flaps previously so commonly used [e.g., the forehead flap] [17]. As in the Tagliacozzi method, the arm or even the leg (Fig. 8.6) often served as the carrier for this flap from one body region to another, requiring sometimes multiple intermediate stages and transfers to allow repeated neovascularization until the final insetting, perhaps with months between each step, and always subject to partial flap necrosis at any time. To minimize that risk, rigid length-to-width ratios were dogma to be obeyed, which for example being no greater than 4::1 in the face, or 1::1 in the less well perfused lower extremity (Fig. 8.7). Unfortunately, the tubed pedicle was the classic "random flap," relying as it could only on the "subdermal plexus" of blood vessels, which represented a dead-end divergence and simultaneously retarded the evolution of the flap, as the anatomists were to prove later once again that the surgeons had been wrong.

Slowly, if not slower, other options began to appear that proved to be more reliable and more efficient than the tubed pedicle. Even the cosmetic surgeon Jacques Joseph [1931] [18] in his book on rhinoplasty included a description of a medial based deltopectoral flap from the upper chest that captured the internal mammary musculocutaneous vessels at the second or third intercostal space as its source of circulation, information he had gleaned from Manchot's treatise that had depicted the same [8]! Bakamjian [1965] [19] later wrote that this same deltopectoral flap was based on "perforators" and could be extended horizontally from the sternum to the shoulder to immediately allow reliable coverage

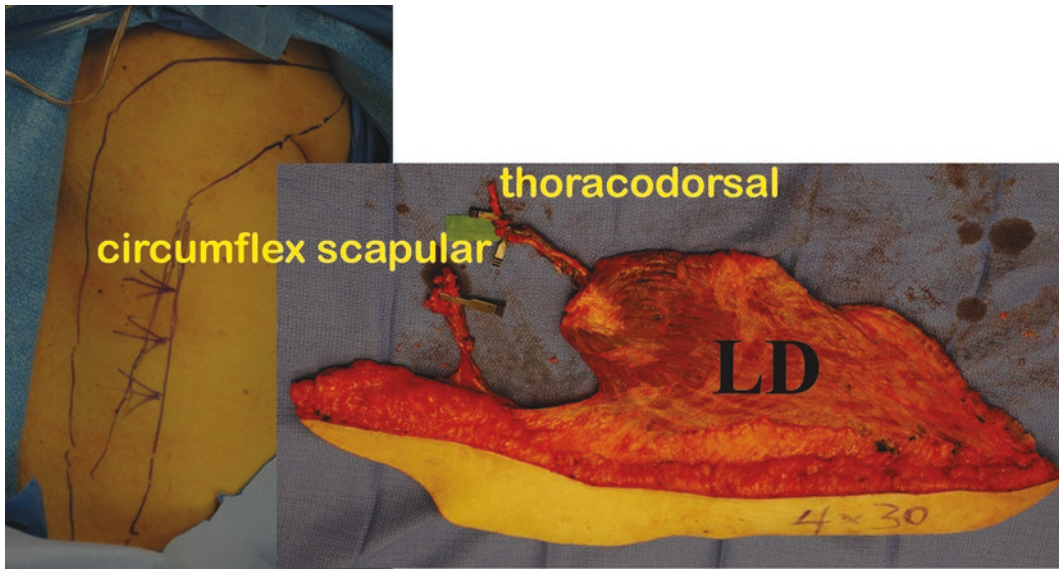

Fig. 8.4 A *musculocutaneous* flap from the back whose vascular supply is from the axilla—the cutaneous branch of the circumflex scapular to the skin, and the thoracodorsal vessels to the latissimus dorsi [LD] muscle

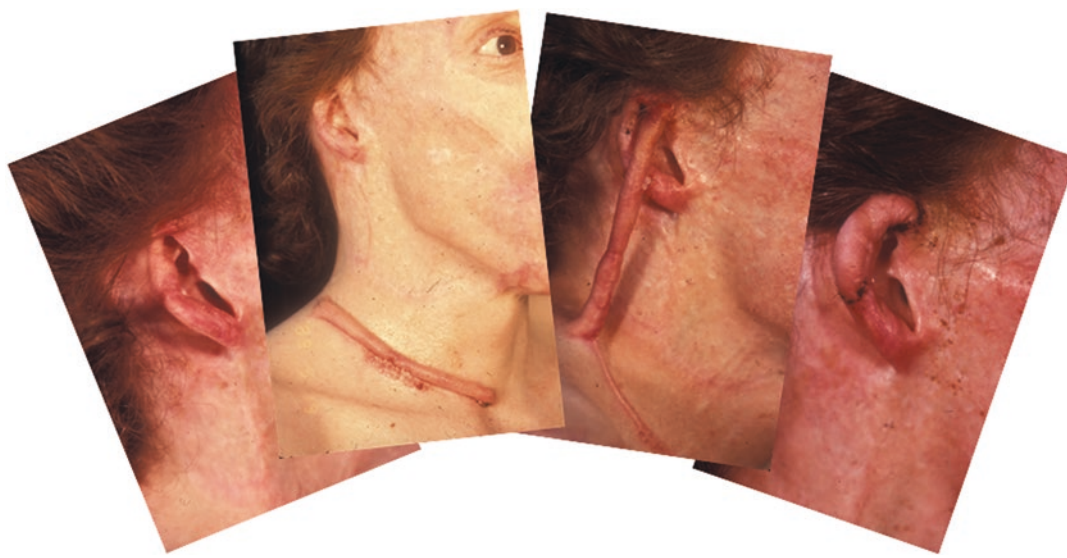

Fig. 8.5 Burned superior helix of the ear restored using the skin of the neck first rolled into a skinny tube, then at the second surgical step with one end still attached ["pedicled"] to the neck transferred to the ear, and finally, after many more weeks, detached from the neck to complete the reconstruction

for otherwise unsalvageable pharyngoesophageal extirpations. Milton [1970] [20] ascertained the validity of these new surgical approaches by proving in laboratory animals the fallacy of the length::width ratio of the "random flap." Instead, of greatest importance to ensure soft tissue flap viability, whether it be skin or muscle, was to know and maintain the intrinsic CIRCULATION. The anatomist had rudely intersected the path of the surgeon, and now the surgeons knew their future tact would be forever altered.

Key Point
The length-to-width ratio is a now archaic dogma that was once the reasoning behind determining how long a flap could be according to how wide or narrow was its pedicle base. This varied depending on the body region, as it was well known that the blood supply in the head and neck is far superior to that of the lower limb. As our anatomical knowledge evolved, we now know that rather than the dimensions of a flap, survival depended on what was the source of circulation that had been captured.

Among the first to straighten this new course were McGregor and Jackson [1972] [21], who sought to mimic the virtually closed arterio-venous system of the deltopectoral flap in a different body region. Perusing nineteenth-century anatomical textbooks, this pair explored the cartwheel of vessels known under the inguinal ligament where the superficial circumflex iliac arterio-venous system became their vascular basis for the oblique flap extending from the femoral triangle to the anterior superior iliac spine, which was termed the "groin flap" (Fig. 8.8). Since the nutritive vessel extended in a nearly straight line along the major axis of this elliptical flap, the appellation "axial" flap was quickly adopted. This discovery resulted in a scurry of activity. No wonder the first successful

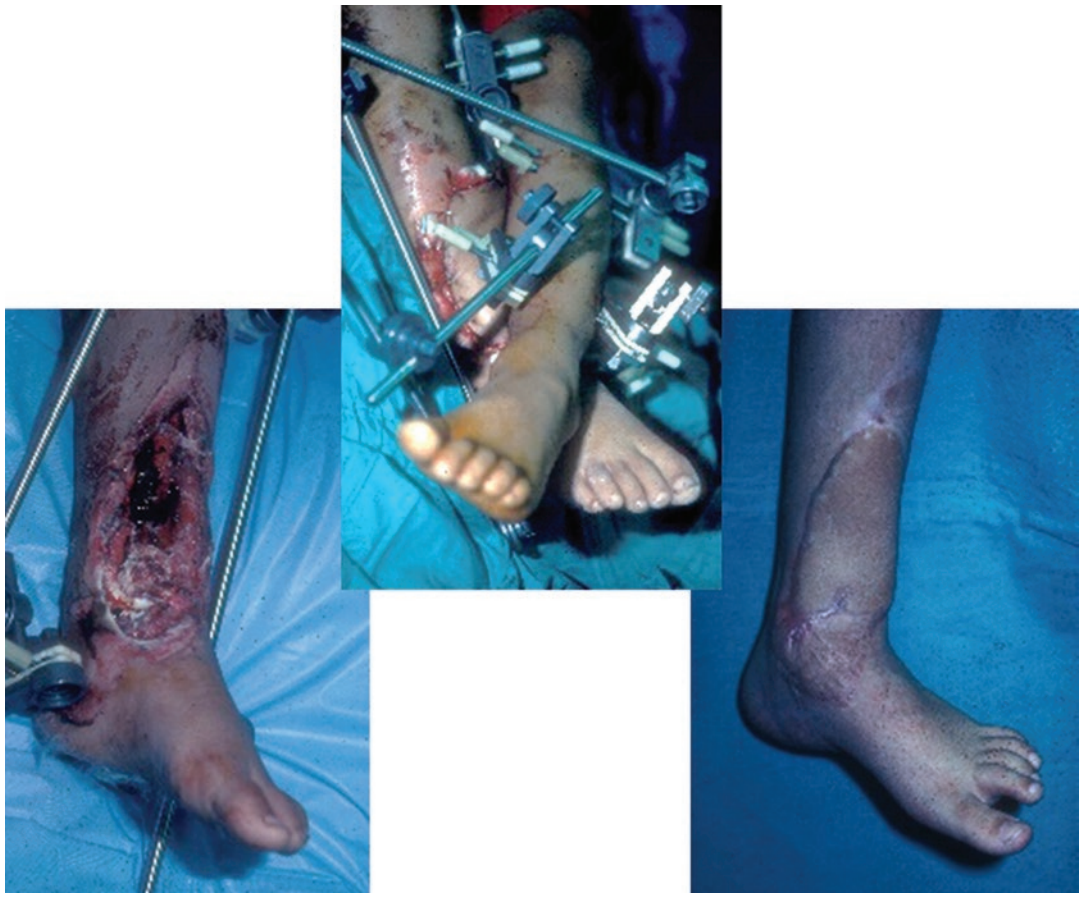

Fig. 8.6 Skin still attached ["pedicled"] to one leg transferred to cover the exposed bone of the other as a "cross-leg" flap. After a month and development of sufficient neovascularization, the original pedicle can be divided and the legs separated

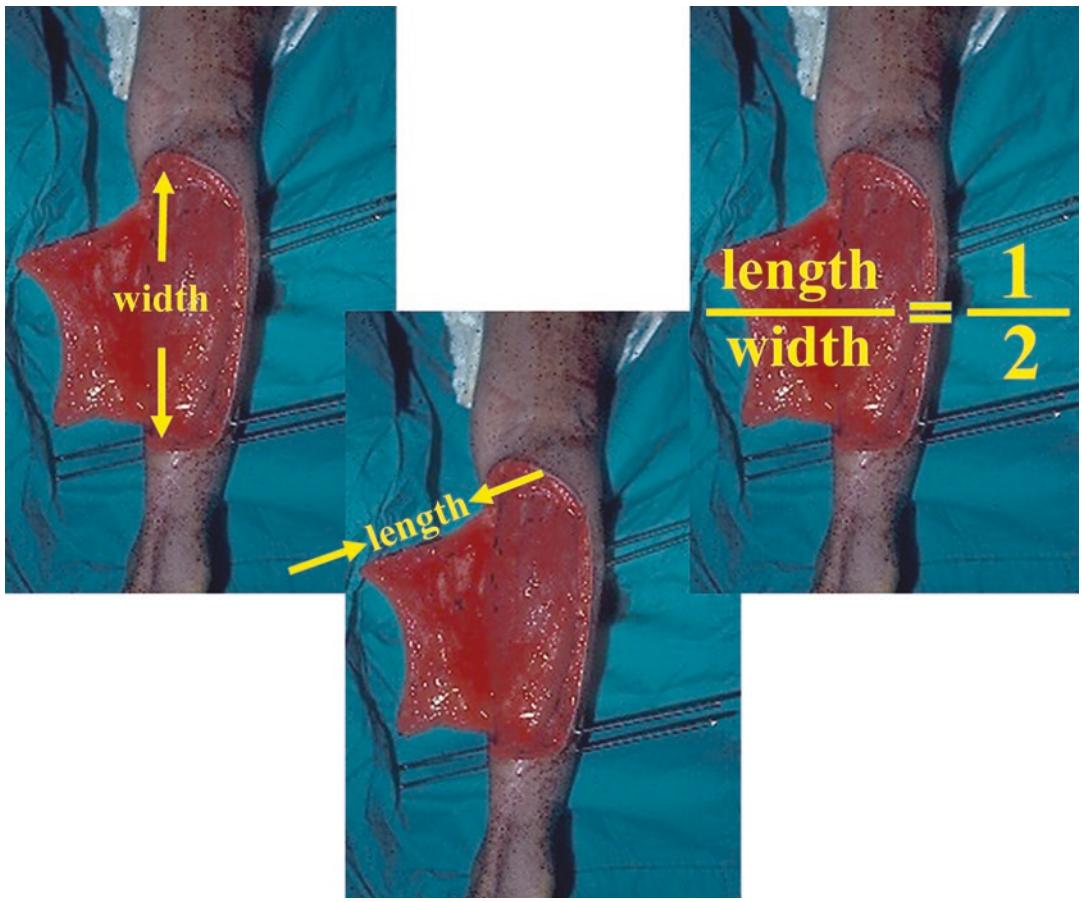

Fig. 8.7 Calf flap remaining attached to the leg only on one side like the page of a book for blood supply. The width of the base or flap pedicle is twice that of the raised length of the page, so the length::width ratio is 1:2, which in the leg should be quite reliable

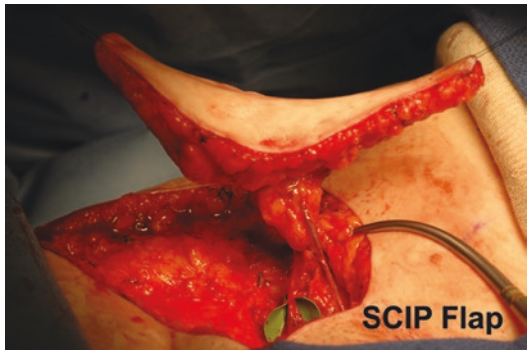

Fig. 8.8 The "groin" flap can today be supplied only by superficial circumflex iliac artery perforators [SCIP], as seen lying here on the green microgrid

composite tissue "free flap" by Taylor and Daniel [1973] [22] harvested this same donor region, albeit the larger nearby superficial inferior epigastric artery was instead selected as the pedicle. Unlike other flaps, their "free flap" was temporarily totally cut free from the body to be taken elsewhere, with its artery and vein then reconnected by microanastomoses to similar vessels at a recipient site near the given defect. Without the innovative genius of Acland [23, 24] (Fig. 8.9) in customizing miniature vascular clamps, essential diminutive tools, and suture needles, the hunt would not have been as soon on for other similar free flap donor sites [25].

Key Point
A "free flap" or microvascular tissue transfer, unlike a local or regional flap, is not restricted in movement by its vascular pedicle. Instead, that can be severed, the tissue transferred elsewhere, and then the circulation reestablished after completion of microsurgical anastomoses of both flap artery and vein to those found at the new recipient site. Note that briefly this tissue has no blood supply, so in reality some could appropriately consider a "free flap" to be at least for a time a "microsurgical graft."

Even a delay in complete elevation of a flap, often used to enhance the dimensions of a tubed pedicle, could be avoided when Orticochea [1972] [26] rediscovered the musculo-cutaneous flap, a possibility he attributed to perforating branches seen to cross the deep fascia from the muscle to the skin—their existence long ago known to Manchot [8]! Note that McCraw

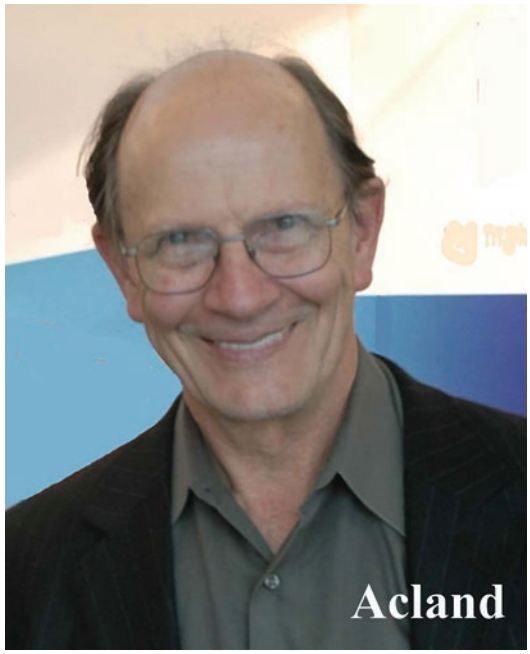

Fig. 8.9 Robert D. Acland, anatomist, microsurgeon, innovator, and "genius"

Fig. 8.10 John B. McCraw, heralded the advent of musculocutaneous perforators and myocutaneous flaps

(Fig. 8.10) and Dibbell [27] soon thereafter in their definition of independent myocutaneous vascular territories throughout the body stated that "most of the cutaneous blood supply is derived from *perforating* muscular vessels." McGregor and Morgan [28] postulated that even circulation in their "axial" pattern flap was "deriving from and draining back into the *perforating* branches" found in the superficial subcutaneous tissues. Taylor confirms this rationale on an embryological basis, describing how the nascent perforator initially penetrates the deep fascia to supply its superficial surface; and then branches in a stellate pattern toward an area of overlying skin to define its cutaneous perforator angiosome [29, 30] [the latter defined as that skin territory supplied by that perforator, or more concisely stated by Saint Cyr (Fig. 8.11) as its "perforasome" [31]]. During dynamic further pre-natal and/or post-fetal growth and move-

Fig. 8.11 Michel Saint-Cyr, originator of the term "perforasome"

ment, these perforators may be stretched in one or multiple directions, which if excessive some have called *direct cutaneous* vessels [née axial], while in reality these are only a dynamic variation of the other septocutaneous perforators that were not so transformed [29, 30].

Key Point
A delay of a flap was a means to enhance the length-to-width ratio. Partially cutting sides of a flap, often in stages many weeks apart, if done properly resulted in changes in the intrinsic circulation of the flap that enhanced perfusion. Such a maneuver rarely has to be done today, as instead a donor site with the desired attributes can be immediately chosen.

To avoid the complexity of microvascular surgery, especially in the treatment of lower extremity injuries, the South African Ger [1966] advocated the use of local muscles as flaps, always keeping intact their intrinsic circulation [32]. To avoid even the use of muscles, as every muscle has a function, the Swede Pontén [1981] [33] reintroduced the "fasciocutaneous flap," which is a skin flap with the deep fascia kept on its undersurface, as another local flap alternative. Whether based on septocutaneous or neurocutaneous perforators, the length::width ratio of the local peninsula-shaped "super" flaps of Pontén in the lower limb merely by retaining the deep fascia unexpectantly exceeded 3::1 whereas traditionally otherwise should be only 1::1 [33]! Asko-Saljavaara [1983] [34] would take any adequate available suprafascial perforator to nourish a skin flap and called them "freestyle" flaps. In the following year, Song et al. [1984] [35] from China portrayed the anterolateral thigh flap that "in addition to the conventional axial flap and myocutaneous flap, we have at our disposal a new type of septocutaneous arterial flap"—although today this "ideal soft tissue" of Wei et al. [36] (Fig. 8.12) is found more often to rely on a musculocutaneous perforator.

Key Point
First intraoperatively find a perforator in a desirable donor site. Then design a flap about it. This would be a "freestyle" perforator flap. However, more often than not today, a desired perforator can be found preoperatively using a CT scan, MRI, or color duplex ultrasound. Therefore, the design of the flap incorporating that perforator can be done before the surgery even starts and is no longer "freestyle."

All this repetition about "perforators" logically led to the manuscript of Kroll and Rosenfield [1988] [37], who, at least in the English language, first used the words "perforator flap" in the title of their manuscript. However, the skin flap without the muscle of Koshima (Fig. 8.13) and Soeda

Fig. 8.12 G. Ian Taylor, first to successfully transfer a composite tissue "free flap" and anatomist extraordinaire; and Fu-chan Wei, master microsurgeon of the world!

Fig. 8.13 Isao Koshima, respected as the "father of perforator flaps"

[1989] [38] from Japan more often is credited as the beginning the *perforator flap* era. By 2012, at least by citation count, the concept of the "perforator flap" had finally become mainstream [39] in the toolbox of the surgeon, primarily due to their extraordinary ability to allow function preservation since no muscle is ever included while being selected to capture the attributes of any donor site in the body where the only prerequisite is an adequate perforator. But what really is a "perforator flap [40]?" As defined by the Gent Consensus [2003] [41] of the International Perforator Flap Faculty (Fig. 8.14), "a perforator flap is a flap consisting of skin and/or subcutaneous fat. The vessels that supply blood to the flap are isolated perforator(s)." Taylor [42, 43] emphasized in his "discussion" that followed that a "***cutaneous perforator, by definition, is any vessel that perforates the outer layer of the deep fascia to supply the overlying skin and subcutaneous tissues, regardless of its pathway from the underlying source vessel***." Of course, surgical manipulations continued to make even perforator flaps more versatile, primarily by removal layer by layer of the thick subcutaneous tissue to create the "thin perforator flap" of Kimura and Satoh [1996] [44, 45] where the deep fat layer was removed below the superficial fascia; or the "super-thin" flap of Hyakusoku et al. [1994] [46] (Fig. 8.15) where only a miniscule layer of fat is left below the subdermal plexus to preserve their subdermal vascular network flaps.

Finally, we reach the "present" time in this odyssey, finding the "pure skin perforator flap" of Narushina et al. [2018] [47] and Yoshimatsu et al. [48] (Fig. 8.16), which is a "dermal flap"—skin altogether without subcutaneous tissues! Some might argue that this is more a skin graft

Fig. 8.14 The International Perforator Flap Faculty on site in Sydney, Australia

Fig. 8.15 Hiko Hyakusoku, conceived the term "propeller flap" and investigated "superthin" perforator flaps

than a perforator flap, but unlike a graft that by definition has no blood supply whatsoever, the "dermal flap" remains supplied by a cutaneous perforator! Indocyanine green angiography has shown that the ~0.1 mm skin perforator branch as it enters to terminate within the intradermal plexus of the dermis itself has stellate reduced caliber "choke" vessels that in turn connect to those of an adjacent skin perforator branch, as well as direct "true" anastomoses, vessels without reduction in caliber, that connect adjacent intradermal branches [48]. Amazingly, this pattern reflects the angiosome concept of Taylor and Palmer [29], in that circulation is contained in a continuous three-dimensional connective tissue mesh of vessels that spans all components of the entire body! All tissues, from bone to skin in a given angiosome territory, will be served by the same source vessel so that all can be transferred simultaneously surviving only on that source pedicle as what is called a "chimeric flap" (Fig. 8.17). By definition, this form of combined flap consists of **multiple flap territories, each**

Fig. 8.16 Hidehiko Yoshimatsu, major investigator of the "pure skin perforator flap"

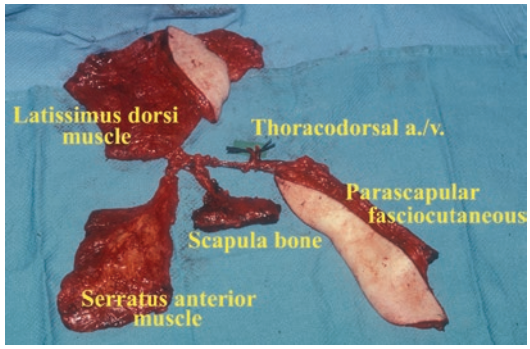

Fig. 8.17 This *chimeric* flap consists independently of a fasciocutaneous flap, musculocutaneous flap, bone flap, and muscle flap, all connected only by branches of the thoracodorsal artery [a.] and vein [v]

with their own independent vascular supply, and simultaneously independent of any physical interconnection, except where linked only by that common source vessel [49]. This penultimate surgical feat relies on an understanding of the basic anatomy to allow three-dimensional reconstructions by simultaneous transfer of multiple free flaps, yet needing only a single recipient site to connect the common vessels of the flap, and all this causing morbidity but for a single donor site!

Key Point
Compound flaps have multiple tissue constituents. If the latter are each dependent on the other for circulation, this would be a composite flap [e.g., a musculocutaneous flap]. If consisting of multiple flaps, such a combination if each flap were independent of the other except for a common source vessel would be called a chimeric flap. If the flaps are not totally independent of each other and have a common boundary, that would be a conjoined flap.

This short history of flaps, a few thousand years compared to the billions of life on Earth, has had an even briefer evolution that has been most vibrant in the past half-century. Although vascularized composite tissue allotransplantation allowing the transfer of body parts such as the face (Fig. 8.18) from one individual to another has been shown to provide superior results to conventional flap reconstructions, this is still in its early stage of development, which rightfully should be so respected and restricted to specified regional centers [50–52]. Perhaps someday a flap like this can be chosen on demand from the shelf, altogether sparing donor site morbidity, whether of "biological"

Fig. 8.18 Laurent Lantiere, Bohdan Pomahac, Eduardo D. Rodriquez, and Maria Siemionow, pioneers in facial vascularized composite tissue allotransplantations

origin as Esser would have it, or manufactured via 3D printing. Obviously, the "future" will demand extensive research by the surgeon and anatomist alike until more pragmatic alternatives become universally available. Until then and surely long afterward, the surgeon must adapt and retain sufficient flexibility in mind and skillsets for the acquisition of the best new ideas that have sustained reliability, while always minimizing complications and untoward events for their patients—indeed realizing that change is inevitable and the concept of flaps will continue to evolve ad infinitum [53] (Fig. 8.19).

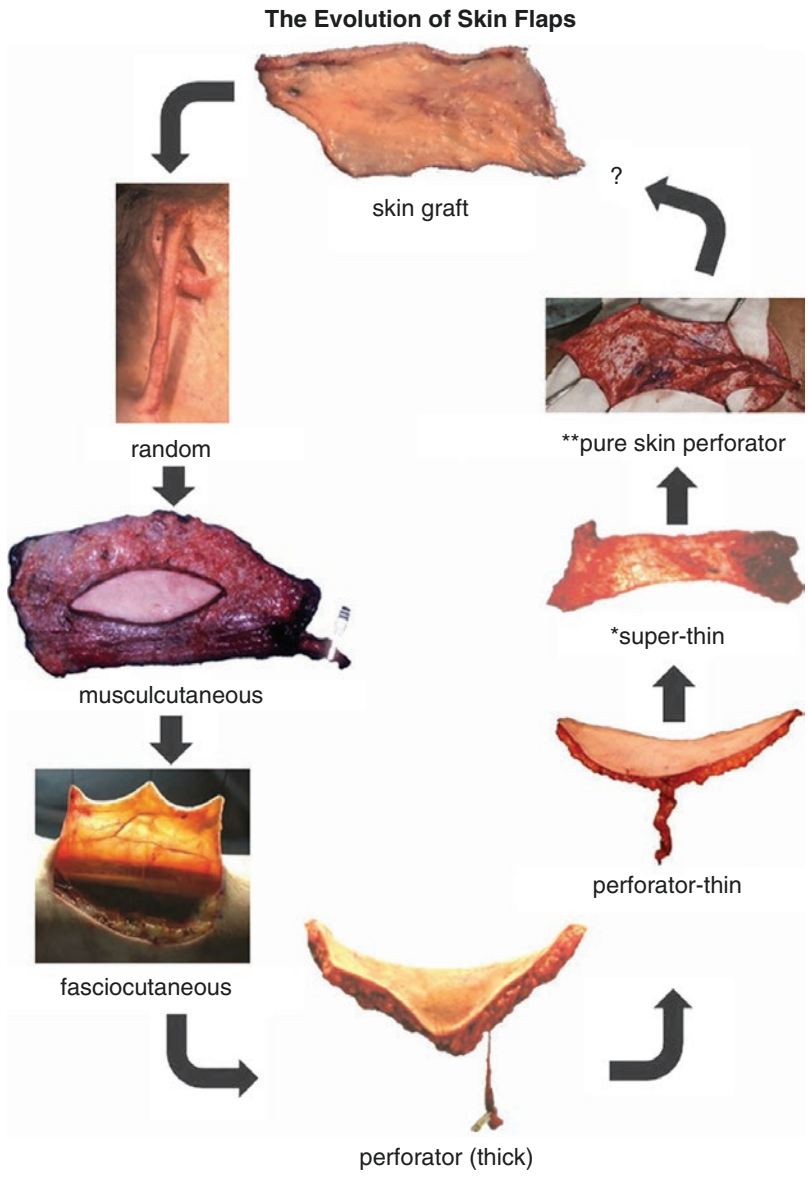

Fig. 8.19 The circumnavigation of the *Evolution of Skin Flaps*, "back to the future" and back again from the skin graft to the skin flap. [*"super-thin" flap photo courtesy of Professor Hiko Hyakusoku, M.D., Ph.D., Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School, Tokyo, Japan. **"pure skin perforator" photo courtesy of Hidehiko Yoshimatsu, M.D., Department of Plastic and Reconstructive Surgery, Cancer Institute Hospital of the Japanese Foundation for Cancer Research, Tokyo, Japan]

Take-Home Message

- Although oftentimes a skin graft will suffice for cutaneous replacement, sometimes the wound bed cannot provide adequate nourishment to sustain it, so tissues that already have their own blood supply—and that would be a flap— will be required.
- Soft tissue flaps can be found in many forms—muscle, fascia, fat, and even just skin, or any combination of these components.
- A basic knowledge of the anatomy of the circulation throughout the body is imperative to ensure a viable flap is possible from a potential donor site. As this knowledge had expanded, so too has the scope of flaps evolved.
- Currently, the perforator flap is in vogue. These are based on a perforating vessel

of the deep fascia. A major advantage is that no muscle need be included, allowing function preservation.

- Another advantage of a perforator flap is that any body region having the desired characteristics of form and contour will suffice as a donor site—as long as an adequate perforator exists there to provide the necessary circulation.
- The pure skin perforator flap is like a full thickness skin graft, but instead vascularized by a discrete perforator. Will this be the next step in the evolution of autogenous soft tissue flaps?
- Vascularized tissue allotransplantation may be a donor source allowing superior aesthetic and functional results with no donor site morbidity, but at the present time requires immunosuppression and the constant risk of recipient site morbidity.
- In this historical journey, the nomenclature of flaps can be more than just confusing and overwhelming! Don't despair, but more specific reading will be required!

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Flaps in Plastic Surgery

9

Joon Pio Hong and Jin Geun Kwon

Background

This chapter introduces the definition of flaps. The use of flaps has been part of the surgical armamentarium for centuries. As the previous chapter noted, the evolution using flap to reconstruction of soft and bony tissue still continues. Thus, various classifications and new applications are being introduced. However, despite this continuous evolution in reconstructive surgery using flaps, the flaps can be classified accordingly using the comprehensive 6C classification. This overview also introduces the core principles for flap surgery, helping the reader grasp the general idea behind reconstruction using flaps. Finally, this chapter will show cases on how flaps are clinically applied.

9.1 Introduction

Flaps are an essential part of reconstruction, whether it may be soft tissue or bone. Flap with its own vascular supply allows transfer from one place to another. Flaps can come in various forms, shapes, and functions, and thus understanding the classification can lead to better application. A flap can be composed of the skin or combined with deep fascia, muscle, nerves, and even bones. Understanding the defect and deciding how the composition of the flap will be is an important step in flap surgery. Various methods can be used to classify flaps. But commonly used classifications are based on the locality of the flap, vascular supply of the flap, and tissue components of the flap. By applying a precise knowledge of the anatomy of skin, muscle, bone, fascia, and other tissue in planning reconstructive procedures, the surgeon has the ability to restore form and function in congenital and acquired defects. Note that the topic of flaps can be vast and complex, but the goal of this chapter is to help you understand the basics of flap surgery. This chapter reviews the flap definition, classification, indication, and principles of flap surgery and finally presents few cases for you to understand how it is surgically applied.

Key Point

– Flap surgery is a technique in plastic and reconstructive surgery where any type of tissue is lifted from a donor site and moved to a recipient site with its own intact blood supply.

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- 6C classification of flap is based on circulation, constituents (composition), conformation (form/shape), contiguity (destination), construction (type of pedicle), and conditioning (preparation).
- Reconstructive elevator concept chooses the most appropriate flap or flaps for reconstruction based on the specific requirements of the patient, the wound, and the circumstances.
- Flaps are used to reconstruct after defects originating from various causes. However, despite the best effort, necrosis can occur partially or totally to the flap. The overall survival depends not only on the proper flap selection but also on preoperative planning, intraoperative techniques, and postoperative management involved in reconstruction.

9.2 Definition

Flap surgery is a technique in plastic and reconstructive surgery where any type of tissue is lifted from a donor site and moved to a recipient site with its own intact blood supply. This is different from a graft, which does not have an intact blood supply and therefore relies on the growth of new blood vessels once applied to the defect area. A skin graft is usually applied over a well-vascularized surface, which will allow new vessels to grow within the skin graft. Thus, a flap with its own vascular supply will not be restricted to cover any raw surface regardless of vascularity such as bones, tendons, and other tissues without robust vascularity. The flap is also used to not only provide coverage but to provide a favorable esthetic outcome. A typical example would be breast reconstruction surgery. After resection of the breast, the muscle does allow for skin graft to provide coverage, but the flap will provide a far more functional and esthetic result. The flap will also allow better functional outcomes with an example being functional muscle transfer. By using a muscle flap with the nerve attached, the muscle can function to provide contraction between the two joints and thus functional reconstruction can be performed. Having its own vascular supply will allow flaps to provide functional and esthetic outcomes in reconstruction. Understanding the vascularity of the flap, the pedicle, is crucial in having a successful outcome. However, understanding the flaps is not limited to vascularity. There are multiple additional factors that play a role. Further explanation will be given in the next section under classification.

9.3 Classification of Flaps

A flap consists of tissue that is mobilized on the basis of its vascular anatomy. Flaps can be composed of skin (including subcutaneous fat), skin and fascia, skin and muscle or skin, muscle and bone, or various compositions of tissues. Because the circulation to the tissue to be mobilized is crucial for flap survival, the development of flap techniques has depended on defining the vascular anatomy of the skin and underlying soft tissue. Through the natural evolution of flaps as discussed in the previous chapter, classification has also changed over time. Therefore, it is important to understand the basic principle for classification, which will be discussed here, followed by showing typical examples of widely used classification.

Circulation being clearly the most important character of the flaps with identified pedicle, Cormack and Lamberty were the first to advocate the source of the circulation as the most important character of flap selection [1]. The six Cs in addition to circulation included constituents (composition), conformation (form/shape), contiguity (destination), construction (type of pedicle), and conditioning (preparation). Hallock further outlined this classification in accordance with the six Cs and named it "complete classification of flaps" (Fig. 9.1) [2]. With the addition of recent flaps and advances, a modified outline for the basis of flap classification is shown in Table 9.1.

Circulation is related to the blood supply into the flap. Direct vessels are axial and septocutane-

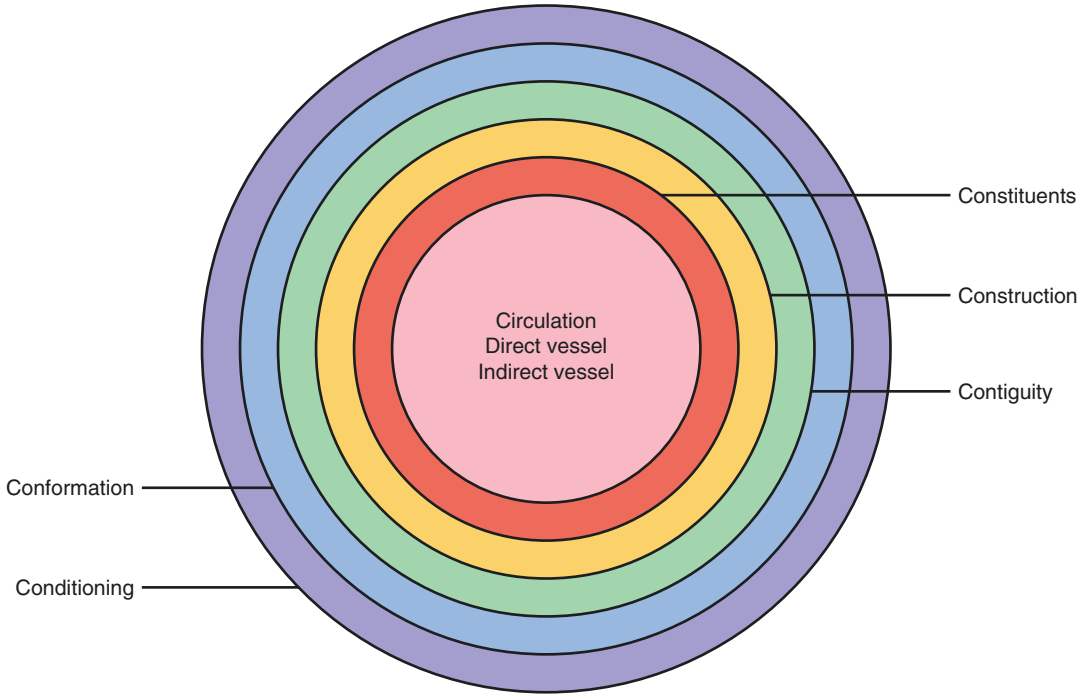

Fig. 9.1 Updated modified "atomic system" with "six Cs" of flap characteristics, but especially "core" or source of flap circulation, where each has a distinct role in determining flap nomenclature. (Reprinted with permission from Hallock GG. The complete classification of flaps. Microsurgery. 2004; 24:157–161)

ous or can be endosteal, which usually provides a linear artery that runs for a considerable distance allowing greater vascular supply to the flap. These vessels are usually named. The forehead flap based on the frontal branch of the superficial temporal artery can be a good example. Indirect vessels can be myocutaneous or periosteal, where these are vessels stemming from the direct vessel source and reaching the flap by small perforating vessels. An example can be a musculocutaneous flap where the skin of the flap is being supplied by small vessels, which originated from a direct vessel and the branches piercing the muscle ultimately reaching the flap. The flap elevation practice changed with the work of Taylor and Palmer presenting the angiosome concept increasing our knowledge of vascular territory of the skin flap [3]. Now, the concept of vascular territory has evolved from thinking of angiosome as the basic unit to applying the perforator as the basic unit termed "perforasome" [4, 5].

Constituents or composition classifies flaps based on the composition of the flap (Table 9.1). A fasciocutaneous flap would be flap with deep fascia and all the structures above the deep fascia like the fat and the skin. Another example can be musculocutaneous flap, which is composed of muscles, deep fascia, and all the structures above. The composition of the flap can include any tissues based on the reconstructive needs. The four most commonly used flaps based on constituents are muscle/musculocutaneous flaps, fascia/fasciocutaneous flaps, perforator (skin with fat and with and without fascia) flaps, and bone flaps, which are further explained in the following sections.

1. Muscle and musculocutaneous flaps

   The muscle and musculocutaneous flaps are widely used not only to resurface the defect but also to provide a functioning reconstruction. Thus, it is important to understand

Table 9.1 The basis for flap classification (Reprint with permission from Elsevier. From Hong JP. (2018) Flap classification and applications. In Neligan (eds) Plastic Surgery)

1. Circulation (blood supply)
Direct vessels
Axial
Septocutaneous
Endosteal
Indirect vessels
Myocutaneous
Periosteal
2. Constituents (composition)
Skin (with subcutaneous fat)
Fasciocutaneous/fascia
Muscle/musculocutaneous
Visceral
Nerve
Bone
Cartilage
LN (with subcutaneous fat)
Other
3. Contiguity (destination)
Local
Regional
Distant (free)
4. Construction (flow)
Unipedicle*
Bipedicle
Anterograde*
Retrograde (reverse)
Turbocharged
Supercharged
Arterialized venous
5. Conditioning
Delay
Tissue expansion
Prefabrication
Sensate (sensory nerve)
Functional (motor nerve)
None*
6. Conformation
Special shapes
Tubed
Combined flaps
None*

the anatomy of these flaps as this will ensure better results not only in flap survival but to understand the limitation of the flap, especially when used as a local flap. When used as a local flap, the pedicle needs to be preserved having a limited reach (arc of rotation based on the pedicle). For example, a gastrocnemius muscle flap can be used as a local flap to cover the lower knee defect but cannot reach the upper knee based on its pedicle. The most commonly used Mathes–Nahai classification depicts the relationship between the muscle and its vascular pedicles: the regional source of the pedicle entering the muscle, the number and size of the pedicle, the location of the pedicle with respect to the muscle's origin and insertion, and the angiographic patterns of the intramuscular vessels [6]. This classification helps the surgeons understand the vascularity of each muscle flap ensuing the flap survival. There are five different vascular patterns by which the various muscles are categorized (Fig. 9.2) [6]. Table 9.2 shows the typical muscle flap examples for each type.

Type I: the muscles are supplied by a single vascular pedicle.

Type II: the muscles are supplied by both a dominant and minor vascular pedicle. The larger dominant vascular pedicle will usually sustain circulation to these muscles after the elevation of the flap with or without the minor pedicles. This is the most common pattern among muscle flaps.

Type III: the muscles have two large vascular pedicles from separate vascular sources. These pedicles have either a separate regional source of circulation or are located on opposite sides of the muscle. Division of one pedicle during flap elevation rarely results in loss of muscle and can survive on one of its two dominant vascular pedicles.

Type IV: the muscles are supplied by segmental vascular pedicles entering along the course of the muscle. Each pedicle provides circulation to a segment of the muscle, and division of the pedicles may result in segmental muscle necrosis.

Type V: the muscles are supplied by a single dominant pedicle and secondary segmental vascular pedicles. These muscles have one large dominant vascular pedicle near the insertion of the muscle with several segmental pedicles near the origin and can survive on either dominant or segmental pedicle allow-

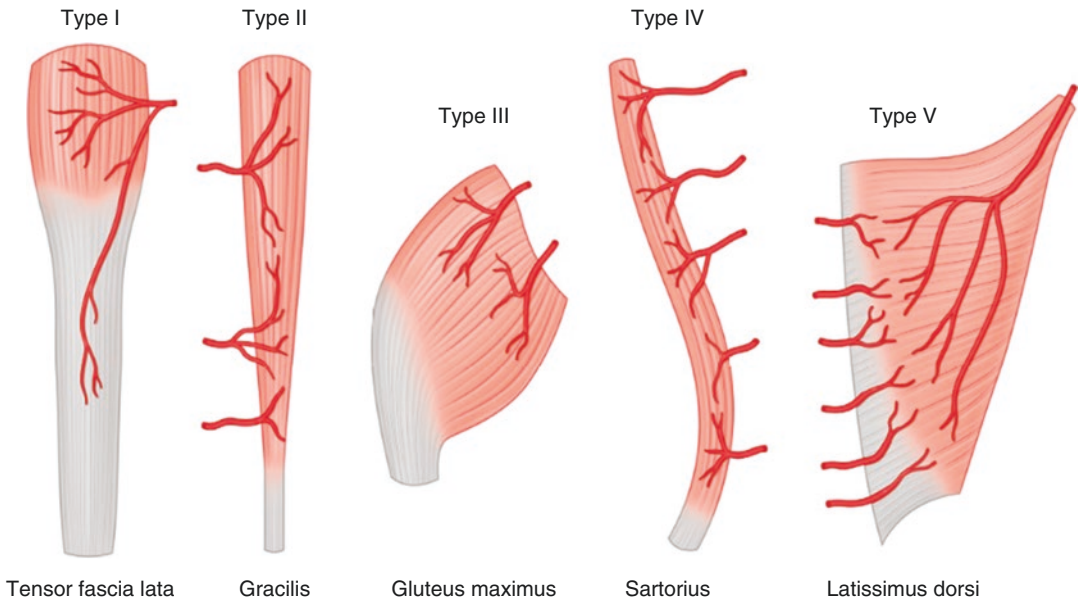

Fig. 9.2 Mathes–Nahai classification for muscle and musculocutaneous flaps (Reprinted with permission from Springer Nature. from Peredo A.L., Iorio M.L., Mathes D.W. (2020) Principles of Local Muscle Flaps for Lower Extremity Wounds. In: Hollenbeck S., Arnold P., Orgill D. (eds) Handbook of Lower Extremity Reconstruction. Springer, Cham)

ing the muscle to have a different rotation arc when done in a local flap.

2. Fasciocutaneous flaps

A fasciocutaneous flap, originally called an axial flap, includes the skin, subcutaneous tissue, and underlying fascia. The vascular supply is derived at the base of the flap from musculocutaneous perforators or direct septocutaneous branches of major arteries perforating the deep fascia. Understanding the anatomy allows the surgeon to maximize the reconstructive result. Thus, based on the anatomy of the pedicle type when designed as a local flap, the arc of rotation is determined by the extent of elevation of the deep fascia. The point of rotation is based on the site of entrance of the dominant vascular pedicle into the fascia. There are multiple classifications for this flap. The two most commonly used classifications are the Cormack and Lamberty classification and the Mathes–Nahai classification. Cormack and Lamberty classified fasciocutaneous flaps into four major types, differentiated by the origin of the circulation (Fig. 9.3) [1, 7]. Type A flap had multiple fascial perforators that enter at the base of the flap and extend throughout the longitudinal length. The flap can be based proximally, distally, or as an island. Type B flaps contained a large, single septocutaneous perforator, which is large and relatively consistent. Type C flap was based on multiple small perforators from a source artery that needed to be included in the flap. Type D is similar to Type C in that it is based on multiple small perforators; however, it is raised as an osteomyofasciocutaneous flap. The Mathes–Nahai classification is similar to Cormack and Lamberty's classification and is based on the type of deep fascial perforator (Fig. 9.4) [8]. Type A is a direct cutaneous flap, in which the vascular pedicle travels deep to the fascia for a variable distance then pierces the fascia to supply the skin. Type B is a septocutaneous flap, which has a vascular pedicle that courses within an intermuscular septum. Type C is a musculocutaneous flap and is based on a vascular pedicle that is traveling within the muscle substance.

Table 9.2 The classification for muscle flaps (Reprint with permission from Elsevier. From Hong JP. (2018) Flap classification and applications. In Neligan (eds) Plastic Surgery)

Type I vascular pattern muscles
Abductor digiti minimi (hand)
Abductor pollicis brevis
Anconeus
Colon
Deep circumflex iliac artery
First dorsal interosseous
Gastrocnemius, medial and lateral
Genioglossus
Hyoglossus
Jejunum
Longitudinalis linguae
Styloglossus
Tensor fascia lata
Transversus and verticalis linguae
Vastus lateralis
Type II vascular pattern muscles
Abductor digiti minimi (foot)
Abductor hallucis
Brachioradialis
Coracobrachialis
Flexor carpi ulnaris
Flexor digitorum brevis
Gracilis
Hamstring (biceps femoris)
Peroneus brevis
Peroneus longus
Platysma
Rectus femoris
Soleus
Sternocleidomastoid
Trapezius
Triceps
Vastus medialis
Type III vascular pattern muscles
Gluteus maximus
Intercostal
Omentum
Orbicularis oris
Pectoralis minor
Rectus abdominis
Serratus anterior
Temporalis
Type IV vascular pattern muscles
Extensor digitorum longus
Extensor hallucis longus
External oblique
Flexor digitorum longus
Flexor hallucis longus
Sartorius
Tibialis anterior
Type V vascular pattern muscles
Fibula
Internal oblique
Latissimus dorsi
Pectoralis major

Table 9.3 shows the examples of the fasciocutaneous flaps according to this classification.

3. Perforator flaps

Perforator flaps have evolved from musculocutaneous and fasciocutaneous flaps without the muscle or fascial carrier. It was a natural evolution as reconstruction needed fine-tuning while aiming to minimize donor morbidities, as shown in Fig. 9.5. Note how unwanted tissues are discarded when only the skin is needed based only on a single perforator [9]. Thus, a perforator flap is a skin flap (with or without fascia) based on a single perforator [10]. Like the angiosome concept showing the vascular territory of a source vessel, one must understand the anatomy and physiology of a single perforator territory to understand the limits and application for the perforator flap [3]. The perforasome theory by Saint-Cyr reported four major characteristics of a perforator flap: (1) each perforasome is linked with adjacent perforasomes by means of direct and indirect linking vessels; (2) flap design and skin paddle orientation should be based on the direction of the linking vessels, which is axial in the extremities and perpendicular to the midline in the trunk; (3) filling of the perforasomes occurs within the perforasome of the same source artery first followed by perforators of the other adjacent source arteries; and (4) vascularity of a perforator found adjacent to an articulation is directed away from that same articulation [4]. This theory provides insights into perforator flap vascularity and can clinically guide to harvest a safer free or pedicle perforator flap [5]. In 1989, Koshima and Soeda used the term "perforator flaps" in their harvest for paraumbilical skin and fat island flap based on a muscular perforator and now being applied all over the body [9, 11, 12]. Although understanding the anatomy and physiology is critical for perforator flaps, the classification was of less importance as the perforator flap concept was simplified through the freestyle and supermicrosurgery concept [13–16]. The freestyle approach identifies the perforator feeding the skin flap first and then dissect proximally toward the source vessel, contrary to the clas-

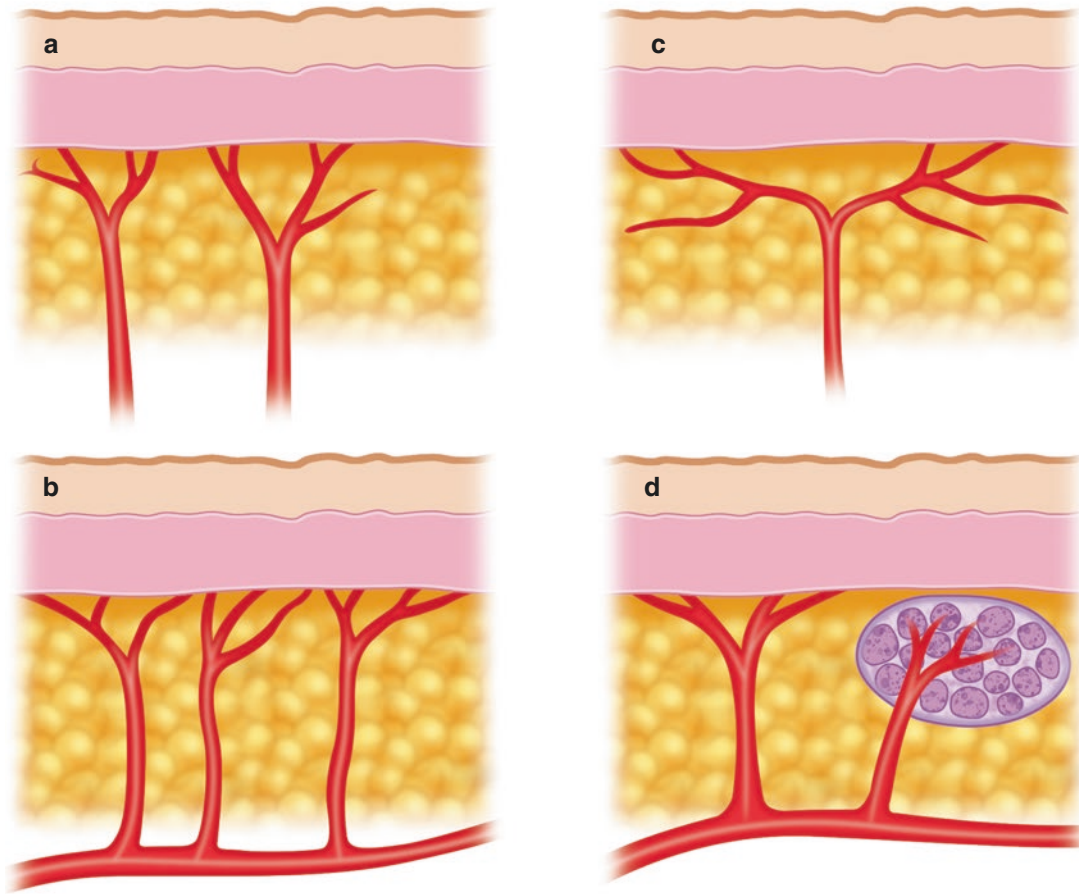

Fig. 9.3 Cormack and Lamberty classification of fasciocutaneous flaps differentiated into four types based on the origin of the circulation. Type A flap had multiple fascial perforators that enter at the base of the flap and extend throughout the longitudinal length (**a**). Type B flaps contained a large, single septocutaneous perforator, which is large and relatively consistent (**b**). Type C flap was based on multiple small perforators from a source artery, which needed to be included in the flap (**c**). Type D is similar to Type C in that it is based on multiple small perforators but raised as an osteomyofasciocutaneous flap (**d**). Reprinted with permission from Springer Nature (Bianconi L., Pierotello L., Molteni G., Pellini R., Marchioni D. (2020) Anatomical Considerations of Free Flaps. In: Pellini R., Molteni G. (eds) Free Flaps in Head and Neck Reconstruction. Springer, Cham. https://doi.org/10.1007/978-3-030-29582-0_2)

sical approach where identification of the source vessel was made first and then dissection toward the perforator. This allows the freedom to design flaps based on any perforator as well as alleviate the risk for pedicle variation [14]. The supermicrosurgery approach, perforator-to-perforator anastomosis, allows harvesting the flap as a short pedicled flap reducing the dissection time and minimizing the risk for traumatizing the pedicel while dissection [5, 15, 17]. One form of perforator based local flap, the propeller flap, is an island flap that reaches the recipient site through an axial rotation [18, 19]. When a perforator propeller flap is being elevated, the perforator is dissected free from the fascial and fat adhesions to minimize the chance of kinking. Although less rotation reduces the chance for kinking, the skin island may be safely rotated up to 180 degrees (Fig. 9.6).

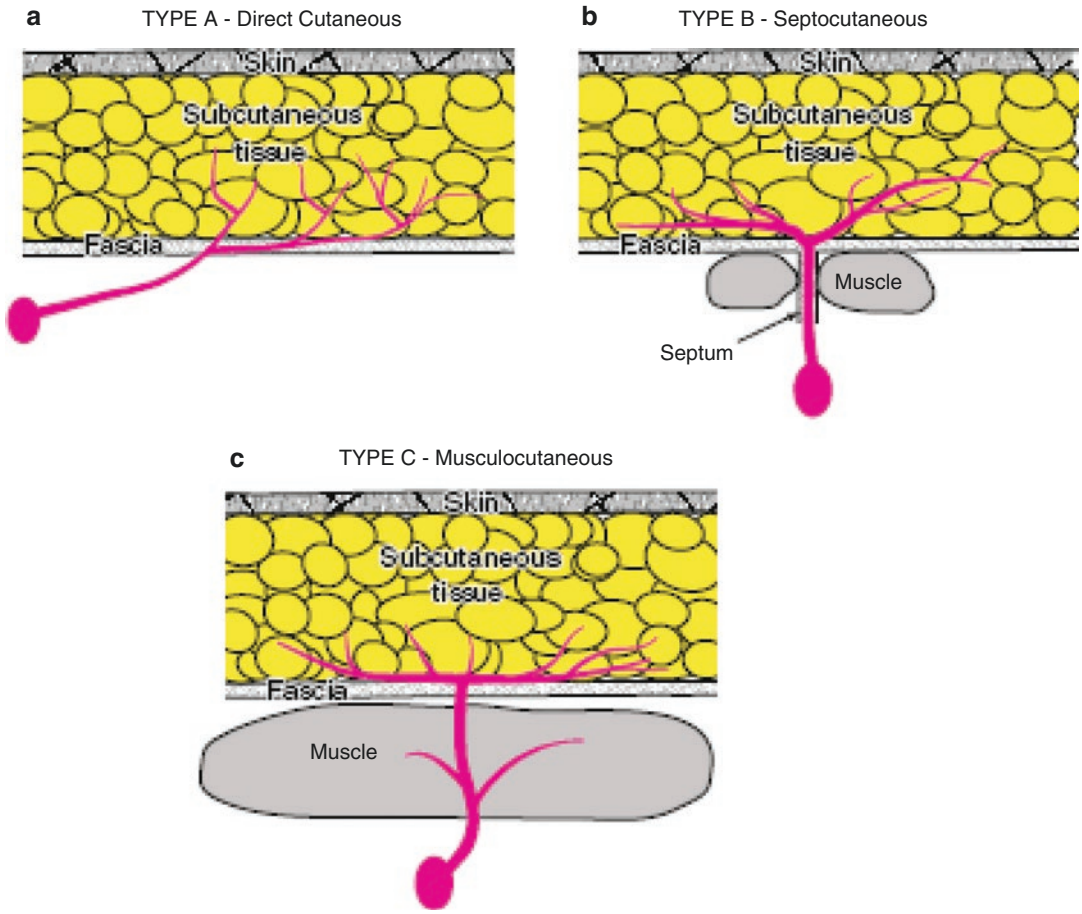

Fig. 9.4 Mathes–Nahai classification for fasciocutaneous flaps. Type A is a direct cutaneous flap, in which the vascular pedicle travels deep to the fascia for a variable distance and then pierces the fascia to supply the skin (**a**). Type B is a septocutaneous flap, which has a vascular pedicle that courses within an intermuscular septum (**b**). Type C is a musculocutaneous flap and is based on a vascular pedicle that is traveling within the muscle substance (**c**). Reprinted with permission from Springer Nature (OBrien M. (2009) Fundamentals of Plastic Surgery. In: Plastic and Hand Surgery in Clinical Practice. Springer, London. https://doi.org/10.1007/978-1-84800-263-0_1)

4. Bone flaps

Bone is vascularized through endosteal and periosteal sources. The complex blood supply of bone is based on nutrient vessels entering the bone directly and through vascular connections between muscles and bone, typically where the muscle has a large bony origin or insertion. Vascularized bone is useful in muscles suitable for microvascular transplantation or in those muscles designed for transposition when the vascular attachments to bone are distal to the point of rotation. The commonly transferred bones include the fibula flap based on the peroneal artery, iliac crest based on the deep circumflex iliac artery, the scapula based on the circumflex scapula or thoracodorsal arteries, and the radius based on the radial artery. The calvarial osseous flap based on the superficial temporal artery or occipital artery with partial- or full-thickness bone is also useful for reconstructing the facial anomalies and deformities [5, 20–23]. The periosteum and part of the cortical bone as an osseous-periosteal flap are widely used for nonunion of the bone and small bone defects. The genicular osseous-periosteal flap, also known as the medial femoral condyle flap, based on the articular branch of the descending genicular artery and vein with the periosteum and thin (0.5–

Table 9.3 The classification for fasciocutaneous flaps (Reprint with permission from Elsevier. From Hong JP. (2018) Flap classification and applications. In Neligan (eds) Plastic Surgery)

Type A fascial and fasciocutaneous flaps
Deep external pudendal artery
Digital artery
Dorsal metacarpal artery
Gluteal thigh
Great toe (hallux)
Groin
Lateral thoracic (axillary)
Pudendal—thigh
Saphenous
Scalp
Second toe
Standard forehead
Superficial external pudendal artery
Superficial interior epigastric artery
Sural artery
Temporoparietal fascia
Type B Fascial and fasciocutaneous flaps
Anterolateral thigh
Anterior tibial artery
Deltoid
Dorsalis pedis
Inferior cubital artery (antecubital)
Lateral arm
Lateral plantar artery
Lateral thigh
Medial arm
Medial plantar artery
Medial thigh
Peroneal artery
Posterior interosseous
Posterior tibial artery
Radial forearm
Radial recurrent
Scapular
Ulnar recurrent
Type C Fascial and fasciocutaneous flaps
Anterolateral thigh
Deltopectoral
Nasolabial
Median forehead
Thoracoepigastric (transverse abdominal)
Transverse back

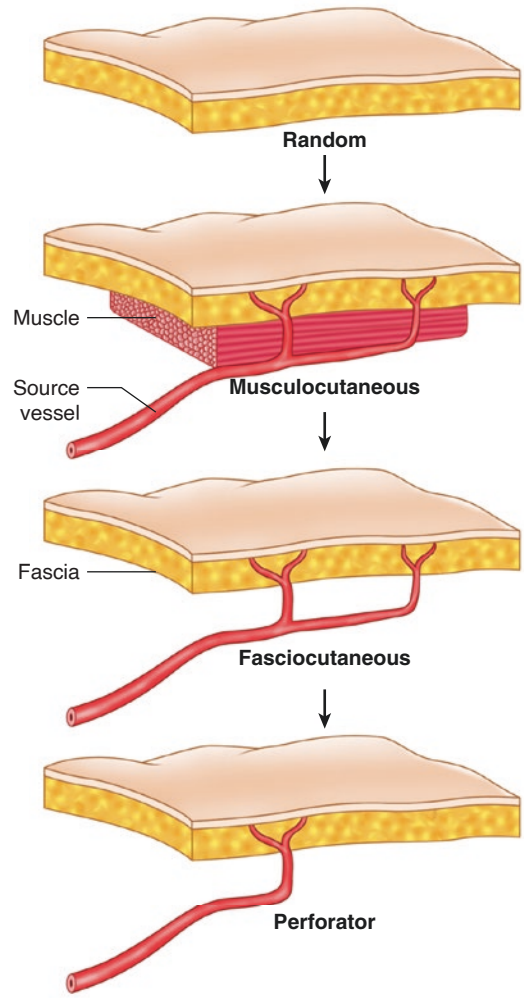

Fig. 9.5 Evolution of flaps from random patter to perforator flaps. Note that the perforator only has the skin and fat component based on a single perforator

1.0 mm) layer of outer cortical bone was first reported by Sakai et al. to treat fracture nonunion [24].

Contiguity refers to the destination of the flap. The flaps can reach the defects locally, regionally, and distantly. Local flaps are flaps next to the defect and can be created by freeing a layer of tissue and then moving the freed layer to fill a defect. It is usually a skin but can be performed with various tissues like muscle, fascia, and others as well. This is the simplest type of flap and can be advanced, rotated, and transpositioned (Fig. 9.7). A combination of these simple techniques like the keystone flap utilizing bilateral V–Y advancement is still commonly practiced to cover large defects, especially for the trunk and extremity (Fig. 9.8). Regional flaps are flaps not immediately near the defect. Thus, the flap is like an "island" based on a pedicle and can be moved over or underneath normal tissue to reach the defect. The pedicle not being detached and able to move to reconstruct the defect is in a wide sense a local flap but should

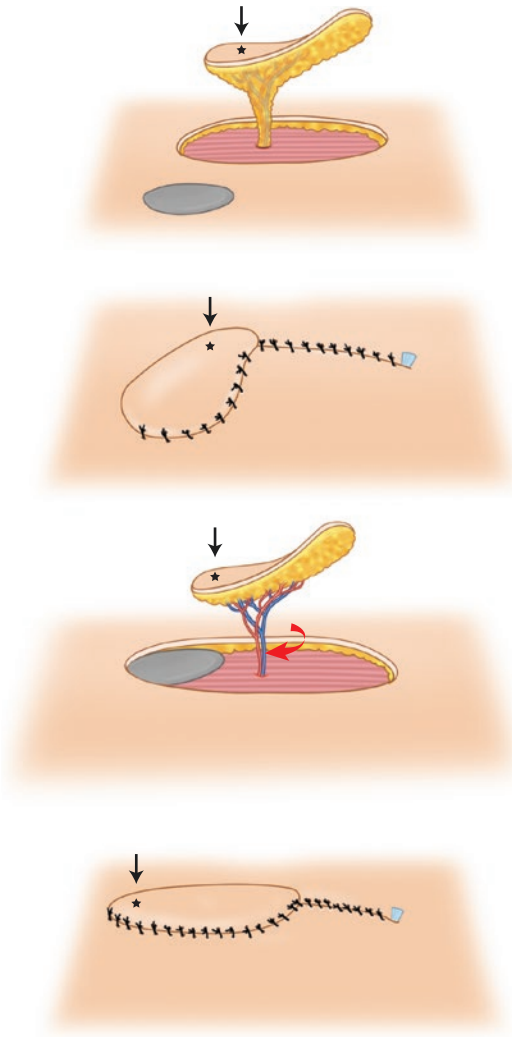

Fig. 9.6 The propeller flap, which is the local flap based on a single perforator rotated to cover the defect

be distinguished from the true local flap mentioned above as a regional flap (Fig. 9.9). Examples would be trapezius muscle flap to reconstruct the neck, pectoralis major musculocutaneous flap to reconstruct head and neck deformities, and transverse rectus abdominis muscle (TRAM) flap to reconstruct breasts. Distant flaps are flaps that are far from the defect and are the most complex among the three. The previous chapter discussed direct or tubed flaps forming a bridge to reach the defect, and later the pedicle detached after the flap becomes stable. However, these methods are now less used, and most distant flaps follow a free flap approach where pedicles are cut and reattached using a microscope allowing the tissue to be viable.

Construction refers to the vascular flow of the pedicle to the flap. In most of the flaps, whether it be muscle or skin or other combined with various tissues, the pedicle usually is a single source making unipedicle the most common form. Thus, the term unipedicle is a default to communicate and not actually written out or spoken [5]. The same can be said for anterograde (orthograde) flow, where the flow to the flap is normal as in the direction from the heart to the distal tissue. Bipedicle flap is a flap with dual pedicle often used as a random pattern skin flap to cover the defect on the extremity, or transabdominal bipedicle flap can be raised to provide coverage on the dorsum of the hand. The reserve (retrograde) flap is when a pedicle is based on a reserve flow manner. Instead of using the proximal flow stemming from the heart, the pedicle is based on the vessels exiting from the flap (reverse fashion) when seen from a natural flow perspective (Fig. 9.10) [25, 26]. A typical example can be the reverse-flow island sural flap based on the superficial sural artery or a reverse radial forearm flap based on the distal vessels of the radial artery and vein [26, 27]. As the arterial flow, even in reserve fashion, will have a good supply as the multiple collateral arteries will provide enough pressure in a reverse way. However, the vein can be a different story as the veins may have problems with venous drainage due to the anatomical valves within the vein. There are connections between accompanying veins enabling to detour the valve but can still result in venous congestion. Nevertheless, it is a viable option to reconstruct difficult wounds like the heel and hand dorsum using these reverse fashioned flaps. The terms turbocharged and supercharges are used when the arterial supply is augmented in flow. These terms were borrowed from automotive engines where "supercharging" is using an external power source to boost the engine's performance (in addition to its original vascular source, using an unrelated distant vascular source to anastomosis to a flap) and "turbocharging" is using the own engine exhaust for additional power (using the

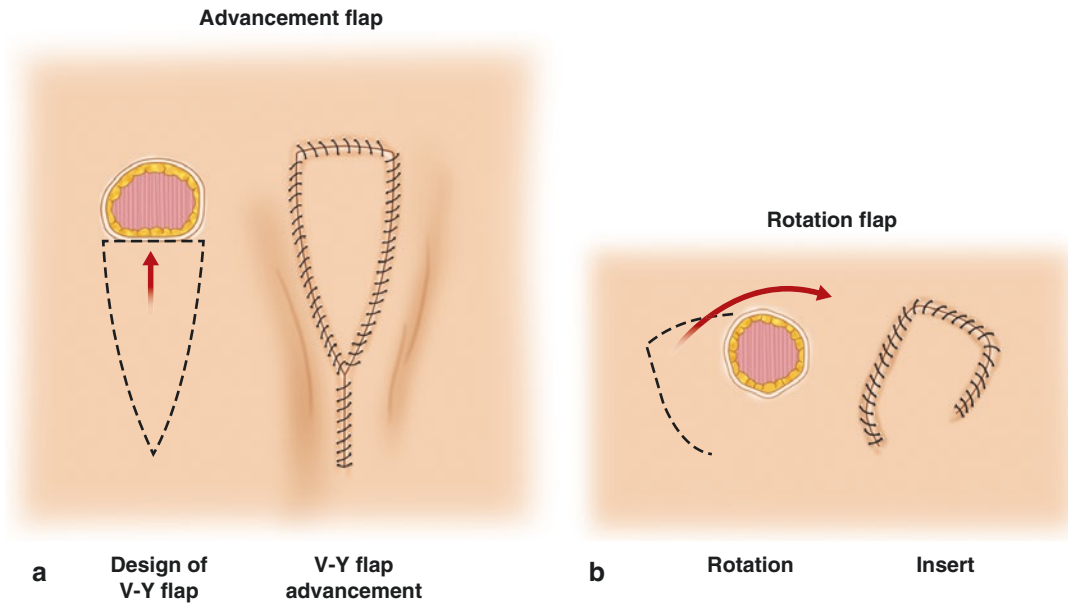

Fig. 9.7 Advancement flap (**a**) and rotation flap (**b**)

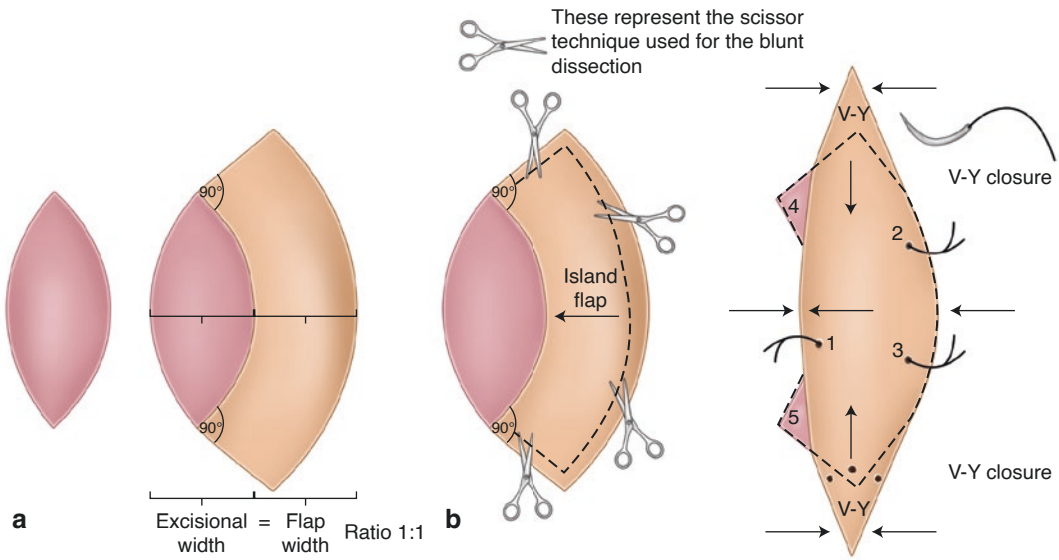

Fig. 9.8 A keystone flap essentially being two V–Y advancement flaps along the long axis of the flap

main vascular source to connect to an additional pedicle from the same flap creates a direct flow to the vascular territory of the connected branch) (Fig. 9.11) [28, 29]. The last category in this classification of construction (flow) is arterialization of vein to supply flow to the flap. A venous flap is defined as a composite flap of skin, subcutaneous tissue, and other tissues such as nerve, tendon, and bone that uses a subcutaneous vein for the arterial inflow and venous outflow (Fig. 9.12) [30]. Unlike the classical flap where a pedicle is composed of artery and vein, this flap does not require to include an artery within the flap but rather has multiple superficial veins, of which

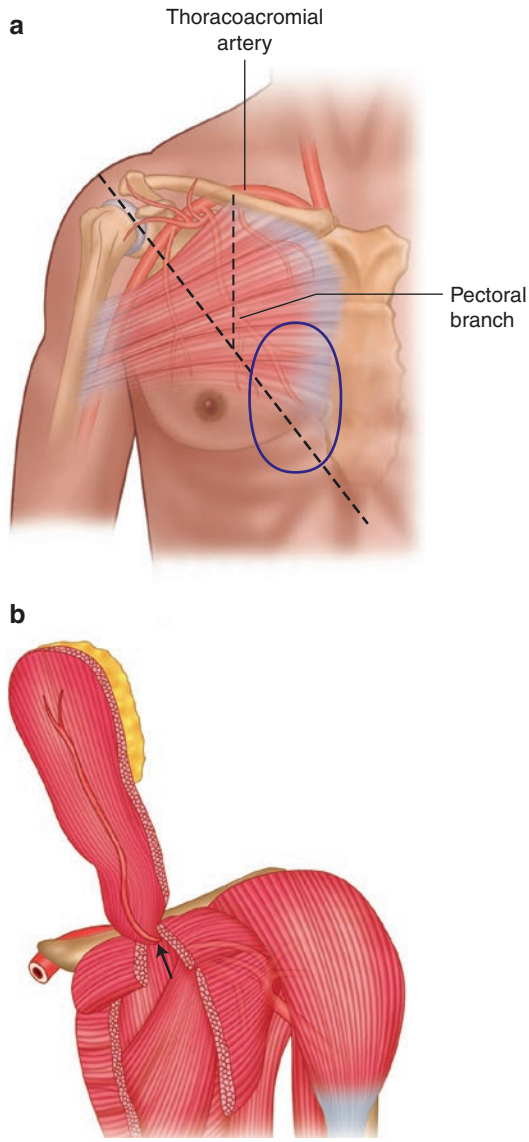

Fig. 9.9 Pectoralis major musculocutaneous island flap based on the thoracoacromial vessel prior (**a**) and after elevation (**b**)

one is anastomosed to an artery while others are connected to the other veins. One of the main limits in this flap is the size. Nevertheless, these flaps can be useful in small defect reconstruction as arterialized venous-free flaps can provide a good solution for successful soft tissue reconstruction.

Conditioning means providing a certain maneuver to the flap to achieve wanted results. Specific maneuvers or classification of conditioning can be delay, tissue expansion, prefabrication, sensate flap, and functional muscle flap. Most flaps do not undergo conditioning, so "none" is default and not mentioned specifically. The "delay" procedure conditions the flap to maximize perfusion, allowing to harvest a larger flap [31]. Flap delay may be used to increase circulation to the muscle or fascia or to enhance vascular connections to the overlying cutaneous territory or adjacent structures to be included during flap elevations (tendon, fascia, and bone). Although delay may be accomplished by biochemical means to improve flap perfusion, currently the most effective method to ensure delay is surgical manipulation of the flap [5, 32]. One typical example can be a surgical delay. Surgical flap delay is accomplished in two ways: standard delay, with an incision at the periphery of the cutaneous territory or partial flap elevation, which increases the perfusion to the flap within 1–2 weeks followed by full elevation of flap [33]; and strategic delay, with a division of selected pedicles to the flap to enhance perfusion through the remaining pedicle or pedicles. Tissue expansion uses a tissue expander, which is inserted under the skin, muscle, or fascia to mechanically expand the tissue above the expander [34]. The expansion of the expander is done gradually, accommodating the stretch of the tissue with increased vascular supply. Usually, the expansion occurs using the adjacent tissue near the defect, then rotating, advancing, and transpositioning the flap. However, expanded free flaps have also been used to close large defects as well as to close the donor site primarily [35–37]. Another conditioning method is "flap prelamination," which is a process of two or more stages for constructing a complex three-dimensional structure [38, 39]. A typical example can be seen for nasal reconstruction, which involves multiple stages. The first stage involves adding different layers into an existing axial vascular territory as composite grafts, allowing time for the tissues to mature, before being transferred. An intermediate stage may be needed to further modify the flap, such as thinning, delaying, or adding additional tissue approaching a near-complete appearance

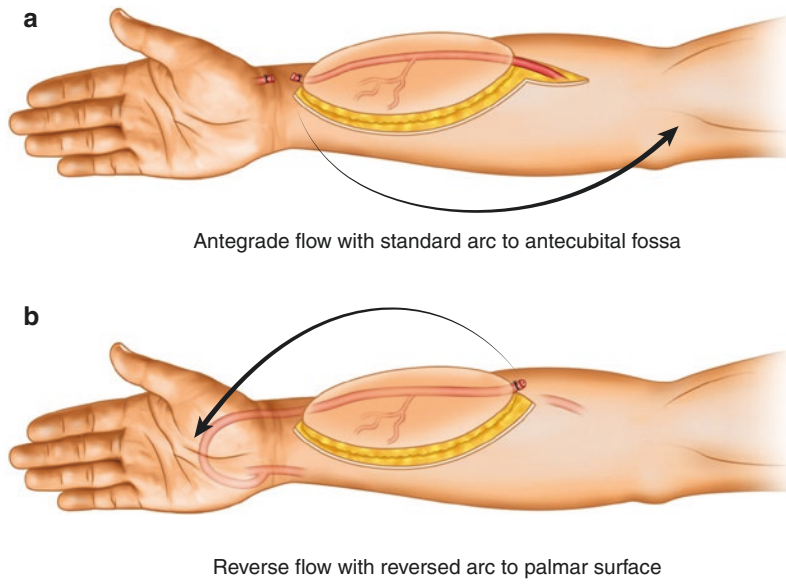

Fig. 9.10 A flap based on the antegrade flow has a major pedicle that flows with the flap (**a**), but when the same flap has its orthograde pedicle ligated proximally, it becomes a flap based on the distal part of the major pedicle and the flow of the flap becomes reversed (**b**)

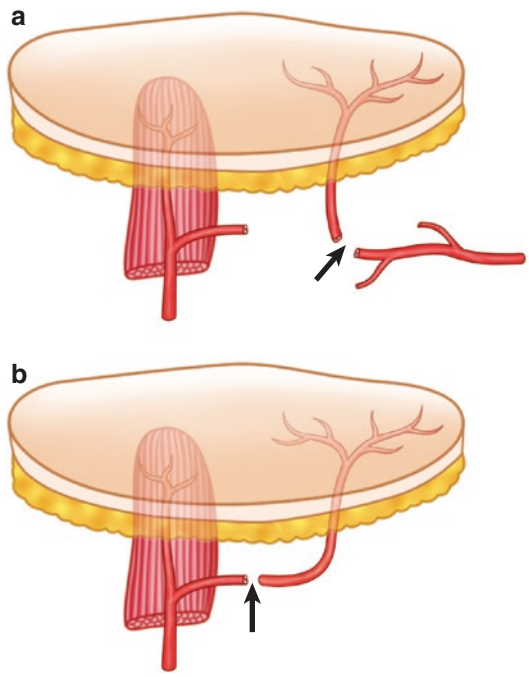

Fig. 9.11 Supercharging is using an external power source to boost the engine's performance (**a**). Turbocharging is using the engine's exhaust for additional power, like using the same main vascular source to connect to an additional pedicle from the same flap (**b**)

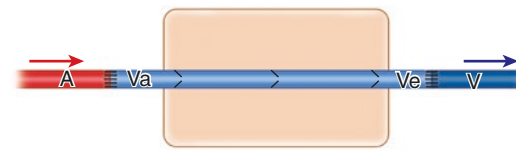

Fig. 9.12 The venous flap having an arterialized vein as the arterial inflow

of the nose prior to the final stage. The final stage is to transfer the composite flap based on the original axial blood supply for the reconstruction.

Flap prefabrication involves creating a flap with a new axial blood supply by implanting a vascular pedicle into the donor tissue, thus rendering that tissue transferable once neovascularization has occurred [38, 39]. However, with the development of various flap elevation techniques and new flaps, this technique is rarely used. Sensate flaps are flaps with sensory capability. The sensory nerves can be identified above the deep fascia in the subcutaneous fat. Thus, all flaps using the skin component may be designed to incorporate the sensory nerve in the flap base. The donor nerve can be anastomosed to the recipient sensory nerve allowing the flap to ultimately feel sensation. An example can be where a skin flap such as an anterolateral thigh flap with the cutaneous femoral nerve is used for plantar reconstruction [40]. Functional flaps are muscle flaps that convey motor function on the recipient. In order for the transferred muscle to function, the motor nerve must be preserved along with domi-

Table 9.4 The classification for Compound flaps (Reprint with permission from Elsevier. From Hong JP. (2018) Flap classification and applications. In Neligan (eds) Plastic Surgery)

Solitary vascularization
Composite flaps
Combined vascularization
Conjoined flaps
Perforator-based
Branch-based
Independent
Common
Chimeric flaps
Perforator-based
Branch-based
Sequential
Internal

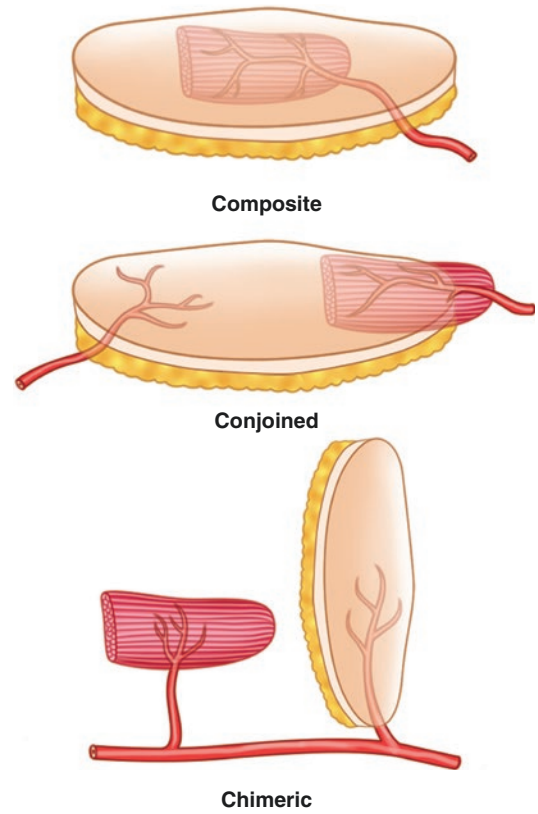

Fig. 9.13 Compound flaps can be divided into solitary (composite) or combined types (conjoined and chimeric) based on the primary source of vascularization

nant vascular supply, the muscle must be reattached to a new bone or tendon across a joint, and the muscle must exert a direct force on its new point of attachment [41, 42]. An example can be where a functional gracilis muscle is used to reanimate the paralyzed face [43].

Conformation of flaps is the description of forms regardless of circulation and focused on shapes and the methods to transport flaps to a distant region [2]. The concept of conformation now further describes the combination of multiple flaps to adequately address the complex defect [5]. A compound flap typically consists of multiple tissue components linked together in a manner that allows their simultaneous transfer and consequently more efficient reconstruction [2, 44, 45]. Hallock's classification of compound flaps has been simplified to enhance communication and further advance the role of complex flaps, not only microsurgical but also local flaps [44, 45] (Table 9.4). The compound flap can be divided into two major classes according to their primary means of vascularization, which can be solitary or combined vascularization (Fig. 9.13). The "solitary vascularized compound flaps" are composite flaps based on solitary circulation and are the simplest form of a compound flap that contains en bloc multiple tissue components [1]. A typical example would be a musculocutaneous flap where the components are dependent on each other and must remain intact together supplied by a solitary source [2, 5, 46]. The "combined vascularized compound flaps" are flaps that have multiple sources and combined vascularization [2, 5]. There are two major subtypes, conjoined flaps, and chimeric flaps, primarily differing in physical relationship of their component but retains an independent blood supply for each component [5, 44, 45]. The "conjoined flaps" are flaps with at least two anatomically distinct territories, each retaining their independent vascular supply but joined by means of some common physical boundary [45]. The "chimeric flaps" consist of multiple otherwise independent flaps that each has an independent vascular supply, but in turn, all pedicles are linked to a larger common source vessel [45–47]. Understanding the conformation of the flaps and knowing that it can be combined with various flaps can help the surgeon accommodate a difficult reconstruction.

9.4 Indication

Because the flap is a tissue based on its own vascular supply, it does not depend on the recipient bed to perfuse the donor tissue like skin grafts. Thus, flaps can be indicated for any defects that skin graft is not feasible. In addition to simple coverage, as we have reviewed the classification of the flaps, the expected roles for flaps can vary. With the evolution of flap selection and better understanding of physiology and development of new techniques, now flaps can be harvested on any perforator and able to reconstruct the most complex defects. As a combined flap, it can provide various tissues for functional reconstruction with reasonable esthetic outcomes. However, one should always remember that flaps are most often taken from a healthy donor site and thus can cause additional morbidity and always be prudent when using flaps. From defects caused by trauma, oncologic resection, congenital anomalies, chronic disease with wounds, and much more, the use of flaps has dramatically broadened the ability of reconstructive surgeons to provide an adequate solution. Furthermore, the evolved reconstruction using flaps has allowed more aggressive approach in pushing the limits for a curative solution.

9.5 Principle of Flap Surgery

9.5.1 The Reconstructive Elevator

Unlike the reconstructive ladder concept that was proposed to establish priorities for technique selection based on the complexity of the technique and the defect requirements for safe wound closure like climbing the rung of the ladder, the reconstructive elevator concept chooses the most appropriate floor from which to choose our reconstruction, based on the specific requirements of the patient, the wound, and the circumstances [48]. The reconstructive elevator requires creative thoughts and considerations of multiple variables to achieve the best form and function rather than a sequential climb up the ladder. Like the evolution in flaps, this paradigm change is built on past concepts of reconstruction and can be a natural course in one's practice. Based on the reconstructive elevator, a method of reconstruction should be chosen based on procedures that result in optimal form and function [5].

9.5.2 The Guide for Reconstruction Using Flaps

Flaps, whether it be pedicle or free, are used to reconstruct after defects originating from various causes. However, despite the best effort, necrosis can occur partially or totally to the flap. The overall survival depends not only on the proper flap selection but also on preoperative planning, intraoperative techniques, and postoperative management involved in reconstruction [5].

- **Preoperative Planning**

  Preoperative planning begins with an analysis of the defect, including the location and condition of the recipient bed (infection, components of the lost tissues) and systemic comorbidities (e.g., cigarette smoking, history of radiation therapy, diabetes mellitus, peripheral artery disease) [49–57]. Selection of flaps must consider the donor site morbidity. Once a plan has been postulated, the first critical step is for the surgeon to educate the patient and family about the procedure and the possible outcome obtaining an informed consent [58]. When involving multiple departments or teams, sufficient communication must be made for the multidisciplinary team to be on the same page.

  The essence of flap surgery is understanding the vascular status of the flap. This extends further when planning a free flap as now the surgeons must also consider the status of the recipient vessel. Imaging using CT (computed tomography) scans, angiograms, or MR (magnetic resonance) angiograms, ultrasound, and handheld Dopplers help to identify the vasculature of the recipient and donor site [59, 60]. The use of CT angiography may obtain vascular information of the recipient region without the risk of complications from arterial puncture of

the groin and also can provide vascular information of the donor flap facilitating the planning and the surgical procedure [61, 62]. While the CT angiogram gives overall information of the vascular layout, the ultrasound may provide real-time information on donor and recipient vessels such as the caliber of the pedicle, the intramuscular course of the pedicle, location of the corresponding flap, and the subcutaneous branching from the pedicle [59, 63, 64]. The handheld Doppler allows to simply and quickly gather information about the perforator and the main axial vessels. However, it may lack detailed information such as the course of the perforator, and the actual positive finding may not correlate clinically. Nevertheless, handheld Doppler remains the first tool to gather information regarding the pedicle of the flap.

Flap selection should be based on the elevator reconstruction concept addressing the need of the defect and the ultimate functional and esthetic outcome. Perforator flaps can be selected by factors such as the dimension of the flap, the length of the pedicle, composition of the flap, thickness of the flap, and the patient position during operation [65]. Donor site morbidity should also be considered when selecting a flap. When possible, the donor site should be closed directly to preserve form. Use of a flap that requires a skin graft for donor site closure is justified when the flap harvested is clearly superior to alternate flaps for the defect. Finally, for the preoperative planning, the surgeon should always think of a plan B flap [5]. This allows preoperative visual practice, reduction of surgical time, minimizing unwanted variables, and maintaining the high spirit of motivation [66, 67].

- **Intraoperative Techniques**

When possible, the patient is positioned to allow visualization of both donor and recipient sites. This allows a two-team approach and does not need additional surgical time to change the patient's position during operation. For surgeries expecting long operating time, careful padding of potential pressure sites to avoid injury to normal structures, active warming to minimize hypothermia (which may decrease peripheral blood flow), and deep vein thrombosis prophylaxis, and an intensive glucose control for diabetes is needed to ensure a positive outcome [58]. One should be flexible to change in the initial design of the approach as unforeseen events frequently occur. When insetting the flap, tension must be avoided, especially around the vascular pedicle. Meticulous coagulation of the flap as well as the recipient bed is crucial to minimize hematoma after surgery. A closed suction drain system is generally used at both the donor and recipient closure sites.

- **Postoperative Management**

Postoperative flap management is of equal importance to the success of a reconstruction. The maintenance of proper positioning, temporary immobilization, and proper dressing of the wound are critical. Pressure on the flap base is to be avoided during the postoperative period. Continued use of postoperative antibiotic therapy should be based on wound cultures and selection of culture-specific antibiotic agents [68]. Patient-specific ambulation should be planned, avoiding unnecessary bed rest. Postoperative monitoring of a flap is critical to discover any problem with the anastomosis early enough to salvage the flap [5]. Clinical observation generally involves assessment of skin color, tissue turgor, temperature, capillary refill, and pinprick. The ideal monitoring measure should be reliable, reproducible, sensitive, cost-effective, user-friendly, and continuous [58].

9.6 Clinical Cases

Case 1. A 55-year-old male patient had a traffic accident that ended in a tibia bone infection with soft tissue defect of the right leg (Fig. 9.14). The defect showed a tibial bone defect of 10 cm with skin loss (A). Evaluating the vascular status, both anterior and posterior tibial vessels were intact (B). Complete debridement of bone and soft tissue was performed prior to reconstruction. The

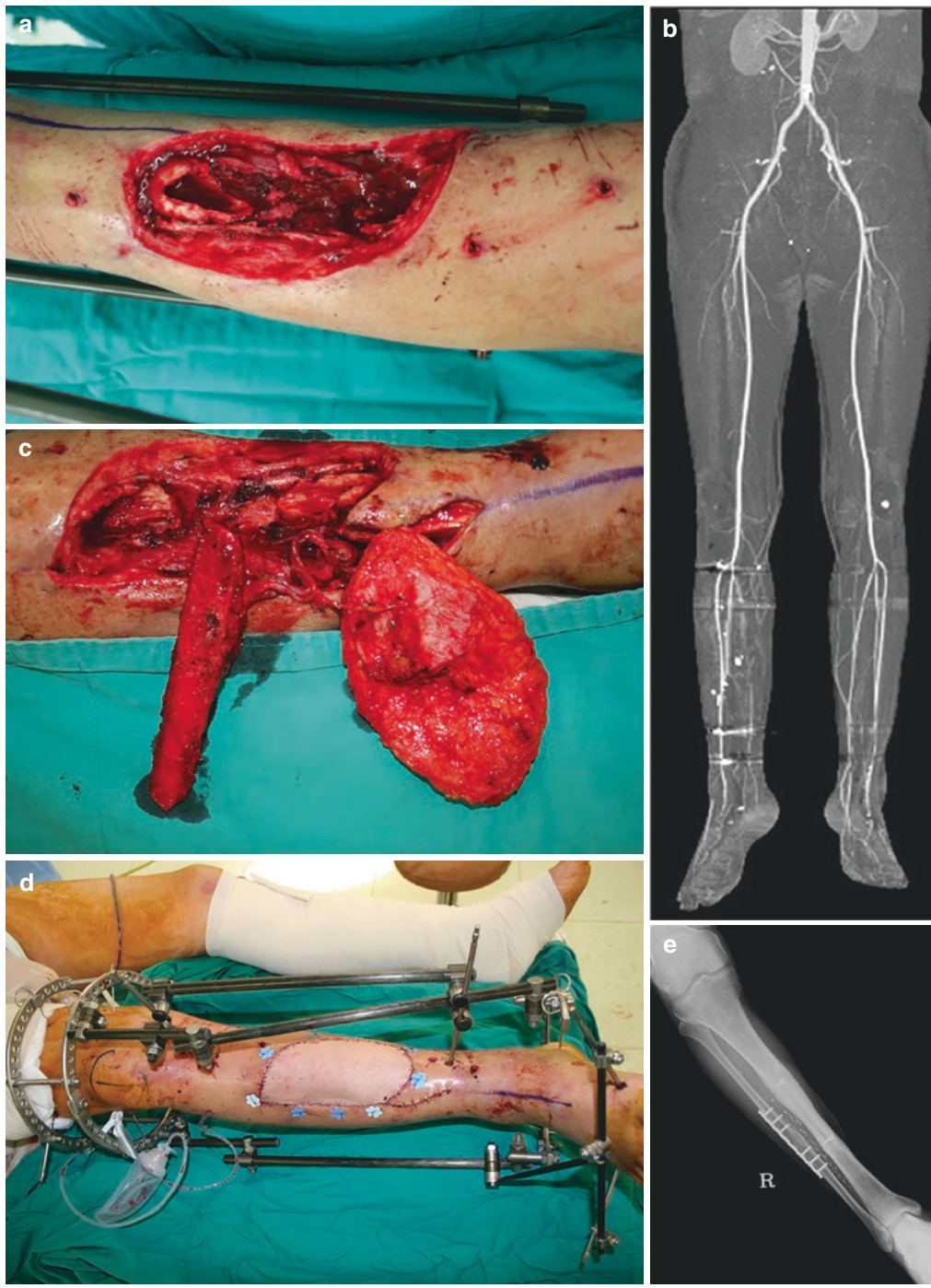

Fig. 9.14 A 55-year-old male patient had a traffic accident that ended in a tibia bone infection with a soft tissue defect of the right leg (**a**). Evaluating the vascular status, both anterior and posterior tibial vessels were intact (**b**). An anterolateral thigh perforator flap based on the descending branch of the lateral femoral circumflex vessel combined with a contralateral fibular bone flap based on the peroneal vessels was planned. The flaps were prefabricated into a combined chimeric flap by anastomosing the peroneal vessels to one of the branches of the descending branch of the lateral femoral circumflex vessel (**c**). The immediate postop is shown (**d**). The patient follow-up at 4 years presents a well-healed bone and soft tissue allowing the patient to ambulate without any assistance (**e**)

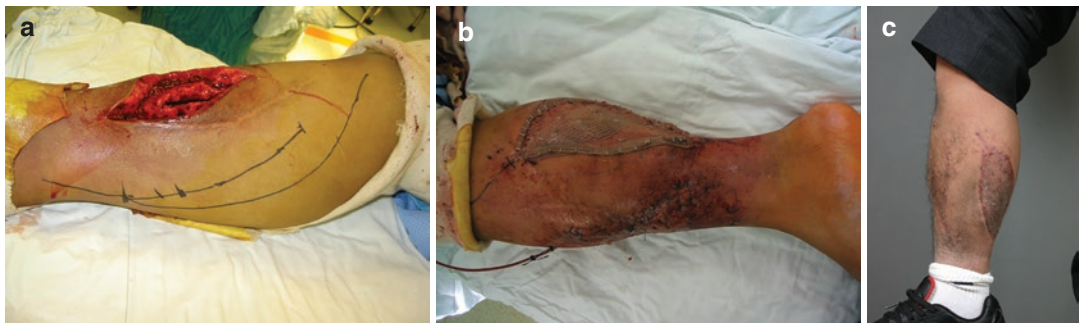

Fig. 9.15 A 32-year-old male patient with chronic osteomyelitis of the right tibia is presented with a skin defect and a small bone defect after debridement. A random local bipedicled flap was designed adjacent to the defect (**a**). After advancing the flap to cover the defect, a skin graft was performed over the donor site (**b**). At 1 year after the operation, the flap is covering the tibial without any further bone infections (**c**)

anterior tibial artery and vein were planned to be used as recipient vessels. In concordance with the elevator approach, an anterolateral thigh perforator flap based on the descending branch of the lateral femoral circumflex vessel was planned for resurfacing combining with a contralateral fibular bone flap based on the peroneal vessels. The flaps were prefabricated into a combined chimeric flap by anastomosing the peroneal vessels to one of the branches of the descending branch of the lateral femoral circumflex vessel (C). The immediate postop is shown (D). The patient follow-up at 4 years presents a well-healed bone and soft tissue allowing the patient to ambulate without any assistance (E).

Case 2. A 32-year-old male patient with chronic osteomyelitis of the right tibia is presented with a skin defect and a small bone defect after debridement (Fig. 9.15). A random local bipedicled flap was designed adjacent to the defect (A). After advancing the flap to cover the defect, a skin graft was performed over the donor site (B). At 1 year after the operation, the flap is covering the tibial without any further bone infections (C).

Take-Home Message

The topic of flaps can actually make up an entire book. Due to the limited pages allotted, the definition, classification, indication, and principle were covered enough for the reader to understand the concepts surround flaps. Flap surgery being a technique in plastic and reconstructive surgery where any type of tissue is lifted from a donor site and moved to a recipient site with its own intact blood supply has enormous potential, and the evolution in this field continues. I hope this chapter opens your mind to further explore the wonderful and fascinating world of flap surgery.

Pearls and Pitfalls

- The design of the flap must be based on the characteristics of the defects and should be examined and measured three-dimensionally since the width,

depth, and length will not always conform to a two-dimensional plane.
- A flap can be designed with "like with like" tissue.
- Identify the right anatomical structure of the flap in relationship with the pedicle.
- The success or failure of a flap is dependent upon blood supply. One should understand the limitations of the vascularity for a single flap based on the anatomy of the artery and veins when utilizing a flap.
- One should consider a flap design where reach (arc of rotation) will be sufficient to cover the defect when planning a local flap.
- Avoid excessive traction on the pedicle when positioning the flap over the defect.

Tips and Tricks
- Using preoperative tools such as handheld Dopplers, CT angiograms, and other modalities to evaluate the vascular status of the flap can minimize unwanted complications during flap elevation.
- Identify systemic risk factors such as hypercoagulative disorders, malnutrition, and others and correct them prior to surgery.
- Identify the right anatomical layer of elevation for each flap, usually on an avascular plane.
- Design the flaps bit larger than the defect anticipate swelling after the flap positioning.
- The flaps need a few weeks for the new vascular ingrowth to occur and fully allow integration to the surrounding tissue of the defect. Postoperative evaluation must include observing the overall vascular status of the flap.

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Microsurgical Procedures in Plastic Surgery

10

Filippo Marchi and Fu-Chan Wei

Background

Microsurgery is a general term for surgery requiring dedicated surgical instruments and a magnification system. Depending on the structure operated on and its size, terms such as microvascular surgery (surgery on blood vessels around 1 mm), microneural surgery, microlymphatic surgery, and microtubular surgery, etc., can be coined.

Despite its age, microsurgery is still an evolving technique, and new ideas and solutions make it an even more comprehensive, varied, and exciting. Microsurgery is also a philosophy of thought rather than action, which allows us to reconsider the indications and surgical techniques already consolidated over time in light of the new indication, such as a last resort after the failure of other options into the first choice, which reverses the reconstructive ladder.

However, microsurgery comes with a relatively high price, demanding experience, and resources. Nevertheless, with professional training, specialized infrastructures, and dedication, microsurgery can be performed daily with convenience.

This chapter covers the principles and techniques of basic and advanced microsurgery, its application in different surgical subspecialties, and future directions.

10.1 Tools

10.1.1 Magnification System

Microsurgery requires a magnification device, which can be the microscope or the loupes (microsurgical glasses).

Loupes can provide variable magnifications (2×, 4×, or more), especially useful in the early stages of dissection or to repair larger vessels and nerves [1]. The working distance of the loupes varies according to the degree of magnification and ranges from 250 mm to 450 mm. When more surgeons are involved in the same procedure, ideally their loupes should have a similar working distance.

The microscope allows higher magnification. It is a system of converging lenses that produce enlarged images of small objects, allowing the operator an exceedingly close view of minute structures.

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The lens is an optical system composed of transparent material enclosed between flat or curved surfaces, which has the property of deflecting light rays. Usually, for microscope, the lenses are spherical, symmetrical with respect to the axis of rotation, which is called the "optical axis."

Nowadays, the microscope includes several components: binocular head with adjustable eyepieces and an additional head to allow two people to work together.

The main head contains lenses and provides magnification, which works by modifying the distance between the optical elements. Magnification requires adequate light, and the need for more illumination increases as the magnification increases. The source can be external or internal to the body.

The focal distance of the lens is particularly important as it determines the working distance; usually, it is 200–250 mm.

Tilt, focus, and zoom can be controlled via a foot pedal or a hand control panel.

The stand is the support of the microscope; its base can be mobile or fixed, on the floor, on the ceiling. The mobile system is often preferred for reasons of practicality and mobility of the microscope.

The accessories can be many: multifunctional pedal, the third eyepiece (beam splitter), and adaptors for cameras and for video or photo shooting (Figs. 10.1 and 10.2).

Key Points

- Spend time getting the position right, making sure that the interpupillary distance and diopter correction are right.
- Focus should be adjusted with the scope at the highest magnification before starting.

Fig. 10.1 Surgical microscope (courtesy of Chang Gung Memorial Hospital (Taipei, Taiwan) and Leica Microsystems (Wetzlar, Germany))

Fig. 10.2 Surgical loupes (magnification rate 3.5, focal distance 420 mm)

10.1.2 Microsurgical Instruments

The microsurgical instrumentation is extensive, but in clinical practice, the essential devices for the execution of procedures are limited and most surgeons become proficient with a reasonably small set, which includes forceps, needle holders, scissors, vascular dilators, free micro clamps, and approximators.

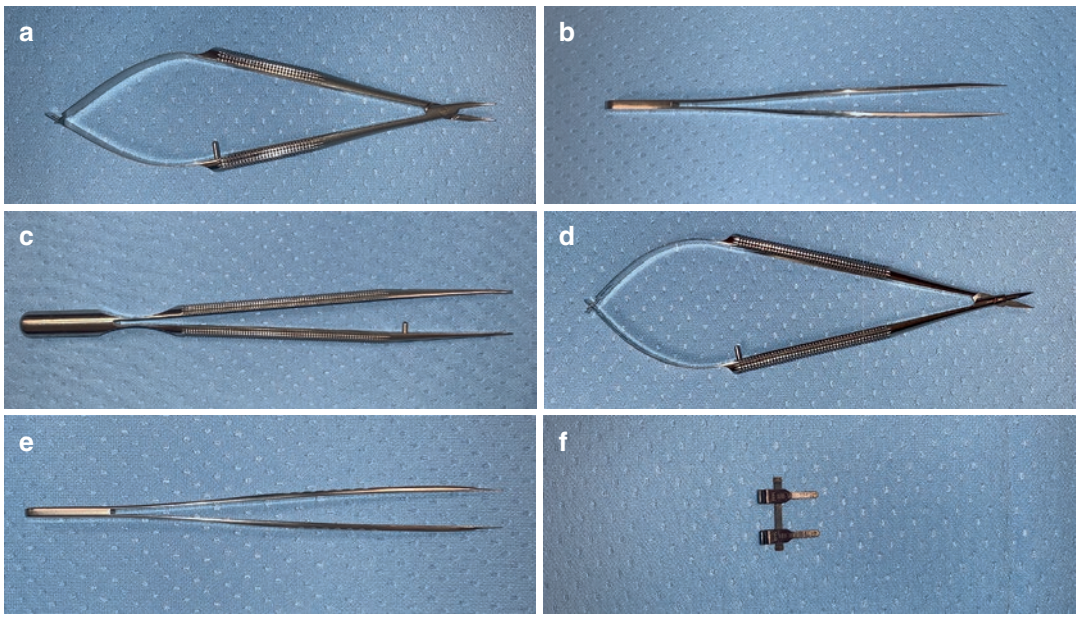

Fig. 10.3 Basic microsurgical set of instruments. (**a**) Needle holder, (**b**) short forceps, (**c**) long forceps, (**d**) scissors, (**e**) vessel dilator, and (**f**) double approximator clamp

The basic requirements of microsurgical instruments are handling, precision, and delicacy in grasping tissues. Handling depends on the shape and weight of the tool. The shape may also vary: flat shape is recommended for forceps and dilators, while curved shape may be preferable for scissors and needle holders that require subtle rotational movements. The weight of the microsurgical instrument must be correctly distributed in order to maintain the center of gravity included in the space between the thumb and index finger of the operator's hand (Fig. 10.3).

Key Points

- All instruments need to be in excellent working condition.
- Instruments tip shall not touch another hard object.

10.1.3 Sutures

The most used sutures in microsurgery are nylon or polypropylene. These have a smooth surface, allow for easy closure of the knots, and generate limited tissue reactions. The most commonly used wires are 9–0, 10–0, and 11–0 (from 26 to 18 μm in diameter); 3/8 circle needles can have different sections—the length of the 10–0 needle is approximately 3.8/4 mm. Those with a cylindrical section are less traumatic for vascular and nerve walls in order to minimize the interference with surrounding tissues. The needles with a triangular tip have greater ease of entry into the more resistant tissue but are not widely used. In general, the needle used in the vascular suture must not have a greater size than the suture in order not to damage the vessel wall during the passage [2].

10.2 Lifestyle and Ergonomics

To obtain good and consistent results, ergonomic shrewdness is necessary, such as correct and comfortable positioning, with the aim of reducing tiredness, discouragement, and tremors. The length of the operations (often several hours) and the need to maintain the same position can cause low back pain, neck pain, and more [3]. Only through constant practice can one become famil-

iar with microsurgery, improving the refinement of the senses, the perception of depth of field, sensory feedback, and proprioception.

Tremor has a negative impact on the quality of the micro-surgical gesture with the consequent possibility of error and damage to the tissues. Physiological tremor can be amplified by muscle fatigue, excessive effort, anxiety, cold, hunger, the use of stimulants, the use of alcoholic beverages, or metabolic oscillations or hyperthyroidism.

The surgeon must be well seated with the head slightly flexed (about 30°), the back must be straight, the arms must be resting, the forearms must be well supported up to the wrists and ulnar edge of the hand, the feet must be stable on the ground. The chair and table must be adequate to assume a correct position. The distance between the surgical field and the microscope eyepieces should correspond to the vertical distance between the surgeon's hands and eyes (on average 20–25 cm). Microsurgical instruments must be held like a pen with the tip of the thumb, index, and middle fingers at a distance of 3.5–4 cm from the tip of the instrument.

Tips and Tricks

Familiarize with microscope

Feet flat on the ground to provide a stable base

Upper extremities well supported to minimize fatigue and tremor

Three points of stabilization while holding instrument: elbow, wrist, and last 3 fingers

10.3 Categories of Microsurgery

10.3.1 Microneural

The ability of peripheral nerves to regenerate their axons and reinnervate their targets after injury depends much on nerve coaptation accuracy. The timing of the repair, the type and extent of the injury, and patient features also contribute to the outcome after nerve injury [4]. The field of application of microsurgery ranges from trauma of the limbs, brachial and cervical plexus injuries, reimplantation, and facial nerve reanimation after tumor ablation of congenital diseases.

The basic principles of microsurgical management of nerve injuries are the following: quantitative preoperative assessment of the residual function, adequate debridement nerve stumps to healthy nerve fibers to allow nerve regeneration to proceed across the repair area, and nerve repair in a tension-free manner under magnification; when a tension-free direct repair is not possible, other techniques are used for reconstructing the nerve gap with nerve grafts or nerve transfers. Where primary repair is not optimal (in cases with a severe crush, stretch, or loss of nerve tissue), delayed repair approximately 3 weeks postinjury is advisable. Depending on the type of lesion, the size of the nerve trunk, and the three-dimensional structure of the nerve, different suturing techniques can be used. The simplest suture is the end-to-end neurorrhaphy in which two nerve stumps connect. This type of suture is divided into epineural, perineural (or fascicular), and epi-perineural. The term lateral neurorrhaphy refers to connecting a nerve stump with an intact nerve segment after creating an epineural window; it is a procedure with more restricted indications. Nerve anastomosis should be performed with either 9–0 or 10–0 nylon, interrupted sutures. The stumps must be prepared sharply using either a sharp blade or a straight microscissor to achieve a clean cut.

Finally, postoperative management is fundamental to optimize the outcome; occupational and physical therapy is performed to maintain range of motion and sensory and motor re-education.

10.3.2 Microvascular

Known also as microvascular surgery, it is the main branch of microsurgery that allows connecting arteries and veins of a small caliber (from 1 over even smaller). Microvascular surgery stands for the widest field of application of microsurgery, and autologous free tissue transfer

(named free flap) is one of its most frequent application [5]. Success in microvascular surgery is multifactorial, with technical skills in vessel anastomosis as the first step on the road. Another important factor in ensuring success is the use of healthy recipient vessels of appropriate size with good outflow. A healthy vessel has a soft wall and a vascular sheath that can be easily dissected, while traumatized vessels may be encased in fibrotic tissue. The dissection of the vascular pedicle proceeds under magnification to free sufficient length to allow a tension-free anastomosis. Gross trimming of the adventitia is performed around the area of the anastomosis, allowing sufficient length of the trimmed vessel for application of the vascular clamp.

It is vital to check the flow within the artery. Expansile pulsation of the artery usually indicates adequacy but should be confirmed by healthy spurting from the divided vessel. If a healthy-looking vessel does not spurt well, check that the patient is normotensive. The ideal recipient vein should be at least as wide as the donor vein; otherwise, it may produce a bottle-neck effect and compromise drainage. The vein is divided to assess its quality, and good backflow from the vein indicates a fairly health vessel. The vessels should be irrigated during and after dissection with heparinized saline, and on completion of the dissection, covered with 2–4% lidocaine or 3% papaverine-soaked gauze pieces to prevent desiccation and vasospasm. The vessel ends to be anastomosed are placed in a double approximating clamp under microscope magnification. This allows the vessels to be manipulated so that the lumen and intima of both ends can be clearly visualized, to compare the caliber, and eventually to adjust it with different refinements. A sudden change of caliber may cause turbulence that might lead to thrombosis. Pliable nonadherent and nonreflective background material is placed under the vessels. Moistened gauze pieces are placed around the vessel to prevent the suture from adhering to surrounding structures and to position adequately the clamp. Good hemostasis should be maintained at all times. The vessel lumens may need gentle dilatation with a vessel dilator or microneedle holder to increase the size and to prevent vasospasm. Different anastomotic techniques can be utilized: direct end-to-end and end-to-side, utilizing continuous suture, interrupted suture, or loops [6]. The choice depends on the orientation, the vessel's size, and the preferred technique of each surgeon [7]. Patency should be assessed after the completion of each anastomosis. This can be done by simple observation or by conducting a patency test. A sign of patency of the artery includes good flow from the vein. If the recipient vein fills well and has a natural round diameter, it is likely to be patent. If it is engorged and the blood column is darker than that in the recipient vessel, it is thrombosed and will require to do the anastomosis again. Empty and refill should only be performed when needed [8]. After completing the anastomosis, should be checked possible leaks. If a small amount of blood leaks temporarily from the sutures' hole, no more sutures are needed to seal the anastomosis; however, if the spurt is from the suture line, additional stitches are required. Because of technological advances, reconstructive microsurgery has reached the stage where anastomosis of vessels as small as 0.3 mm is feasible. This type of microsurgery, called as "supermicrosurgery," is now applied for "perforator-to-perforator" flaps and complex digital replantation.

10.4 Pictures of Microvascular Anastomosis

10.4.1 Microlymphatic

Lymphedema, due to congenital diseases, infections, or iatrogenic insults, refractory to nonsurgical therapies, may be managed by surgical treatment. From simple excision to advance microsurgical techniques, a variety of surgical modalities have been shown to improve, and sometimes reverse, the devastating effects of this disease. Indications include insufficient lymphedema reduction by well-performed medical and physical therapy, recurrent episodes of lymphangitis, intractable pain, and worsening limb function. The first microsurgical technique described is the so-called "derivative operation," which connects lymph nodes to veins. This has been largely abandoned except in endemic areas of lymphatic

filariasis. Because of the difficulties encountered with lymph nodal-venous shunts, different techniques were investigated and gained popularity, which are lymphaticovenous or lymphovenous anastomosis (LVA) and vascularized lymph node transfer (VLNT). These surgeries aim to tackle the physiologic impairment that results in lymphedema, namely bypassing the areas of damaged lymphatics by diverting lymph into the venous system or by replacing the lost lymph nodes and channels, respectively [9]. It is generally agreed upon that LVA is easier and more effective the earlier it is performed [10]. First, a suitable lymphatic channel must be identified. This can be done using a distally injected dye (e.g., indocyanine green) and/or lymphoscintigraphy. Next, a suitable vein must be identified for anastomosis. A suitable vein must be of a compatible size, in the proper location, and show minimal, if any, backflow when divided. Of the current surgical therapies for lymphedema, VLNT is the newest addition that has shown promising results [9]. In this new field, however, there remain many unanswered questions with regard to mechanism of action, donor site selection, recipient site selection, and postoperative care.

10.4.2 Microtubular Surgery

Microtubular refers to a subspecialty of microsurgery focused on repairing/restoring the continuity of nonvascular tubular structures, including fallopian tube, vas deferens, lacrimal ducts, biliary tree, and salivary ducts. Recent advances in microsurgical techniques using a higher magnification and atraumatic technique have resulted in an increased success rate in the repair of all those tubular structures [11].

Tips and Tricks

Moist gauze placed beneath the vessel elevates the plane to aid lumen visualization

Arterial anastomosis first helps to reestablish circulation and reveals the dominant venous drainage to aid the selection of donor vein

10.5 Replantation and Tissue Transplantation

Reimplantation, or replantation, refers to a procedure that aims to reconnect a part of the body and revascularize at its original site that was mechanically mutilated. Transplantation is a procedure in which a tissue is removed from one body and placed in a new recipient site to replace damaged or missing tissue. Tissues that are transplanted within the same human body are called autografts. Transplants carried out between two subjects of the same species are named allografts. Allografts can either be from a living or cadaveric source.

To succeed, all the structures that guarantee the trophism and the function of tissue should be restored; these include arteries, veins, nerves, bones, tendons, and muscles.

Reconstructive microsurgery began from digital replantation in the 1960s, then gradually opened a broad spectrum of applications. Free tissue from skin, muscle, bone, fascia, periosteum, nerve, or combinations can be transferred to defects in the extremities, the face, the head, and almost every part of the body.

In replantation, although tissue viability is undoubtedly a concern, it is not a unique factor to achieve success. Many considerations must be taken into account, including the level and kind of injury, ischemia time, chance of survival, anticipated functional outcome, patient characteristics, predicted morbidity, and length of rehabilitation. The ideal candidate is a young, healthy patient with a sharp mechanism of injury with minimal tissue destruction and contamination [12]. Absolute indications for replantation include loss of a thumb, multiple digit amputations, and amputations proximal to the palm. Replantation should be considered for pediatric finger amputations at any level, given the plasticity of the digits and healing capacity. Distal and single-digit amputation is also a relative indication for replantation. The amputated part should be wrapped in saline-moistened gauze and placed in a plastic bag that is sealed and placed in ice. The tolerable ischemia times are 12 h warm and 24 h cold for a digit and 6 h

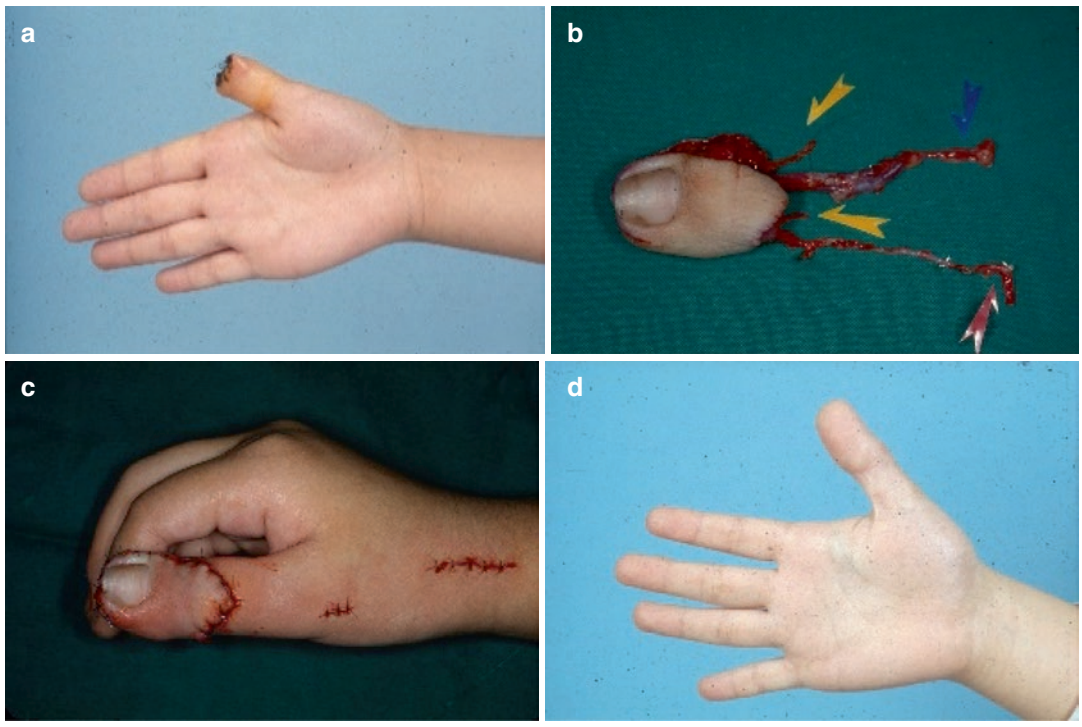

Fig. 10.4 Isolated thumb amputation at distal phalanx reconstructed with a modified great toe wrap-around flap. (**a**) Preoperative picture. (**b**) Harvested great toe wrap-around flap (yellow arrows: nerves; red arrow: artery; blue arrow: vein). (**c**) Immediate view after toe transfer and revascularization. (**d**) Appearance 1 year postoperation

warm and 12 h cold for the hand and proximal amputation [13](Fig. 10.4).

10.6 Multidisciplinary Applications

10.6.1 Orthopedics

Across the last few decades, microsurgery has made elemental contributions to orthopedics in restoring anatomy and function after traumatic injury or for congenital malformations. Fifty years ago, microsurgical composite tissue transfer became a reality, with functioning of free muscle transfers, vascularized bone grafts, toe-to-hand transfers, and so on. Microsurgical techniques have become an integral part of orthopedics and hand surgery; these applications of microsurgery are also named "orthoplastic surgery."

Therefore, limb salvage surgery became the choice of treatment over amputation in many cases. It embraces procedures such as debridement and early coverage in trauma, replacing lost functional units in cancer ablation, vascularity improvement in the ischemic leg, and providing a stable contact surface for trophic ulcers. Flaps with different tissue components (compound and composite), including skeletal, tendon, muscle, vessel, and nerve, help to restore function and play a critical role in limb salvage (Fig. 10.5).

10.6.2 Neurosurgery

Microsurgery allows to restore the blood supply to the brain through extracranial–intracranial revascularization, especially in the presence of complex unclippable aneurysms, occlusive cerebrovascular disease, or in skull base tumor surgery involving major vessel sacrifice, a scenario associated with risk of ischemic complications in ~20% of patients [14, 15].

Several bypass options are available; in theory, cerebral bypass can be classified as low flow

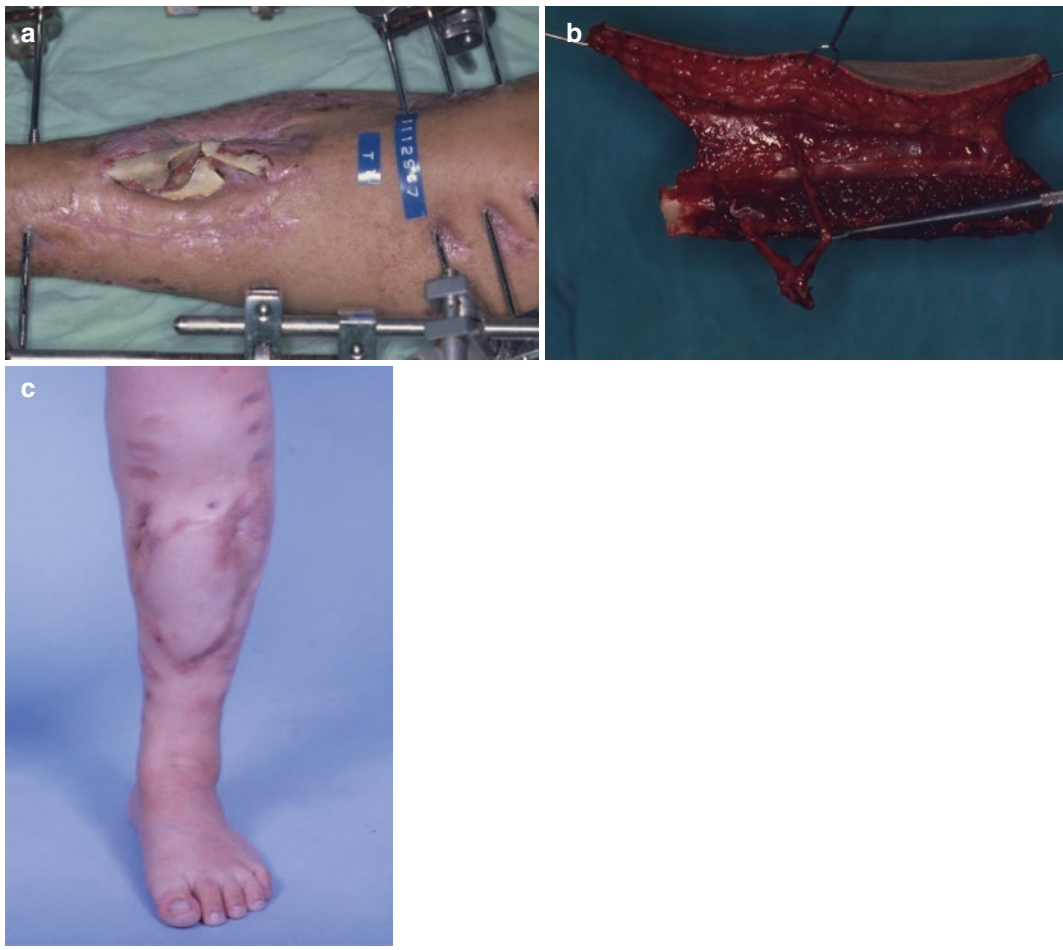

Fig. 10.5 Compound tibia and coverage defect reconstructed with a fibula osteoseptocutaneous flap. (**a**) Preoperative view. (**b**) Harvested fibula osteoseptocutaneous flap. (**c**) Appearance of reconstruction site 10 years postoperation

(15–25 mL/min), medium flow (40–70 mL/min), and high flow (70–140 mL/min) [16].

Another contribution of microsurgery regards the reconstruction of scalp defects. Neurosurgical approaches often require extensive scalp dissection, bone fixation, and tissue destruction. Thus, hardware exposure, bone necrosis, soft tissue infection, which lead to a significant amount of tissue loss, are commonplace. Free soft tissue flaps provide an effective treatment for such conditions.

Cancers of the paranasal sinuses, nasal cavities, and lateral skull base nowadays are approached mostly surgically. Endoscopic and open approaches to the anterior and lateral skull base nowadays are standard procedures. Defects involving the skull base require multiple tissue components (i.e., muscle, fascia, skin, and bone). Microsurgery provides a broad spectrum of options to cover and restore such a complex anatomical area.

10.6.3 Head and Neck Surgery

Major ablative surgeries for cancer or trauma of the head and neck region can be devastating for the patient. Indications in the surgical management of head and neck tumors have been pushed forward due to the development of a wide variety of reconstructive options.

To restore form and function and to achieve total rehabilitation of the patient require reconstruction of anatomic defects to obtain aesthetic

appearance and physiologic function. Thus, two primary goals need to be addressed in reconstructive surgery: aesthetic and functional restoration. With the advent of microsurgery and free flaps, we approached a new era in reconstructive surgery, which allows the reconstruction of previously unreconstructable defects. Consequentially, more complex wounds were created through more radical surgery, for which, in the past, a suboptimal reconstruction was considered the standard of care. However, since the ideal reconstruction is based on the "like-with-like" concept, the description of vascularized bone transfers wedged the modern era of mandibular reconstruction. The turning point in the early 1990s was the introduction of the fibula osteoseptocutaneous flap for mandible reconstruction [17, 18] and the perforator flaps such as the anterolateral thigh flap [19]. Furthermore, it reached its peak with the refinement and the flexibility of the free-style approach to restore complex, tridimensional defects, maintaining the benefits of a two-team approach [20].

Examples of reconstructive attempts to restore the facial aesthetic include restoration of contour, appearance, and expression of the face. Rehabilitation of oral competence also is necessary for defects of the oral cavity, oropharynx, and lips. Examples of functional restoration include speech, mastication, dentition, and deglutition. Soft tissue loss may be due to loss of the cutaneous or mucosal lining or the bulk of underlying soft tissues, or the combination of all. Ideally, all bone losses should be replaced with bone. However, the need for bone reconstruction is dictated by a decision-making process based on several factors (patient condition, prognosis, quality of life, etc.) as well as on the site and extent of bone resection, whether it is in the mandible, maxilla, or calvarium. Besides, the planning of reconstructive surgery requires assessment of tissue loss, which may be from mobile parts of the anatomy of the head and neck region or from immobile tissues. Special thought is necessary for reconstruction of resected nerves, blood vessels, cartilage, or any combination of these tissues. Head and neck reconstructive microsurgery is one of the most representative of the modern multidisciplinary approach required in modern medicine (Figs. 10.6 and 10.7).

10.6.4 Ophthalmology

Microsurgical techniques contribute to a niche of ophthalmology in providing the restoration of corneal sensation after denervation. The normal corneal sensation is essential for corneal function; it initiates blink reflex in response to heat, evaporation, and pain; it also stimulates normal epithelial cell mitosis and migration, maintaining surface integrity. Corneal anesthesia is a devastating condition, causes a decrease in lacrimal gland secretion, and induces loss of the trophic elements supplied by the nerves to maintain appropriate epithelial function. The denervation leads to neurotrophic keratitis, and the corneal surface becomes vulnerable. Corneal neurotization is a revolutionary technique that can offer a potential cure to eyes with neurotrophic keratopathy. Corneal neurotization is a revolutionary surgical procedure in which a donor nerve graft is coapted to the damaged nerve. The technique relies on a transfer of a healthy nerve segment to the corneo-limbal area and restores the basis for sub-basal plexus regeneration and hence the reversal of the neurotrophic disease [21]. Corneal reinnervation can be performed by direct nerve transfers or by nerve graft interpositions. Terzis et al. introduced the first neurotization procedure to treat unilateral facial nerve palsy patients [22]. They mobilized the contralateral supratrochlear nerve at its proximal end near the orbital rim and redirected it under the nasal bridge and through a crease blepharotomy into the conjunctiva. The nerve's endoneurium was opened, and the fascicles were separated and sutures in conjunctival pockets near the limbus. Because direct neurotization is an extensive procedure, sometimes interposition nerve graft is needed. Elbaz et al. introduced the use of sural nerve grafts to connect to the contralateral supratrochlear or supraorbital nerves to the perilimbal region [23]. Corneal sensory recovery is expected at 6 months after the procedure. The physiological mechanisms of nerve regeneration are still to be

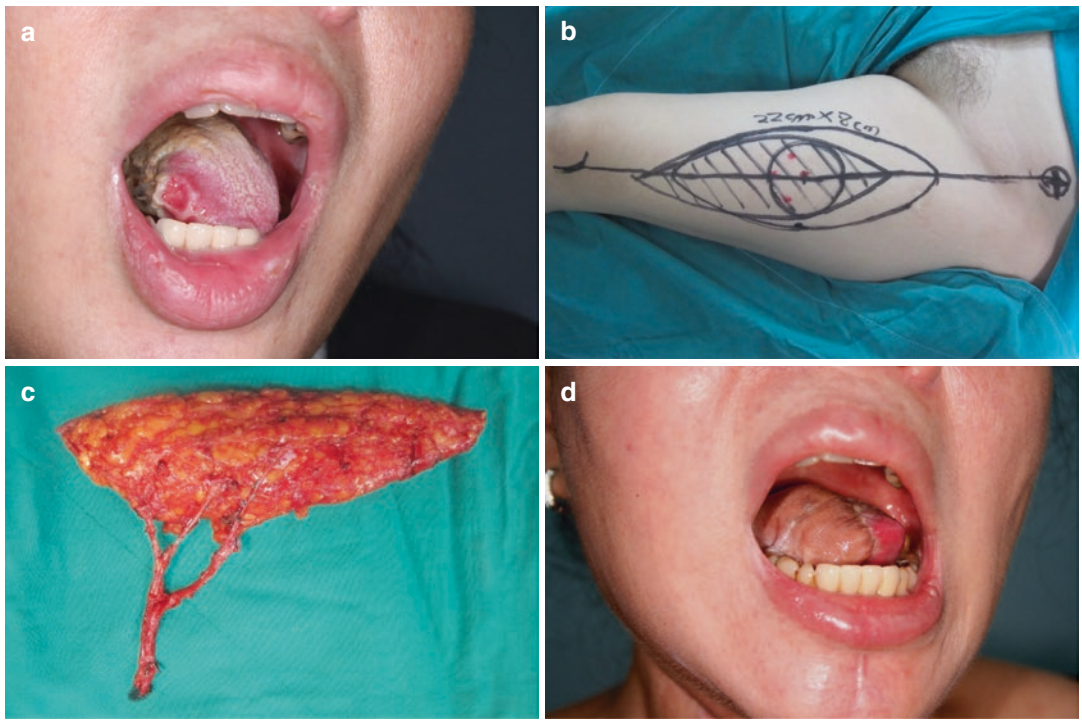

Fig. 10.6 Right tongue squamous cell carcinoma receiving hemiglossectomy and radical neck dissection and reconstruction with an anterolateral thigh perforator cutaneous flap. (**a**) Preoperative view of right tongue cancer. (**b**) Design of an anterolateral thigh flap. (**c**) Harvested anterolateral thigh perforator flap. (**d**) Appearance 3 years postoperation

elucidated: direct sprouting versus neurotrophic stimulus [24].

10.6.5 General Surgery

Microsurgery is mostly applied in two fields in general surgery: breast reconstruction after tumor ablation and liver transplantation.

Reconstruction after mastectomy is often required by women with breast cancer who are not eligible for conservative therapy and women with a high genetic risk for breast cancer. Current breast reconstruction techniques are diverse and may involve the use of an autologous tissue flap, a prosthetic implant, or both. The deep inferior epigastric artery (DIEP) and the profunda femoral artery perforator (PAP) flap are two workhorse flaps.

Liver transplantation is now considered the standard treatment of end-stage liver disease.

Despite the improvements, hepatic artery reconstruction is still the most pivotal and challenging step in the implantation of the new graft from living donor. Microsurgical repair of the hepatic artery decreased the complications and failure rate [25] (Fig. 10.8).

10.6.6 Gynecology/Urology

Genital reconstruction can be classified into congenital and acquired.

For phalloplasty, the radial forearm free flap stands as the gold standard technique. Transferring tissue, including the radial artery, vena comitans, cephalic vein, and lateral and medial antebrachial cutaneous nerves, from the forearm, became possible to reconstruct the penis and urethra. This flap enables single-stage reconstruction of a sensate phallus and glans. Phalloplasty is a complex

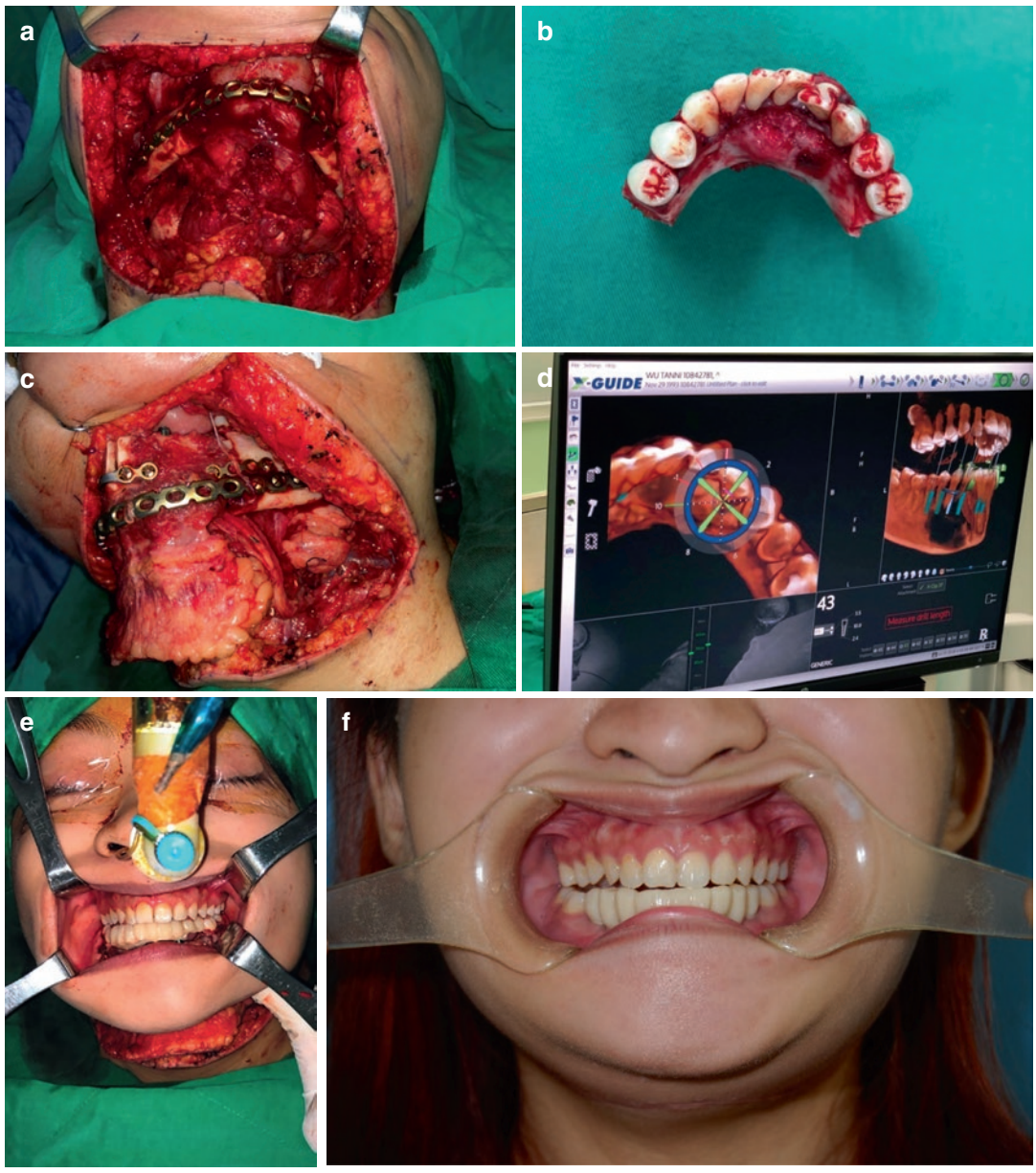

Fig. 10.7 Mandibular ameloblastoma receiving segmental mandibulectomy and simultaneous reconstruction with a fibula osteoseptocutaneous flap, osteointegration teeth implantation, and dental prosthesis on the same day. (**a**) Central mandibular defect after segmental mandibulectomy and reconstruction plate fixation. (**b**) Resected mandibular ameloblastoma. (**c**) Inset and fixation of the transferred fibula in the defect site. (**d**) Intraoral scan after osteointegration teeth implantation. (**e**) Intraoperative placement of temporary dental prosthesis. (**f**) Appearance 18 months after postoperation

procedure that, in some individuals, can help alleviate gender unease [26].

Vulvovaginal reconstruction for congenital defects remains one of the most challenging in reconstructive surgery, particularly from an often overlooked, cosmetic standpoint. Several techniques have been described from simple serial dilations to complex flaps (such as flaps

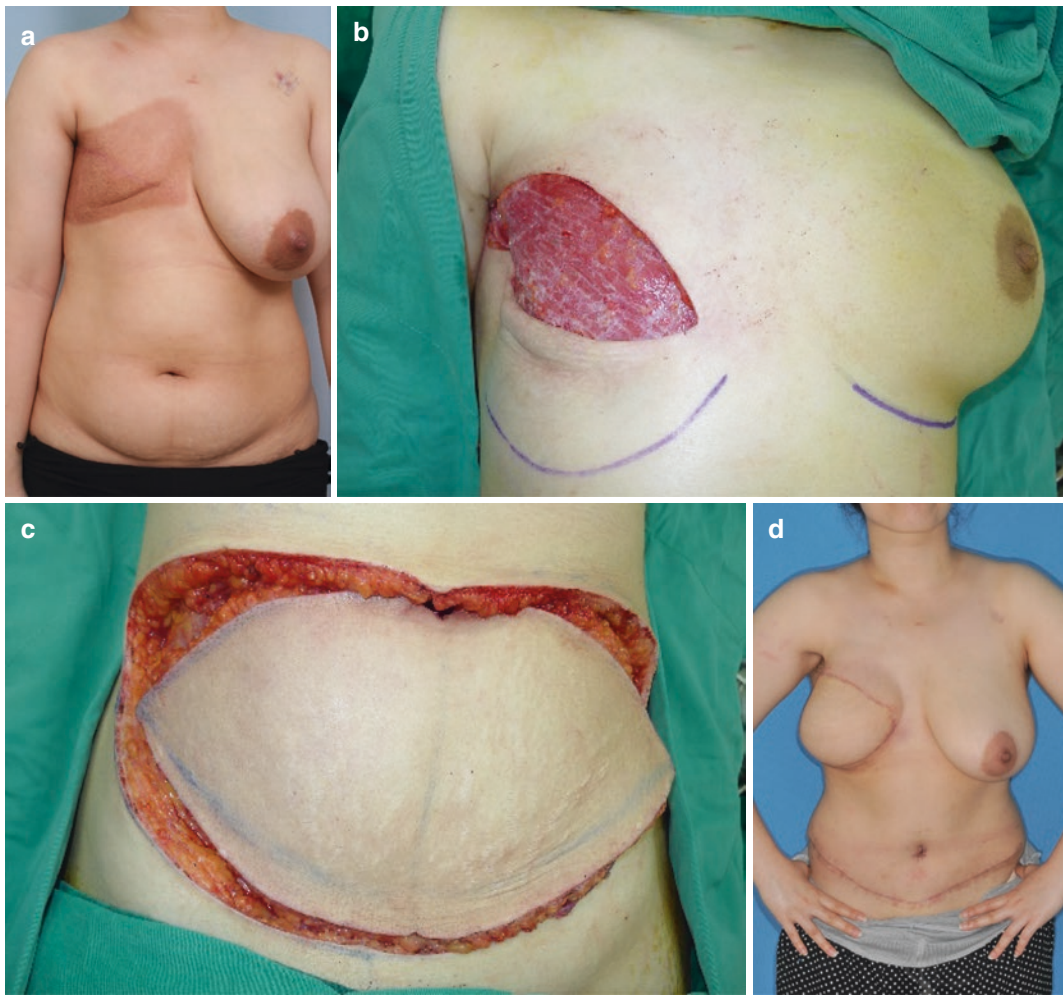

Fig. 10.8 Preoperative condition of patients previously treated for right breast cancer (**a**). Recipient site pocket dissection (**b**). Deep inferior epigastric perforator flap (DIEP) dissection (**c**). Breast reconstruction 1 year follow-up (**d**)

from the groin or the thigh) and intestinal pedicled flaps.

On the other hand, reconstruction of vulvar acquired defects aims to reestablish the anatomy of the external genitalia, ensuring the presence of a wide orifice for the vagina and improving body image by allowing also the restoration of micturition and defecation functions. Over the last decades, a variety of reconstructive procedures have been validated. However, the ideal flap does not exist yet [27].

Lastly, in the past years, uterus transplantation from live donors became a reality to treat infertility. Afterward, it was performed using a deceased donor, proving the concept for treating infertility by transplantation from a deceased donor, opening a path to healthy pregnancy for women with uterine infertility, without the need of live donor surgery [28].

Key Points

Patient factors

- Cardiac and respiratory functions should be optimized before free tissue transfer.
- Age, in itself, is not a contraindication for free-flap as long as the patient is in

otherwise acceptable health and deemed fit for anesthesia.
- Patients should quit smoking preoperatively as the risk of complications is similar to that of nonsmokers if they stop smoking 4 weeks before surgery.
- Obesity increases the risks of hemorrhage and hematomas.
- Alcohol withdrawal is also linked to flap failure and nonflap-related complications. Patients at high risk for alcohol withdrawal syndrome should be identified and treated prophylactically.
- Diabetes mellitus is not an independent risk factor for flap failure, but almost twofold the risk of perioperative complications.
- Liver cirrhosis is a risk factor for perioperative complications, but the disease severity based on Child's scoring system did not have an impact on complications.

Pearls and Pitfalls

Recipients and donor site evaluation

Radiotherapy impairs quality of local tissues and vessels and predispose to complications.

Place the site the anastomosis outside the area of irradiation.

Infected or traumatic wounds should be adequately debrided.

Reconstructive surgery postponed until adequate control of the wound is achieved.

Preoperative angiography is recommended in patients with abnormal distal pulses.

Routine angiography is unjustified.

The design of the flap is centered on perforators that are mapped by a hand-held Doppler.

Choice of flap

There is no flap ideal for all circumstances.

The flap choice is based on the size, tissue components, and reconstruction goals.

Attention to the logistics of patient position and the feasibility of a two-team approach.

Consider recipient vessels in deciding the length and caliber of the flap pedicle.

10.7 Current and Future Perspectives

Several aspects of microsurgery might be impacted by technology in the next future. First of all, the robot-assisted surgery represents the most up-to-date technological innovation in surgery. The Da Vinci Surgical System (Intuitive Surgical Inc.™, Sunnyvale, USA) is the most commonly used. The platform can provide high definition, digital magnification, wide range of motion, fine instrument handling with decreased tremor and fatigue, and improved surgical productivity. In reconstructive microsurgery, the application of robots is still preliminary. Mostly was introduced in head and neck and breast reconstruction. Transoral robotic surgeries have eliminated lip- and mandible-splitting approaches and allowed the ablation of tumors that have until recently been primarily treated with chemoradiotherapy, such as oropharyngeal cancer. Therefore, a robot-assisted insetting of the flap and microanastomosis was described and demonstrated to have similar outcomes compared to the standard approach but with less morbidity [29]. In breast reconstruction finds indications for specific free flaps harvest, which benefit from a minimally invasive approach. Few examples are the latissimus dorsi flap [30] and the deep inferior epigastric artery perforator flap [31].

However, since the Da Vinci Surgical System was not explicitly created for microsurgery, a few limitations might be encountered, in particular in terms of haptic feedback, which is crucial during microanastomosis and ergonomics. The latest version of it, called the Single Port, may over-

come some of these, allowing better movement control in cavities.

Progress in microsurgery has evolved into supermicrosurgery, enabling to couple arteries and veins with diameters between 0.3 and 0.8 mm for the reconstruction of the lymphatic system and free flaps. Supermicrosurgery is bounded by the precision and dexterity of the human body. Robot assistance can help overcome these limitations, thereby warranting a breakthrough in supermicrosurgery. Recently, microsurgeons from the Netherlands have developed the world's first dedicated robotic platform for (super)microsurgery, named MicroSure's MUSA (MicroSure, Eindhoven, The Netherlands) [32]. MUSA is designed to improve the stabilization of movements of microsurgeons by filtering tremors and scaling down motions. The robot is easy to maneuver, equipped with arms holding surgical instruments that are compatible with conventional surgical microscopes. Preclinical tests and clinical case-series with MUSA have confirmed the safety and feasibility of this robot in performing microsurgical anastomosis.

Moreover, smartphone apps may revolutionize free flap monitoring [33], presurgical planning, and flap design guided by dedicated software [34] that is already used in some centers. The combination of robotic-assisted surgery and 5G may unleash the unlimited potential in microsurgery and telemedicine. Furthermore, it will enable the world's experts to perform procedures and train the young generation in any corner of the globe.

Take-Home Message

With the improvements of microsurgical technique, failures became extremely rare, and the success rates of free tissue transfers now range from 96% to 100%. Failures can be attributed to poor planning, choice of flap or vessels, timing, or technique. However, many of the failures may be salvaged, and the success (54–100%) is in part dependent on good patient management, highly trained staff, early detection, and intervention.

For those who aim to develop microsurgery, proper training is crucial; although trainees can learn the techniques from senior surgeons in a clinical setting, training should begin in the laboratory. The requirements of good microsurgical work are a calm disposition and patience. The surgeon must be able to concentrate without unnecessary interruptions and should not be hurried. Undoubtedly, a competent assistant and specialized nurses make a big difference in the operation's speed and ease.

In the next future, microsurgery might become an independent specialty instead of a set of skills used by different specialties, but mainly plastic surgery. Technological refinements and breakthroughs will shape the theme of future microsurgery.

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11 An Algorithm for Approaching Soft Tissue Coverage in the Twenty-First Century

Lucian P. Jiga and Z. Jandali

Background

Microsurgery has enabled reconstructive surgeons to successfully treat problems, which, before the dawn of this era, were considered untreatable. In an effort to minimise trauma but still be able to adequately cover a defect, technical advancements (e.g. instrumentation, imaging) and unprecedented discoveries in the field of vascular anatomy have set the stage for techniques such as supra-microsurgery, free dermal flaps or even super microsurgery enabling safe vascular anastomosis at the submillimetric level.

However, contemplating the actual field of knowledge, there is an obvious shift towards free tissue transfer (e.g. perforator flaps) for defects, which could be amendable with simpler and often more adequate solutions for specific patients, hence the danger for the younger generations of reconstructive surgeons to limit their toolbox to such advanced techniques while minimising the importance of classical procedures, which stand at the foundation of reconstructive surgery as we know it today. Having this said, a harmonic development as a reconstructive surgeon implies, besides obtaining a complete set of operative skills, the capacity to visualise each defect as unique, interpreting it in the patient's context and elaborating a reconstructive plan, which will best suit each case in particular. Here, we offer the reader a thorough overview of the most significant developments in the field of reconstructive surgery and how these lead to shifting paradigms into how we approach soft tissue loss. Thereafter, we propose a systematic approach to soft tissue defects as a tool to properly navigate through the massive body of evidence and thus be able to choose the right type of procedure for each particular wound.

11.1 Introduction

Contemplating on the modern approaches for microsurgical soft tissue reconstruction, over the last decades significant knowledge gains have led to an obvious shifting of classic established paradigms to new more performant concepts that need thorough consideration.

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Our knowledge on using vascularised skin, bone or composite constructs to reconstruct tissue defects all over the body has evolved based on pioneering vascular anatomy studies of Cormack, Lamberty, Taylor, Palmer and others [1, 2]. In 1989, Koshima et al., through their publication on the free epigastric skin flap (later to become the deep inferior epigastric perforator [DIEP] flap), has ignited a new era of perforator flaps [3]. This concept was taken further and developed to a global phenomenon, several of such perforator flaps being standardised to become workhorses for microsurgical reconstruction. The DIEP flap GAP flaps,, ALT flap and MSAP flap are some of the most relevant contributions acting as instrumental evidence for the successful implementation and clinical use of this concept [4–7]. The publishing of the perforasome concept by St. Cyr et al. in 2009 was to add another important piece of evidence to the perforator evidence and simultaneously open the doors to the idea of "freestyle" harvesting of perforator flaps [8]. As such, the possible donor sites for harvesting such flaps were expanded more or less to the entire human body, thereby giving way to a potpourri of new possible flap constructs.

With in-depth knowledge of vascular anatomy, rapidly accumulating evidence on indication and clinical use of perforator flaps and unprecedented development of magnification and microsurgical instruments, the stage was set for the next ground-breaking discovery. The "perforator-to-perforator" concept pioneered and published by Hong et al. in 2013 provided conclusive evidence on the possibility of using perforator instead of main axial vessels at the recipient site to revascularise flaps in the lower extremity. This technique is particularly relevant when approaching ischemic soft tissue loss in patients with peripheral arterial disease and diabetes. Here, axial vessels are many times unusable for a safe anastomosis, whereas perforator vessels (e.g. arteries), besides being enlarged due to the collateralisation process, are usually unaffected by atherosclerosis, thereby offering the ideal recipient vessels in these challenging cases [9]. However, supramicrosurgical skills successfully anastomose vessels in the submillimetric calibre range are a prerequisite to warrant success.

In an effort to further minimise the donor site morbidity and the overall burden of a free flap surgery, several authors went further and using performant ultrasound and CT angiography have defined new anatomical layers for harvesting perforator flaps. The "supra-thin" flaps, although pioneered by Kimata et al. and Kimura et al. in 1989 as "flap thinning after harvesting," have known a new appraisal through the work of Hong et al., which published in 2014 on harvesting "supra-thin" flaps through the "superficial fascial plane" [10, 11]. This dissection in between the two fat layers at the groin, buttock or thigh level yields very thin and pliable flaps, a technique best suited for obese patients where possible skin flap donor areas are a major problem (Fig. 11.1). Lately, Visconti et al. communicate the use of ultrasound to harvest and successfully revascularise "pure subdermal" flaps [12].

In light of all these accumulating discoveries and because of its obvious advantages, the perforator flap has become the preferred choice for soft tissue reconstruction on a global level. Nevertheless, while important discoveries for the sake of science and advancement of our field of knowledge, several of these techniques require unique skills (e.g. supramicrosurgery), which can only be mastered by a distinct rather small group of exceptionally gifted experts around the world. Furthermore, through the globalisation of the perforator flap concepts, the "classical" established approaches to soft tissue reconstruction seem to be coming of age, whereas perforator flaps gradually move to replace these as main indications for several types of tissue defects. While this being a direct and overall beneficial result of evolution, in certain instances using perforator versus muscle flaps remains at least an open discussion for the future. In order to keep this discussion field open and constructive, offering the new generations of plastic reconstructive surgeons the means to master the classical approaches and flap types, before entering the realm of perforators and supra- or supermicrosurgery, becomes mandatory and presumably

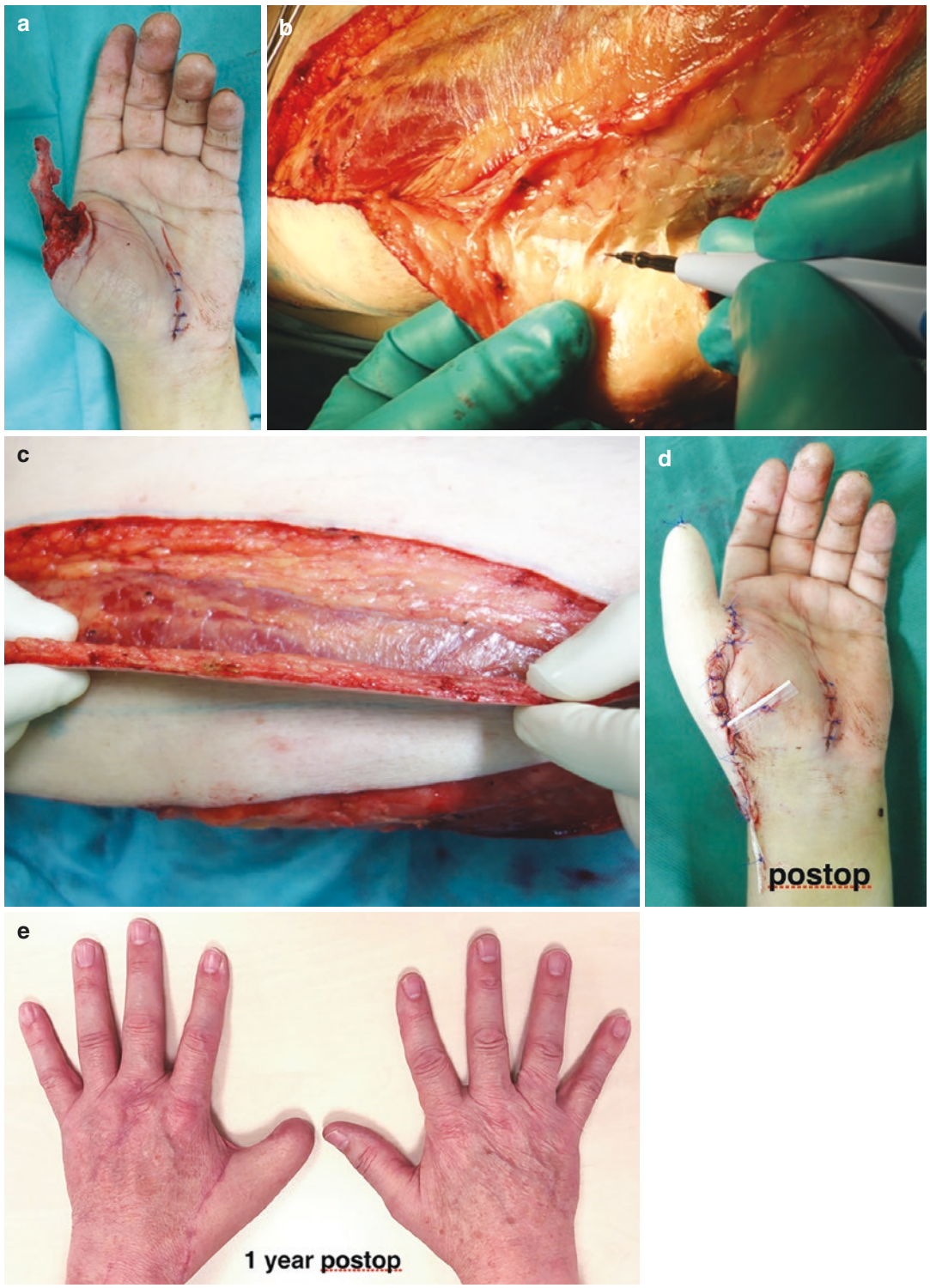

Fig. 11.1 Supra-thin ALT flap for thumb reconstruction. A 52-year-old patient with failed thumb replantation after Level III amputation, which refused a toe-to-hand transfer. After debridement of all soft tissues and IP joint arthrodesis (**a**), a free supra-thin ALT flap harvested between the superficial and deep fat layer (**b**, **c**) using low-intensity monopolar Colorado needle dissection was used to resurface the thumb (**d**, **e**)

the key for future advancement of this field of knowledge. In the following, the reader is offered several scenarios to exemplify and argue this thesis.

Muscle Versus Perforator Flaps for the Treatment of Chronic Osteomyelitis

The therapeutic approach to chronic osteomyelitis of the long bones remains a challenge for the reconstructive surgeon. The "tumour-like" excision with debridement of infected bone and scarred tissues, negative wound swabs followed by reconstruction of the bone frame, obliteration of any dead spaces and reconstructive of the skin continuity are equally important steps leading to successful treatment.

For over four decades, free muscular flaps have been successfully advocated as a primary choice for covering such complex defects. The high-volume blood perfusion warranting effective antibiotic reach in the wound, as well as their capability to improve the overall tissue perfusion in the recipient bed and provide protective cushioning for bony prominences, favours muscle flaps for addressing chronic osteomyelitis [13].

While many clinical and experimental studies have built over the years a solid scientific argumentation for this dogma, newer studies show the potential of fasciocutaneous perforator flaps to be equally effective as their muscle counterparts. In a retrospective study, Hong et al. analysed their results in 120 consecutive cases of osteomyelitis where defect coverage was achieved using a total of six different fasciocutaneous perforator flaps) either with or without a muscular component (e.g. anterolateral thigh flap with vastus lateralis muscle component—43 cases). With a primary reported osteomyelitis remission rate of 91% and major vascular impairment in patients with peripheral arterial disease as the sole factor predicting recurrence, skin perforator flaps can indeed be considered as validated flap choice in these patients [14].

A perforator flap can be harvested while sparring the muscular unit beneath it, thereby preserving the function of the donor site. Furthermore, these flaps can be harvested in a "supra-thin" manner providing optimal contour reconstruction while replacing "like with like." Third, using perforator to perforator supramicrosurgery, these flaps can be revascularised to the superficial perforator vascular system, expediting OR time while avoiding possible other complications during the approach of the main deep vascular system.

While all these attributes are true, one must always keep in mind the four main pillars of success in approaching chronic osteomyelitis: debridement of infected bone, negative swabs, obliterating dead space and reconstructing the soft tissue continuity. Therefore, each patient must be analysed individually as not all defects are amendable with perforator flaps, the right clinical decision on the optimal surgical approach being the ultimate stepping stone towards therapeutic efficacy and success.

Fasciocutanoeus flaps in general and perforator flaps in particular, especially the "supra-thin" ones, have difficulties coping adequately to fill deep dead spaces. Patients where a rather uniform wound bed was attained will definitely do well with a fasciocutaneous flap. In contrast, for defects containing one or several deep holes in the context of exposed bone, muscle flaps with or without a fasciocutaneous component should always be considered first. Hence, muscle flaps remain an important means of defect coverage and are a mandatory component of each microsurgeon toolbox to solve situations where pure skin flaps do not find a primary indication (Figs. 11.2 and 11.3).

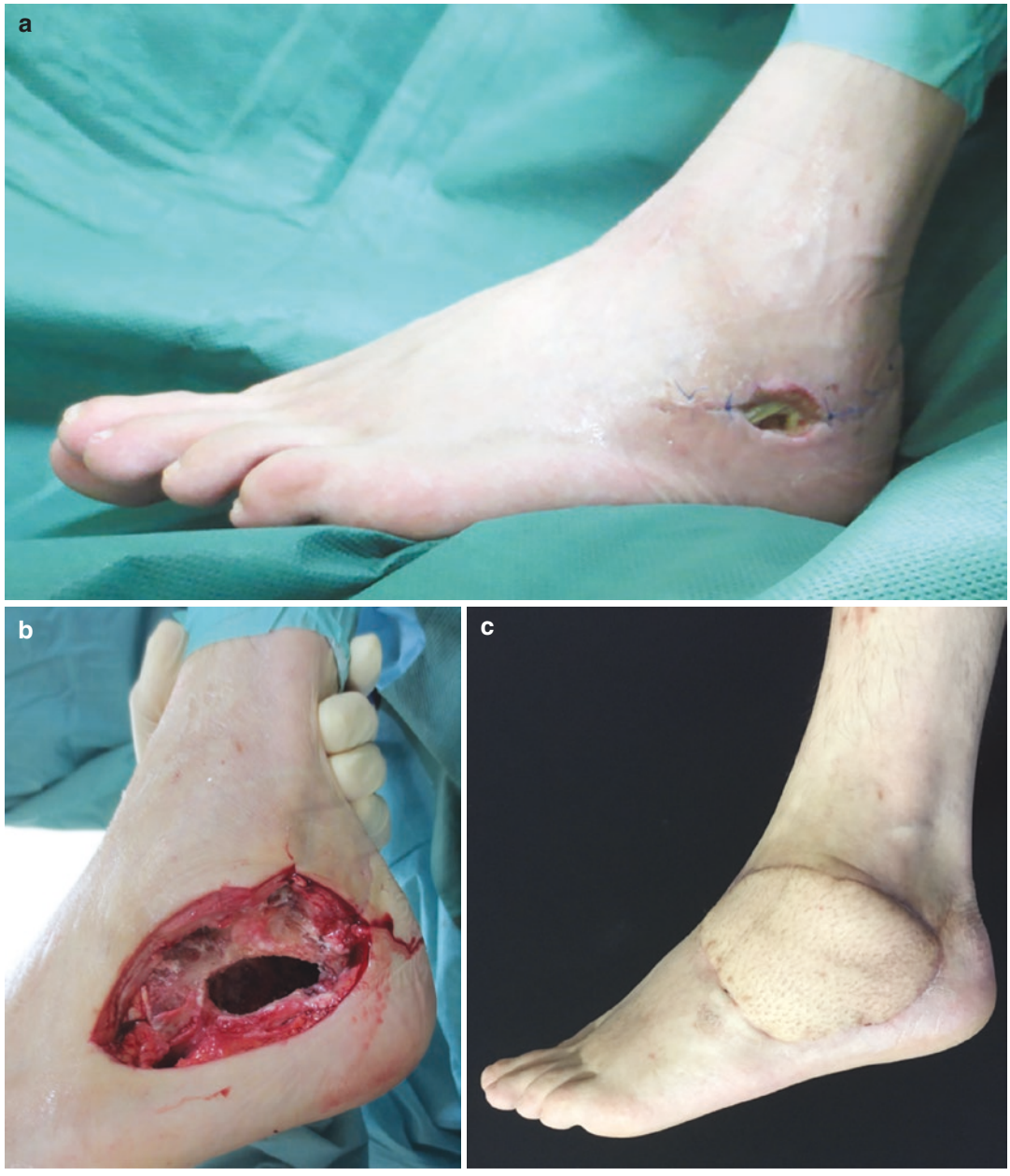

Fig. 11.2 Soft tissue defect with calcaneal osteomyelitis after fracture and failed ORIF (**a**). Debridement of scared tissue and infected bone (**b**) followed by first-stage antibiotic bone replacement and soft tissue reconstruction using a free ALT flap. Definitive bone reconstruction with an autologous graft was performed in a second step, 2 months after soft tissue coverage. (**c**) Healed wound after soft tissue coverage with a free ALT flap and bone reconstruction

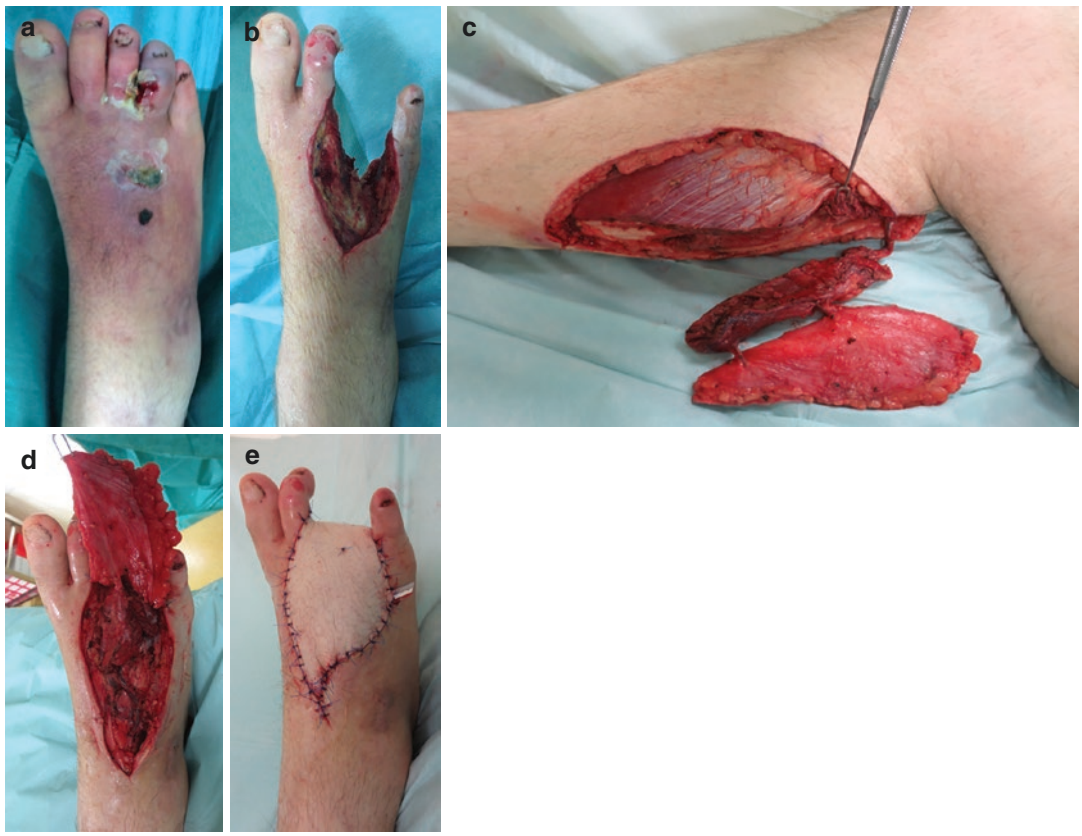

Fig. 11.3 Diabetic patient presenting with massive forefoot infection and septic shock as a complication of a long-lasting mal perforans with chronic osteitis of the fourth metatarsal bone (**a**). After radical debridement and infection control (**b**), a chain-linked medial sural artery perforator flap was used (**c**) simultaneously filling in the forefoot defect and reconstructing the missing skin unit (**d**, **e**)

Key Point

The four main pillars of success in approaching chronic osteomyelitis: debridement of infected bone, negative swabs, obliterating dead space and reconstructing soft tissue continuity.

Skin perforator flaps can be considered validated flap choice in these patients.

Muscle flaps remain an important means of defect coverage and are a mandatory component of each microsurgeon toolbox.

Muscle Versus Perforator Flaps for Covering Weight-Bearing Areas

When faced with tissue defects of weight-bearing areas, young plastic surgeons experience a challenging dilemma on which flap coverage approach should they choose. In the main scientific stream, the term "weight-bearing area" refers mainly to the sole of the foot, in particular fore- and hindfoot.

The glabrous skin of the foot sole, besides withstanding weight-bearing, must

tolerate transient but continuous reduction of tissue perfusion while providing protective sensation. Another important issue to consider when choosing the right flap is maintaining a low shear stress across the tissue planes.

In their meta-analysis published in 2015 on the actual body of evidence regarding muscle vs. fasciocutaneous flaps for reconstruction of the weight-bearing foot, Fox et al. conclude that both solutions are equally effective for covering such defects while underlining the advantages of each type of flap [15].

While the medial plantar flap (either as pedicled or free flap) is the only flap able to fulfil a "like with like" reconstruction by reconstituting the thick glabrous skin of the foot sole, its limited dimensions make this flap usable only in small to moderate defects (Fig. 11.4). Thus, when dealing with bigger defects, either fasciocutaneous or muscle flaps will need attention as the primary reconstructive option.

Contemplating its structural anatomy, as compared with fasciocutaneous flaps, the muscle flap covered with a split-thickness skin graft would be the better option to withstand weight-bearing and avoid increased stress. Furthermore, looking at a normal gait analysis, the majority of weight-bearing during walking is distributed on the tuberculum of the calcaneus (hindfoot) and the head of the five metatarsals (forefoot). As such, when dealing with defects in these areas, a muscle flap could serve better the aims of reconstruction. However, especially in diabetic patients with neuropathic induced deformities (e.g. Charcot), these pressure points have an anomalous much wider distribution and need special consideration when evaluating such defects. One should not forget that soft tissues are only "wrapping" as the outer layer of the complex skeleton of the foot, and in these patients, preliminary reconstruction of the bone structures to reanimate the normal gait followed by soft tissue coverage might represent not only an optimal therapeutic plan but an active measure to prevent wound recurrence.

There are several muscle flaps that have proved their clinical efficacy when dealing with weight-bearing defects (e.g. last dorsi, serratus anterior, gracilis); however, before harvesting a muscle, one always needs to evaluate the possible functional deficit left behind at the donor site. Moreover, muscle flaps are known for their tendency to remain bulky even years after surgery. Thus, the reconstruction plan should definitely take into consideration the immediate and long-term effects such a flap will have on the foot silhouette and function.

One smart but less used muscle flap, which can be an optimal solution for covering the weight-bearing foot, is the vastus lateralis muscle. Described first by D'Arpa et al. in 2015, the compartmental approach for harvesting the proximal superficial unit of this muscle provides a thin muscle flap, which can also be reinnervated as a functional transfer while inducing low to no donor site morbidity [16].

As a clinical rule of thumb guidance principle, as patients get heavier and the defects get wider, the more probable one will need a muscle flap covered with skin graft and vice versa (the lighter the patient and smaller the defect, the more probable a fasciocutaneous flap will do the job). As an exception to this rule, in young patients with posttraumatic significant loss of their weight-bearing foot, a thin muscle flap will always offer a better cushioning and functional outcome (Figs. 11.5, 11.6, and 11.7).

Finally, one will always need to look into his own "toolbox" and offer only reconstructive procedures one is familiar with, as nothing is more dangerous to go into surgery planning to do something one has never done before and not have at least one or two other options as "life boats," which will "save the day" if needed.

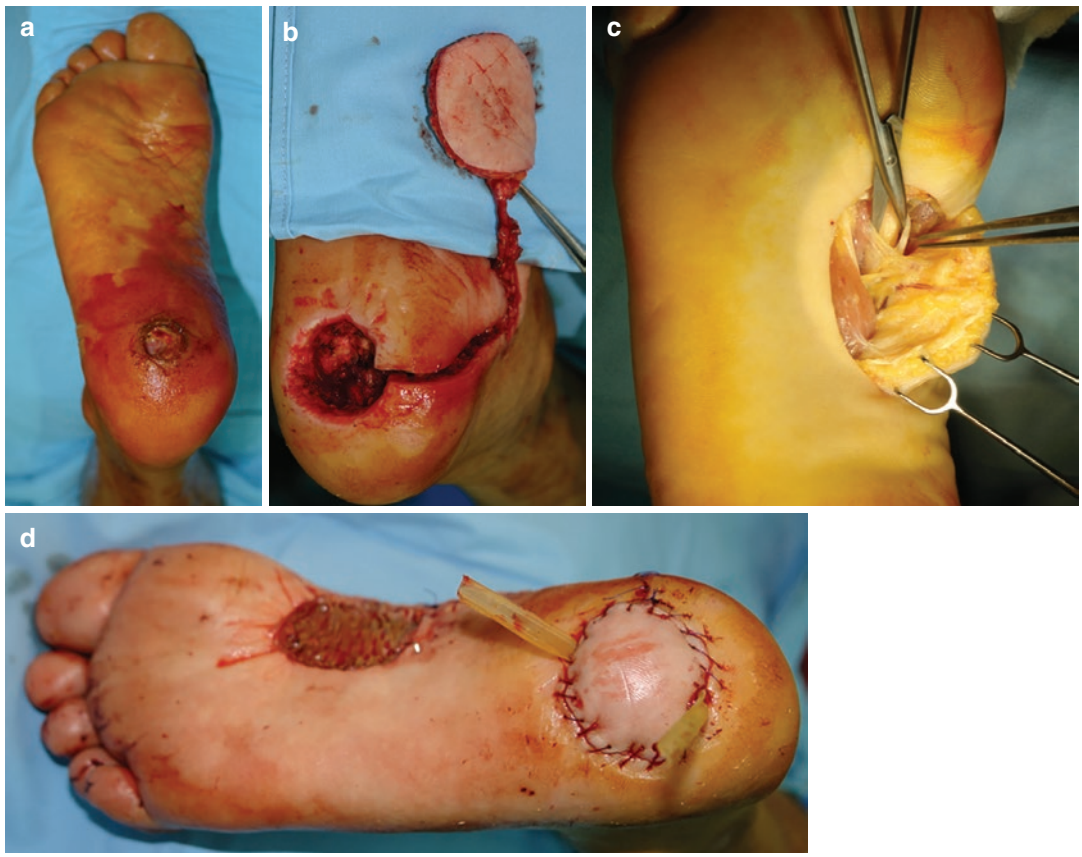

Fig. 11.4 Chronic calcaneal ulcer in a diabetic patient (**a**). In such cases, in the presence of a patent tibial posterior artery, the medial plantar flap (**b**, **c**) can provide a fast and optimal pedicled flap for like-with-like reconstruction of the defect (**d**)

Key Point

As patients get heavier and the defects get wider, the more probable one will need a muscle flap covered with skin graft and vice versa.

Both muscle and fasciocutaneous flaps are equally effective for stable coverage of weight bearing areas.

A thin muscle flap will always offer a better cushioning and functional outcome.

Local Versus Free Perforator Flaps for Soft Tissue Coverage in the Lower Leg

The advent of perforator flaps has revolutionised our way of approaching soft tissue reconstruction. As these continue to replace their muscle counterparts as a primary indication, local perforator flaps have known unprecedented popularity particularly when dealing with defects on the distal upper or lower extremity where free tissue transfers use to hold a type of "traditional exclusivity."

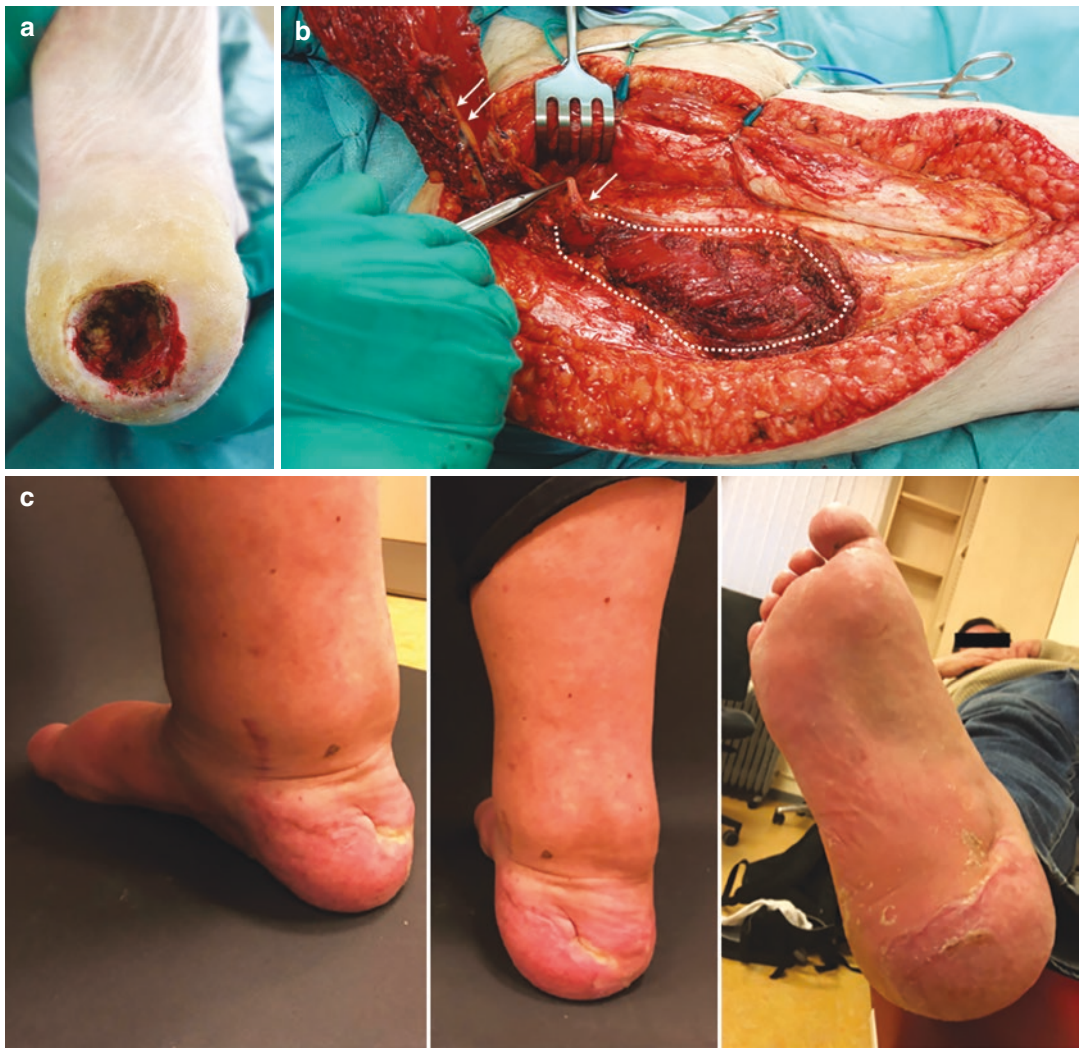

Fig. 11.5 Soft tissue defect with the exposed bone after debridement of an infected pressure sore in a massively overweight diabetic patient (**a**). The distal superficial compartment of the vastus lateralis muscle (*dotted line*) can be safely harvested (*two white arrows*—flap pedicle) without fearing functional impairment (*white arrow*—preserved motor branch to the deep compartment of the vastus lateralis muscle) (**b**). Final result 1 year after surgery with adequate weight-bearing (**c**)

In a comprehensive multicentric comparison of local versus free perforator flaps for soft tissue reconstruction in the lower extremity, Koh et al. reiterate the potential advantages of local perforator flaps for wound coverage of the extremities. According to the authors, the importance of adequate patient and defect evaluation as well as the condition of the neighbouring remaining tissues around the defect are factors of utmost importance, which must be part of the reconstruction plan when considering local perforator flaps, as optimal defect coverage in the presence of high donor site morbidity is not an option [17].

The local perforator flap can be a great tool, especially when dealing with defects on the distal extremities (e.g. lower leg). As the defect localisation moves further distally (e.g. weight-bearing foot), the few remaining choices of local flaps give place to free flaps, which continue to act as a preferred choice in this body area.

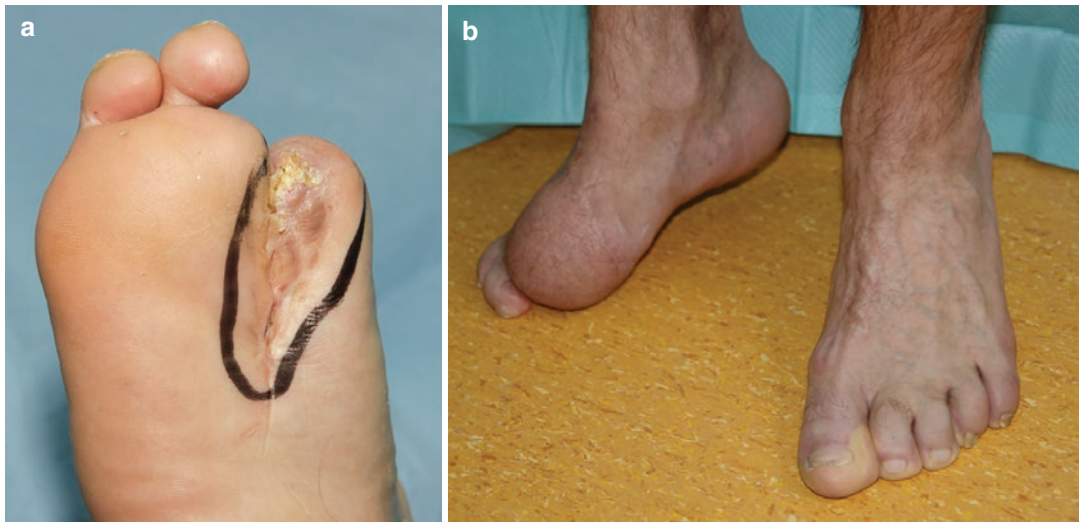

Fig. 11.6 Unstable scar after amputation of the first toe due to frostbite (**a**). Radical debridement with bone length preservation and direct soft tissue coverage using a free ALT flap with a satisfying results 1 year postoperatively (**b**)

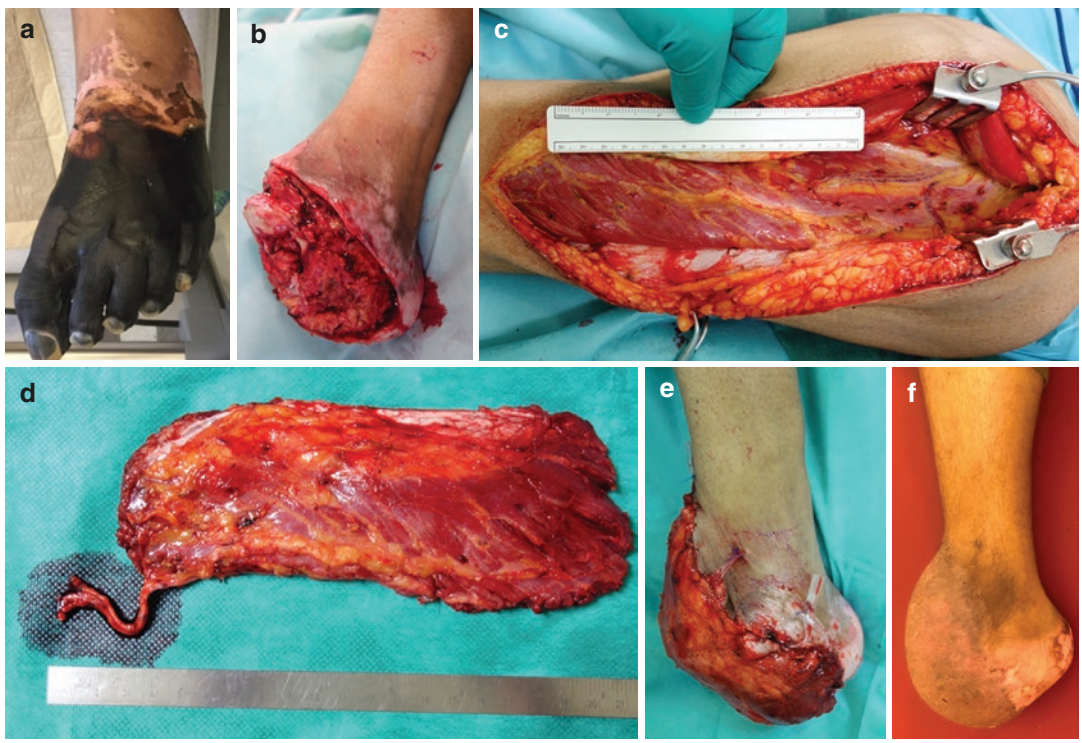

Fig. 11.7 Young patient with complete bilateral forefoot necrosis after prolonged ECMO (extracorporeal membrane oxygenation) support for septic shock (**a**—*left foot is shown*). Atypical amputation with preservation of the hindfoot and tibiotalar joint (**b**) followed by reconstruction of the soft tissue envelope using free vastus lateralis free flap (**c**, **d**, **e**) enabled optimal rehabilitation with full ambulation using custom-made orthopaedic shoes 2 months postoperatively (**f**—*final aspect of the reconstructed area*)

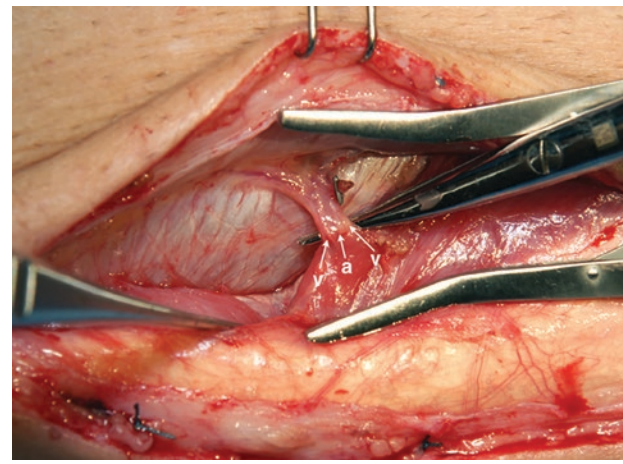

Fig. 11.8 Representative perforator pedicle with one artery and two veins (*see arrows*) arising from the distal peroneal artery, lateral to the Achilles tendon

Knowing the territories of each perforasome in the presence of good perforators and careful evaluation of the defect size as well as its potential mirroring counterpart on the donor site are instrumental steps towards their successful harvesting and use for defect coverage in the lower extremity.

In the authors' experience, when dealing with defects requiring soft tissue reconstruction in the lower leg, while preoperative perforator mapping (Sono- or US Doppler) should always be performed, it is presumably wiser not to consider a local perforator flap as the first choice in the reconstructive plan.

An appropriate free tissue transfer that is proportional to your experience and defect characteristics should always be considered. While exposing the recipient vessels, be aware of all perforator pedicles underneath the fascia and eventually explore the ones that were found to be relevant by the preoperative mapping. A "good" perforator pedicle is defined by its active pulsations, the presence of at least two healthy tributary veins, its calibre (e.g. the bigger, the better) and optimal localisation according to the defect borders (Fig. 11.8). Proper measurement of the flap skin island in relation to the point the perforator pierces the fascia towards the skin, wound size and potential defect of the donor site must all be evaluated intraoperatively if a pedicled perforator flap is to be chosen for defect coverage (Fig. 11.9). Should a proper perforator pedicle be found, which is optimally positioned to allow optimal flap harvesting whereas leaving a decent donor site with no exposed tendon or bone, a local flap instead of the planned free tissue transfer should be performed.

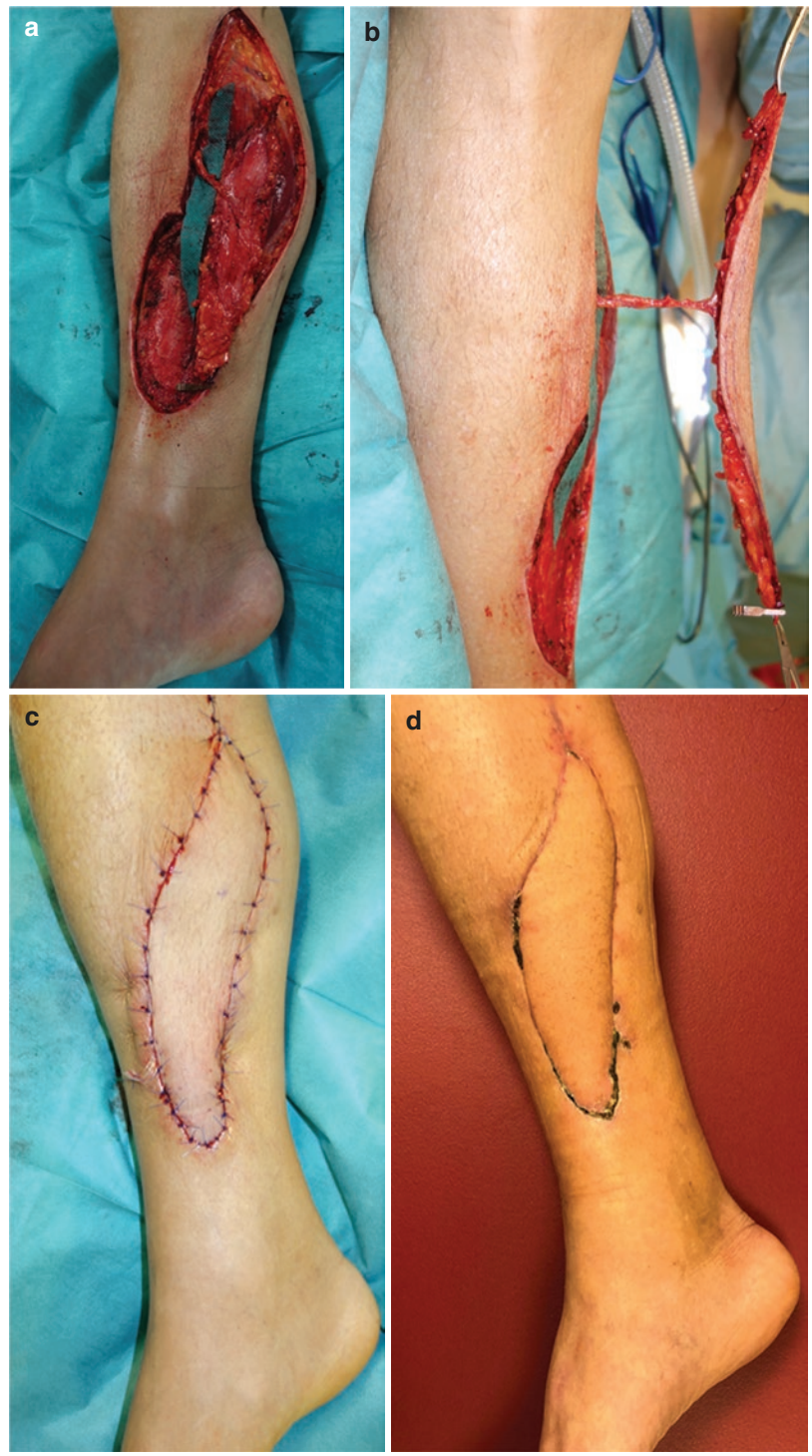

Fig. 11.9 Patient with post-traumatic soft tissue defect of the shank with the exposed distal tibia. While preparing the recipient vessels for a planned free flap, one representative perforator pedicle arising from the tibial posterior artery was found (**a**). As such, the reconstructive strategy was changed to a local fasciocutaneous perforator propeller flap, (**b**, **c**), which healed uneventfully (**d**)

Key Point

The local perforator flap can be a great tool, especially when dealing with defects on the distal extremities (e.g. lower leg).

As the defect localisation moves distally (e.g. weight-bearing foot), local flaps give place to free flaps, which continue to act as a preferred choice in this body area.

A perforator pedicle optimally positioned to allow flap harvesting while leaving a decent donor site will dictate a strategy change to a local flap instead of the planned free tissue transfer.

Perforator-to-Perforator Approach Versus Venous Loops as Recipient Vessels for Ischemic Limb Salvage

Diabetic patients with long-standing neuropathy, simultaneous peripheral arterial disease (PAD) and occlusion (shunting) of the capillary bed often develop foot deformities (Charcot) with chronic ulcerations and intractable infections. These in turn will often lead to severe tissue loss and major amputations due to life-threatening infections.

Reconstruction of the diabetic lower extremity in general but the diabetic foot in particular poses several major challenges, primarily due to lack of adequate recipient vessels but also because of the necessity to carefully evaluate and address all alterations of the bony skeleton leading to pressure maldistribution in the foot sole, thus favouring skin breakdown and ulcer development. Hence, after infection control, the need to evaluate first the entire vascular axis of the affected extremity and prepare a proper vascular recipient bed for reconstruction, then address if needed all pathological "pressure points" by reconstructing the bone with soft tissue reconstruction concluding the reconstructive plan.

In patients with advanced vascular disease and limb-threatening tissue loss, Hong et al. described in 2016 the supramicrosurgical "perforator-to-perforator" approach for free flap anastomosis using superficial perforator vessel pedicles [9]. In spite of major vascular stenosis or obstruction, in the presence of good collateralisation after endovascular dilatation or limb revascularisation, perforator vessels arising from the severely calcified main vascular trunks can be successfully used for flap anastomosis. Situated superficially, these vessels are easily approachable (e.g. shorter operative times) being mostly unaffected by the arterial disease while providing more adequate vessel walls for anastomosis. Using free flaps revascularised on perforator pedicles in the lower leg or foot, Hong et al. were able to attain an overall limb salvage rate of over 83% in a total of 120 patients. While revolutionary, this concept requires advanced supramicrosurgical skills to successfully anastomose vessels at the submillimetric level. However, mastering such skills is available to a rather limited group of microsurgeons, and of these, an even smaller group would include supramicrosurgery in their daily practice.

Instead, using vascular loops for flap anastomosis for ischemic soft tissue coverage in the diabetic PAD patient is a technique that has been safely performed during the last four decades when local recipient vessels are inadequate, damaged or even non-existent. One has the option of installing the vascular loop either before or simultaneously with the free flap transfer. Provided one of the lower limbs of the patient still possesses either the lesser or greater saphenous vein and radical wound debridement with infection control has been achieved, the autologous vein can be harvested and tunnelled as a loop either anatomically (submuscular) or superfi-

cially (underneath the fascia) after which both ends are anastomosed usually at the level of the third segment of the popliteal artery and vein. Even in advanced PAD, most often the distal popliteal or tibioperoneal trunk level remains open and free from severe wall calcifications or obstruction. The flap can be finally anastomosed to the distal end of the loop either to the vein graft or, if needed, for a better calibre match, on a venous branch of the venous graft itself (Fig. 11.10). While proximally vascular anastomosis of the venous loop is facilitated by big calibre vessels, distally the flap vessels can be safely anastomosed on pristine venous walls using a basic microsurgical technique, thus lowering the chance of thrombosis or other anastomosis-related complications.

If longer loops are needed (vascular access for the mid- or distal foot), two veins joined in continuity can be used, yielding loops over 55-cm-long loops. The length of the loop should be calculated by measuring the distance from the proximal vessels until 3–4 cm from the proximal margin of the defect and adding 4–5 cm to this length. In this way, one can avoid possible length deficits or eliciting too much tension on the loop to reach the defect, both of which being deleterious to an optimal functioning vein graft. Before loop construction, each vein must be thoroughly explored under loupe magnification, each branch should be separately ligated (e.g. metal clips will not suffice as these can slip away from a pulsating graft causing major postoperative bleeding or even flap loss). The choice of tunnelling should always be decided intraoperatively. While in thin patients, anatomical tunnelling under the medial soleus muscle within the deep posterior compartment of the shank is usually possible, adipose patients mostly require subfascial loop placement. Both ways, tunnels should be carefully prepared using blunt long instruments (either dressing forceps or special vascular graft tunnelling tools) inserted carefully and if possible under direct view. During anatomical tunnelling, rupture of collateral veins of the tibial posterior or peroneal artery can cause major bleeding. Thus, while easier to perform as the "perforator-to-perforator" principle, this technique can elicit a fair number of complications if not applied in the right clinical context. As both techniques can offer a proper means of soft tissue coverage in the ischaemic lower extremity, vascular workup in the context of type and extension of the tissue defect becomes instrumental for setting the correct indication for reconstruction. For massive infected wounds with exposed bone in the absence of adequate vascular support for the affected limb, primary amputation should always be considered.

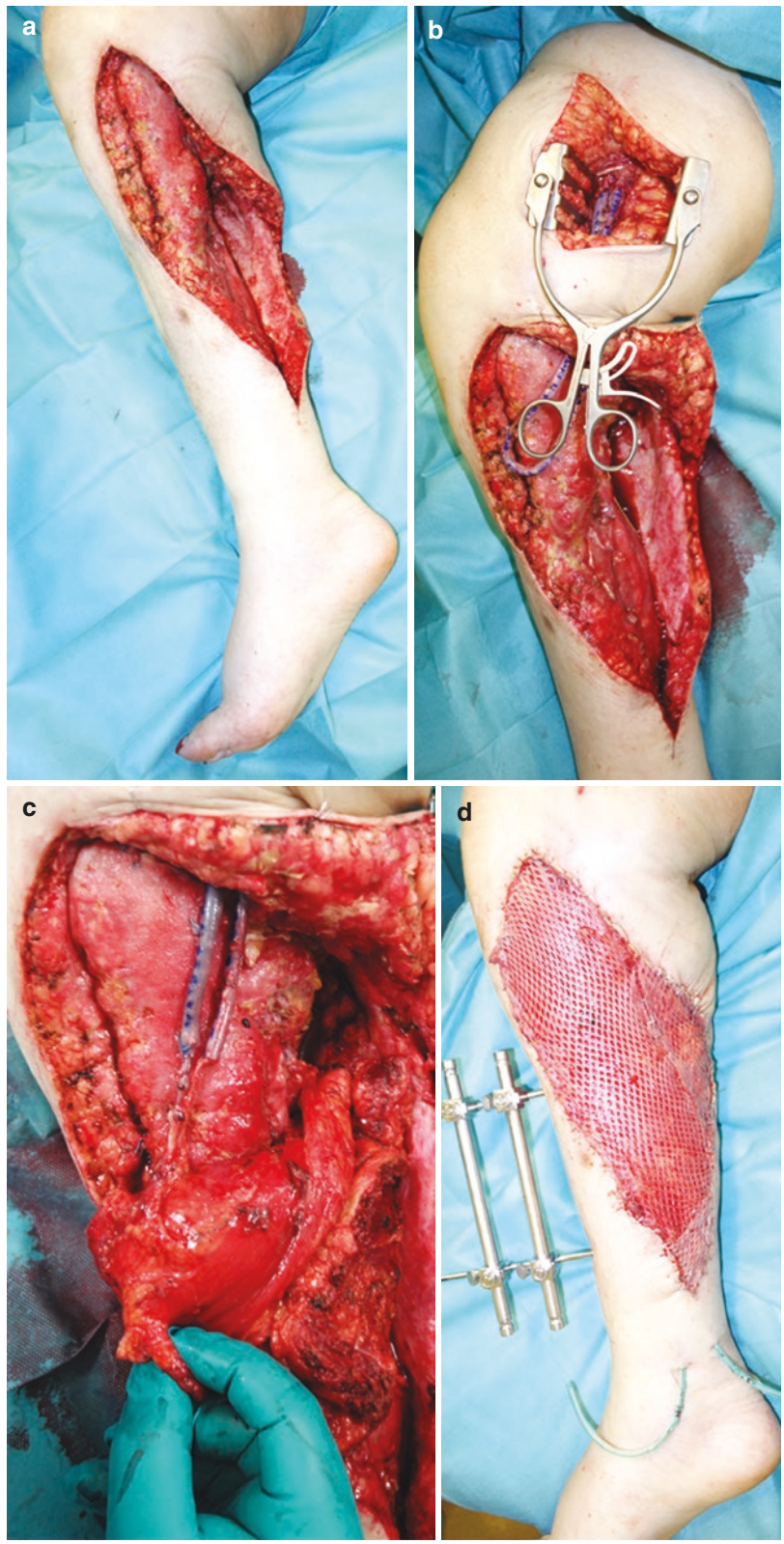

Fig. 11.10 Patient with massive soft tissue defect after open knee joint dislocation, rupture and consecutive repair of the popliteal artery (**a**). Using the contralateral great saphenous vein, a vascular loop was created and anastomosed proximal to the zone of injury to the distal part of the superficial femoral artery and vein (**b**). Consequent subcutaneous tunnelling provided optimal recipient vessels for a free latissimus dorsi muscle (**c**) for proper filling of the dead spaces and contour reconstruction of the medial shank (**d**—*final aspect with muscle covered using a split skin graft*)

Key Point

Reconstruction of the diabetic extremity poses several major challenges, primarily due to lack of adequate recipient vessels.

Provided one is able to perform it, the "perforator-to-perforator" approach should always be considered as the first choice when reconstructing the diabetic foot.

Autologous venous loops always offer a reliable way to create your own recipient vessels provided the ones initially chosen are too diseased to be used.

The "Drive-Through" Algorithm in Approaching Soft Tissue Defects and Reconstruction: A Logical Approach

Very often, the young plastic surgeon facing a complex wound will have difficulties in developing the optimal strategy for reconstruction, these ranging from choosing the right type of flap to elaborating an "escape" plan through other possible options suited for a particular defect. Here we aim to provide an insight on a logical approach the authors have developed and successfully used for over a decade in planning soft tissue reconstruction. This approach can be applied to soft tissue defects, including skin, subcutaneous tissue, tendons, vessels and bone or a combination thereof.

To begin with, it is fair to assume that the more distal defects on a given extremity, the more likely a free flap will be best suited for reconstruction. Basically, a tissue defect, once referred for consultation, will be thoroughly examined. Eventual comorbidities either directly related to the defect (e.g. PAD, extremity paralysis, tumour resection) or which might represent a direct source of possible complications and thus a negative outcome of the planned reconstruction are considered. In the case of lower extremity defects, the vascular status of the patient will be examined in detail using either plain subtraction angiography or angio-CT of the entire limb axis from the common iliac system to the foot arteries.

According to the body area, eventual comorbidities, and vascular and health status of the patient, all defects will be primarily categorised either as primary reconstructable (all conditions for performing tissue reconstruction are fulfilled), secondary reconstructable (e.g. vascular intervention needed prior to reconstruction) or non-reconstructable (e.g. high-risk patients) (Fig. 11.11).

All primary reconstructible defects are then "poured" further through the next funnel landing in either of the three following groups: (I) must local (Fig. 11.12)—defects which will be primarily planned for local flap reconstruction; (II) must see (Fig. 11.13)—defects which could be good amendable to a local flap; however, the final decision on which flap to use will be taken intraoperatively; (III) must free (Fig. 11.14)—defects which from the localisation, type and aetiology can only be reconstructed using a free flap.

Intraoperatively in all patients from the first category (must local), local flaps will be attempted as the first intention. If unfavourable anatomy or different defect properties (after radical debridement) occur, the plan will be changed either primary or in the following surgery to a free flap. Patients from the second category (must see) will primarily receive a free flap. However, if during debridement or exposure of recipient vessels, suitable perforator pedicles for a local flap are found, and the flap can be safely harvested without generating donor sited difficult to treat (e.g. exposure of tendon or bone units), the plan will be accordingly switched to a local rather than a free reconstructive solution. Patients from the

third category present with defects, which according to their localisation, dimensions and aetiology will be amendable only through free flaps regardless of possible favourable local anatomy for a local flap procedure.

The authors are confident that using this "drive-through" algorithm for one can achieve successful soft tissue reconstruction optimally tailored to each particular defect, all over the body. However, the user will need to already have attained several local and free flap techniques as well as have detailed knowledge of anatomy of the approached body area in order to effectively use this concept.

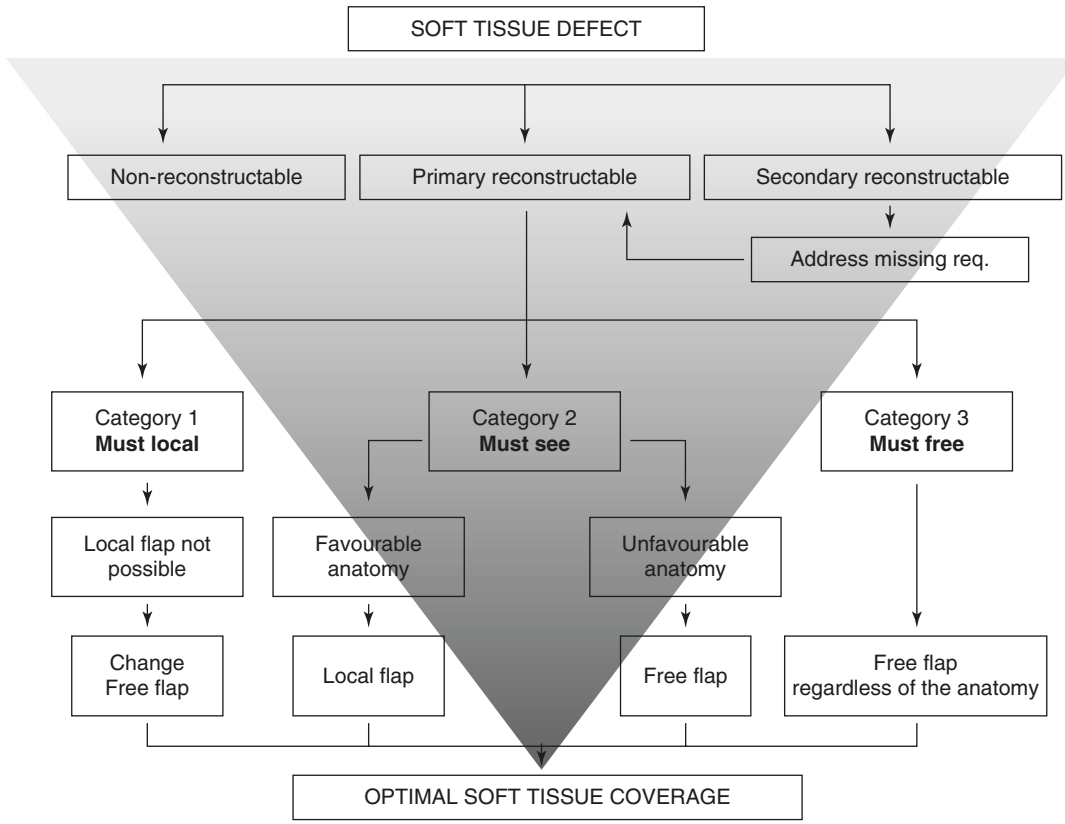

Fig. 11.11 The "drive-through" concept for approaching soft tissue reconstruction

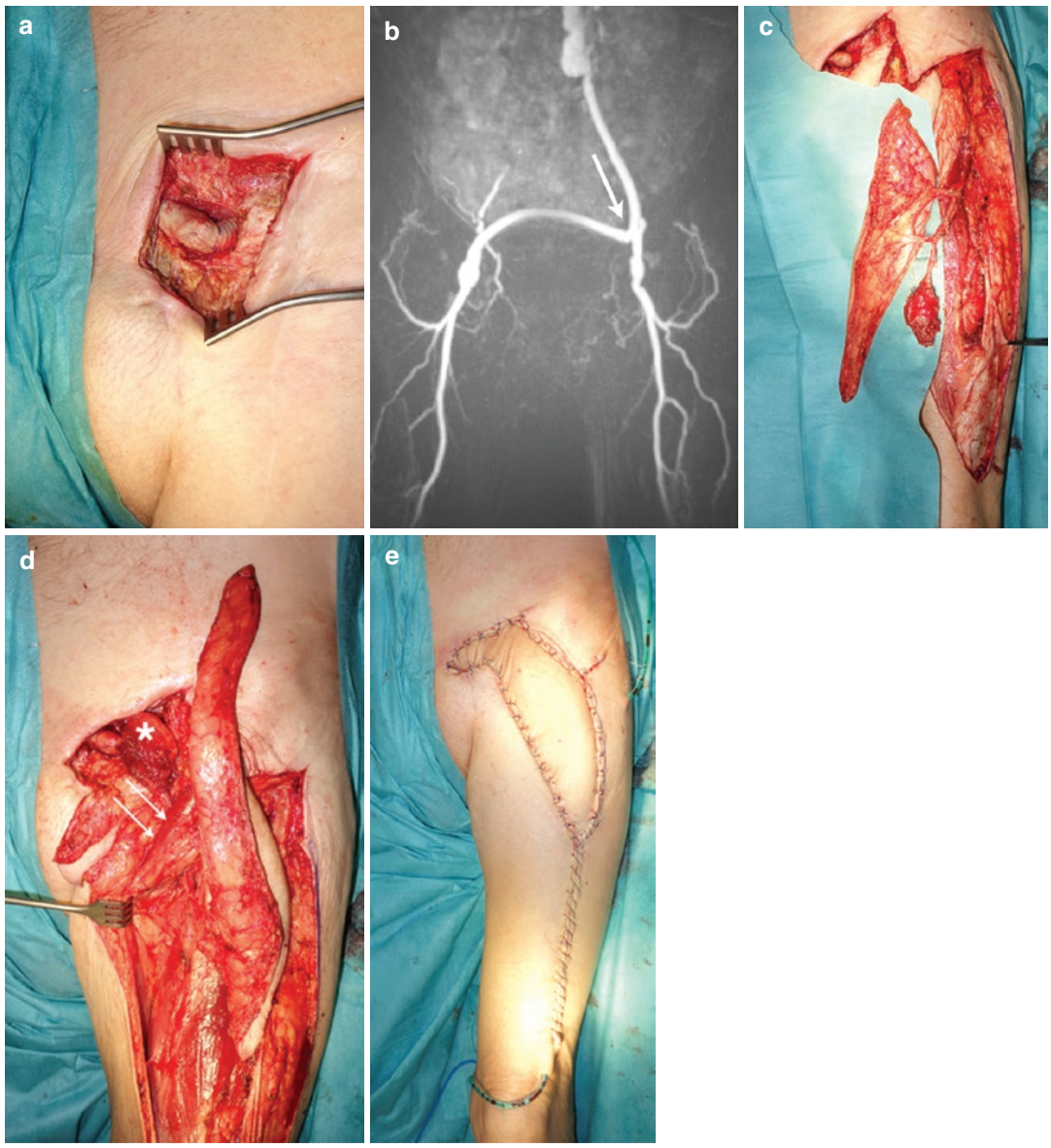

Fig. 11.12 Patient with wound breakdown and exposed vascular graft after explanation of an infected aortobifemoral dacron prosthesis (**a**). Vascular reconstruction through a left aortofemoral bypass completed with a cross-over biological coated jump graft extension to the right common femoral artery (**b**). The defect was reconstructed using a chimeric ALT flap (**c**) with a vastus lateralis muscular component (*) tunnelled under the sartorius muscle (*arrows*) to close the dead space around the exposed prosthesis (**d**) and the skin flap used to reconstruct the missing skin envelope of the groin (**e**)

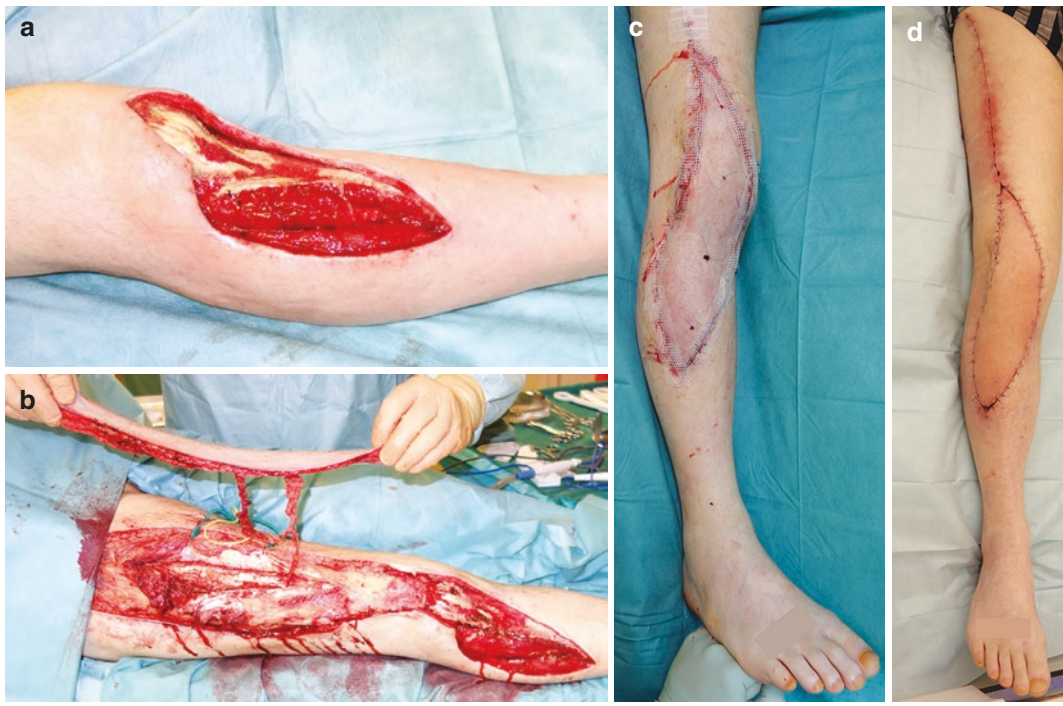

Fig. 11.13 Soft tissue defect of the knee and shank with exposed patellar tendon after heroin injection and massive infection (**a**). While harvesting a planned free ALT flap to cover the defect, a strong distal segment of the descendent branch of the lateral circumflex femoral artery was found and used as a retrograde pedicle for the ALT flap, which was rotated in a propeller manner to completely close the defect (**b**, **c**, **d**)

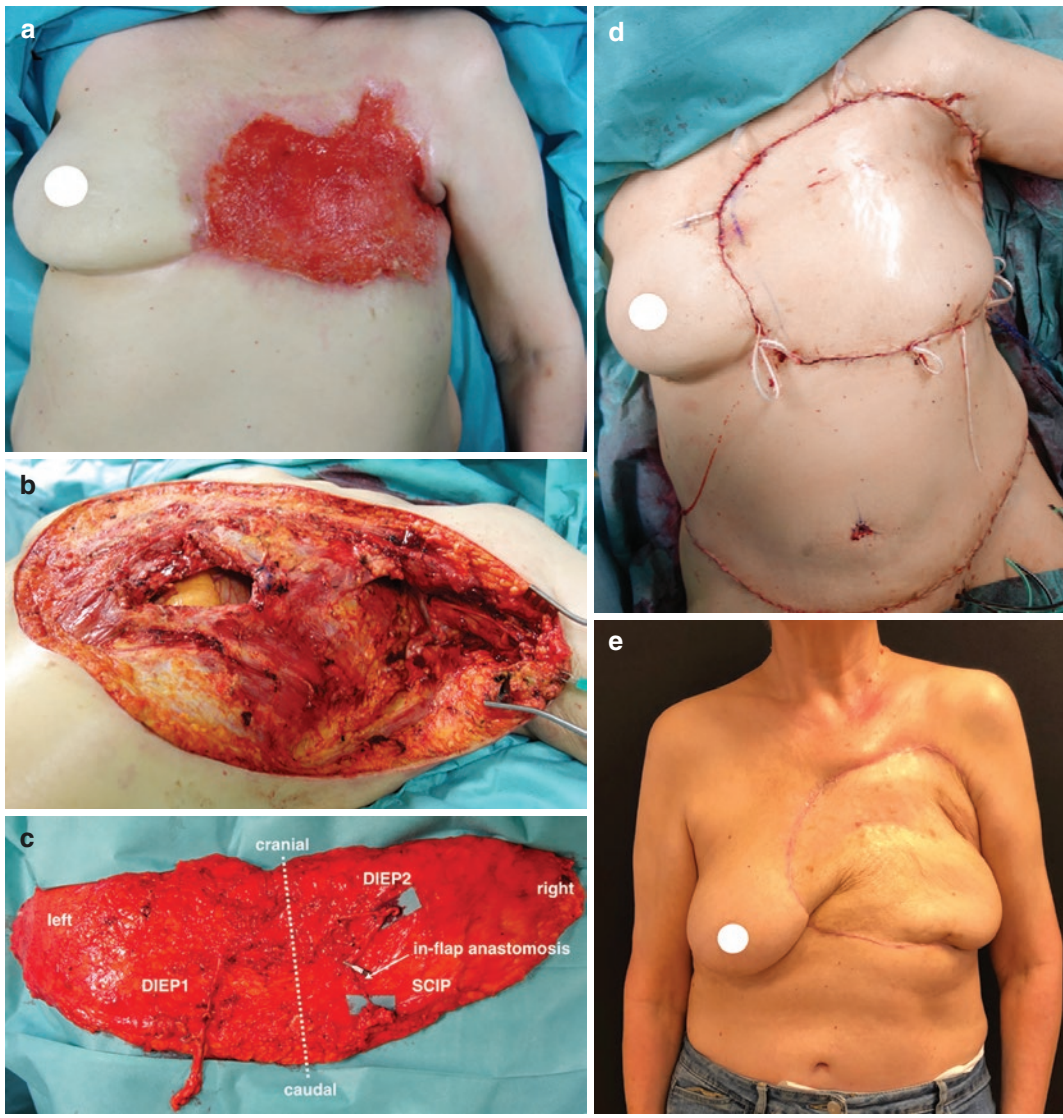

Fig. 11.14 Locally advanced erosive breast cancer with involvement of the thoracic wall (**a**). Radical resection with axillary clearance and preventive lymphovenous anastomosis (LymPHA approach nach Campisi [18]) (**b**). Compound double-DIEP (deep inferior epigastric artery perforator) with SCIP (superficial circumflex iliac artery perforator) flap with in-flap anastomosis between the SCIP pedicle and the cranial stump of the ipsilateral deep epigastric pedicle (**c**). Result immediately postoperative (**d**) and 1 year after reconstruction (**e**)

Key Point

Strive to develop your own dynamic approach to wound management and tissue reconstruction, based on progressive accumulation of technical knowledge and clinical experience.

Think out of the box and stay flexible. If the planed local flap just became undoable, switch to a free flap.

Do not use a certain technique only because everybody else reported good results with it. Always look back to your own experience and learn from your failures.

Ten Tips and Tricks for Efficient Microsurgical Tissue Reconstruction

1. Master your microsurgical skills through extensive training on experimental models as you will depend on flawless microvascular technique in OR.
2. Have at least one fasciocutaneous, one muscle and one bone flap you are confident performing as free flap as starting package on which you can build further your clinical experience.
3. Before you embark on supramicrosurgery and perforator flaps, consider learning first the basic workhorse flaps that are the foundations of modern reconstructive microsurgery as we know it today (e.g. flaps on the subscapular system/latissimus dorsi, serratus anterior, groin flap, fibula flap).
4. Regardless of your primary reconstructive plan, always have at least another one to two flap options you could use as a backup if you fail with your initial flap choice.
5. Use atraumatic technique and a bloodless field when preparing the recipient vessels. The presence of blood in the wound combined with exerting tension on the vessels will favour vessel spasm and possible thrombosis. When dealing with spasm, temporary clipping of the distal vessel with concomitant application of vasodilators (e.g. prostaglandin E2) will usually lead to rapid dilatation of the vessel segment needed for anastomosis.
6. In the presence of atherosclerosis, but no proper skills to approach perforator-to-perforator anastomosis, consider vascular loops. The vascular surgeon in the house can also eventually perform these.
7. The peroneal artery, usually the vascular axis to close last in PAD patients, offers an optimal recipient vessel both in its proximal and distal segment. Its distal segment can be easily approached lateral to the Achilles tendon or by subperiosteal dissection, osteotomy and removal of fibula shaft segment.
8. Both local and free flaps will adapt better to their new vascularisation pattern if held in a warm environment postoperatively. One solution is the use of warm-touch devices, which can provide a continuous warm air environment (38–40 °C) to the flap.
9. The use of external fixation to suspend the affected lower extremity after surgery will not only provide unrestricted access to the reconstructed area for flap monitoring but also prevent postoperative oedema and improve the venous outflow of the flap. It can be placed either on the tibia or over the ankle to one of the cuboid bones if immobilisation of the ankle joint is required after surgery.
10. Hourly control of your free flaps using both clinical (colour, temperature, capillary pulse) and Doppler examination within the first 5 days after surgery will help you dramatically improve your flap failure rates while increasing your efficiency in successfully revising problem flaps.

Take-Home Message

- Strive to reach the technically most challenging flaps after first mastering the basics (e.g. classical flap options, vascular approaches). This will keep the stress away and pave the way to your steady evolution as a reconstructive surgeon.
- Carefully evaluate any given tissue defect in the context of patient-related comorbidities as this is key to successful reconstruction.
- When considering soft tissue reconstruction in the lower extremity, never rely solely on the clinical presence of pulse. A thorough vascular check-up, ideally through subtraction angiography or angio-CT, will keep you out of trouble.
- Do not forget that sometimes a well-done amputation would bring more to a patient than the most complicated reconstructive plan.
- Free skin grafts do work. Do not be afraid to use them but rather educate yourself to indicate them in the right scenario.
- If you are not happy with the given recipient vessels, create your own using vascular loops. The additional OR time is definitely a good investment for the success of your surgery.
- Remember that the flap you just performed remains your responsibility also after surgery. Patient positioning in bed (e.g. preventing pressure sores), warm environment around the flap, pain control and standardised flap monitoring are key factors of utmost importance for a successful reconstruction.

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Part II

Plastic Surgery Approaches to Malformation

Craniofacial Malformations

12

Mario Zama and Maria Ida Rizzo

Background

Craniofacial malformations are relatively rare congenital conditions that exist in different degrees of severity and phenotypes. The etiopathogenesis is complex; it can involve chromosomal, environmental, Mendelian, and multifactorial factors. The majority of craniofacial malformations occur sporadically. Inheritance has a demonstrated role in a minority of them. Studies have shown that many environmental factors may contribute to the etiology of craniofacial malformation (e.g., radiation, infection, metabolic imbalances, and drugs and chemicals). The advent of the genetic knowledge about the exome sequencing approaches continues to produce new data, and in a few decades, this will review our current understanding of the etiology of many craniofacial malformations [1].

Craniofacial development happens between the fourth and the eighth week of gestation. Five prominences (the frontonasal and paired maxillary and mandibular) formed by neural crest migration surround the stomodeum (future oronasal region) (Fig. 12.1).

Two theories describe how embryologic errors result in cleft lip and palate: the failure of ectodermal fusion and the failure of mesodermal migration. Rare craniofacial clefts and the other craniofacial malformations may be produced by similar mechanisms. The fusion failure theory, proposed by Dursy and His, suggests that the free edges of the facial processes unite in the central region of the face. When epithelial contact is established between opposing facial processes, mesodermal penetration completes the fusion. Clefts are formed when fusion of facial processes fails. The failure of mesodermal penetration theory, proposed by Fleischmann and Veau, implicates the lack of neuroectoderm and mesoderm migration and penetration into the bilaminar ectodermal sheets as the cause of craniofacial clefts [2]. Newer studies of neuroembryology suggest that a direct relationship exists between the development of the nervous system and the facial structures (neuromeric theory) [3]. The embryonic central nervous system is seen as the master integrative agent of development. It develops in discrete segmental craniocaudal units of neural crest cells called neuro-

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meres. Craniofacial tissues develop from these neuromeres.

The clinical presentation includes isolated defects, sequences, and syndromes. Several specialties of the health profession are involved in the study and the treatment of craniofacial anomalies: plastic surgeons, geneticists, anatomists, embryologists, neurosurgeons, otolaryngologists, anesthesiologists, pediatricians, odontologist and orthodontists, speech pathologists and therapists, ophthalmologist, orthopedics, cleft nurses, psychologists, social workers, and other specialties if necessary.

Systems of classification have been arbitrary or could not be standardized because of clinical variabilities and genetic findings. Some malformations are identified according to the names of the authors who first described them (e.g., Goldenhar, Pierre Robin, and Pfeiffer). Other malformations are identified by their descriptive appearance (e.g., hemifacial microsomia, and hypertelorism) or based on anatomic topography (such as the branchial arch system) [4–6]. In 1976, the French plastic surgeon Paul Tessier presented a classification system in which a number is assigned to the site of each facial cleft (including both bone and soft tissues), based on its relationship to the sagittal midline. This descriptive system has become widely accepted because of the ease of recording, communication, and correlation between clinical appearance with surgical anatomy [5–8]. So, at present, the axial dysplasia of the craniofacial syndromes proposed by Tessier is the most widely used classification and presented in "Craniofacial Cleft" section of this chapter.

The most common congenital craniofacial anomaly is cleft lip and palate (0.6–2.13/1000 births). Craniofacial microsomia (also known as the first and second branchial arch syndrome or hemifacial microsomia) is the next most frequent congenital facial anomaly (0.18–0.33/1000 births). Craniosynostosis has various estimates of the incidence (0.4–1.6/1000 births). The incidence of the remaining craniofacial anomalies is not well documented because of their very low rate of occurrence (approximately 0.014–0.048/1000 births) [5–7].

Although a majority of patients with craniofacial malformations have no mental impairment, without appropriate staged surgical correction, social interaction may prove impossible. The history of human craniofacial malformations treatment is recent and following the success of Tessier in surgical correction of congenital deformities previously deemed untreatable. Many plastic surgeons from different countries rushed to Paris to study this modern craniofacial surgery. The pupils of Tessier, on returning to their countries, have established multidisciplinary craniofacial centers to care children suffering from craniofacial untreated anomalies, and they also have trained new pupils.

Key Point

Children who have craniofacial malformations require the skills of a multidisciplinary team for their assessment and treatment. The team includes several healthcare professionals who work together for a common purpose.

The exact etiology of craniofacial malformations, as well as the initial embryologic error, is not known.

Craniofacial development happens between the fourth and the eighth week of gestation. Five prominences formed by neural crest migration surround the stomodeum. The most accepted embryo pathogenesis theories are the failure of ectodermal fusion, the failure of mesodermal migration, and the neuromeric theory.

Many classification systems are proposed. The most widely accepted is the Tessier's axial classification for facial clefts, based on bone and soft tissue landmarks, which seems to have a direct relationship with neuromeric theory.

The most common craniofacial malformations are cleft lip and palate, craniofacial microsomia, and craniosynostosis. The incidence of the remaining craniofacial malformations (e.g., craniofacial clefts and craniofacial syndromes) is very low.

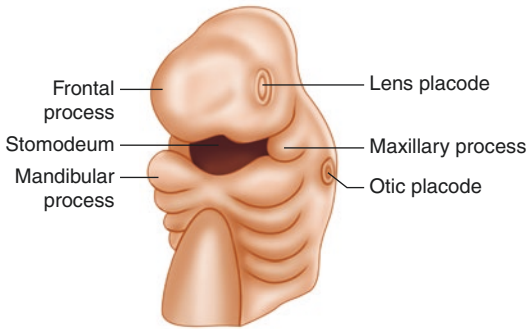


Fig. 12.1 Embryo in the fourth/fifth week

12.1 Introduction

Children with a complex craniofacial condition require a multidisciplinary craniofacial program that provides comprehensive, family-centered care from the time of diagnosis through surgery and long-term care. The multidisciplinary team should include the most experienced specialists in the country to guarantee the best care for children with anomalies of the face and skull, and, moreover, it should be affiliated to a Pediatric Craniofacial and Cleft Center.

Craniofacial malformations are relatively rare congenital disorders with complex etiopathogenesis, and different classifications are proposed. The state of knowledge and the literature review allow using the following didactic framework, whereby craniofacial malformations include

- Craniofacial clefts.
- Cleft lip and palate.
- Craniosynostosis.
- Craniofacial syndromes.
  - Syndromic craniosynostosis.
  - Facial syndromes.
  - Craniofacial microsomia.
  - Frontonasal malformations.
- Microtia.
- Micrognathia.

Although a majority of patients with craniofacial malformations have no mental impairment, without appropriate staged surgical correction, social interaction may be compromised.

Craniofacial surgeons should have great skill in the following topics:

- Cleft lip and palate treatment.
- Management of craniosynostosis.
- Management of craniofacial syndromes.
- Ear reconstruction.
- Glossectomy.

The present chapter briefly examines both the craniofacial pathologies and the surgical treatments.

Tips and Tricks

Remember to send a newborn with a craniofacial malformation to a Cleft/Craniofacial Center to have all the pediatric specialists and the craniofacial surgeons.

The multidisciplinary craniofacial program provides comprehensive, family-centered care from the time of diagnosis through surgery and long-term care. The multidisciplinary team should include the most experienced specialists in the country.

Craniofacial surgeons are trained in the reconstruction of both soft and bone tissues of the skull and face.

12.2 Craniofacial Clefts

Craniofacial clefts are among the most disfiguring of all facial anomalies, occur in different degrees of severity, and include distortions of cranium and face with deficiencies or excesses of tissues that cleave anatomic planes. Unilateral forms are the most common [3]. The majority occur sporadically. However, inheritance plays a role in some rare craniofacial clefts (e.g., a dominant gene defect, *TCOF1*, causes Treacher–Collins syndrome) [9].

In the Tessier classification system, a number is assigned to the site of each cleft, based on its relationship to the sagittal midline. The facial clefts are distributed around the orbit, the eyelids, the maxilla, and/or the lips [5–8]. Clefts of the soft tissues and clefts of the craniofacial skeleton may not always exactly coincide. A horizontal line can be drawn through the canthi as an equator to divide the cranial and facial portions of the cleft. Clefts develop according to constant axes, which are divided into 15 regions numbered 0–14 around the orbit. The clefts 0–7 (facial cleft) are found caudal to the orbital equator, and the 9–14 (cranial cleft) are found cephalad to the orbital equator. The number 8 cleft coincides with the equator and passes laterally from the lateral canthus [5–8] (Fig. 12.2). Because the cranial and facial clefts tend to follow the same axis, Tessier incorporated this concept as the keystone of his classification and with the analysis of the patient [5–8].

The *no.0–14 cleft* of Tessier is a median craniofacial dysraphia. It is comparable to the frontonasal dysplasia of Sedano [10], also referred to as centrofacial microsomia. The cleft involves the frontal bone, the ethmoid region with a duplication of the crista galli, the nose with a duplication of the septum and columella, the maxilla, and lip. A diastema separates the central incisors, and a cleft palate can be present.

The *no.0 cleft* usually results in hypertelorism, whereas, if agenesis or hypoplasia is the predominant malformation, a partial or total absence of the philtrum and the premaxilla can occur. The nose can be small, without columella, with nostrils that are laterally displaced, resulting often in a bifid nose. At the other extreme, a proboscis or arhinencephaly can be seen with the resultant orbital hypotelorism or cyclopia.

Prolongation of the *no.0 cleft* onto the mandible, or *no.30 cleft* of Tessier, could be represented in its minor form as a notch in the lower lip and

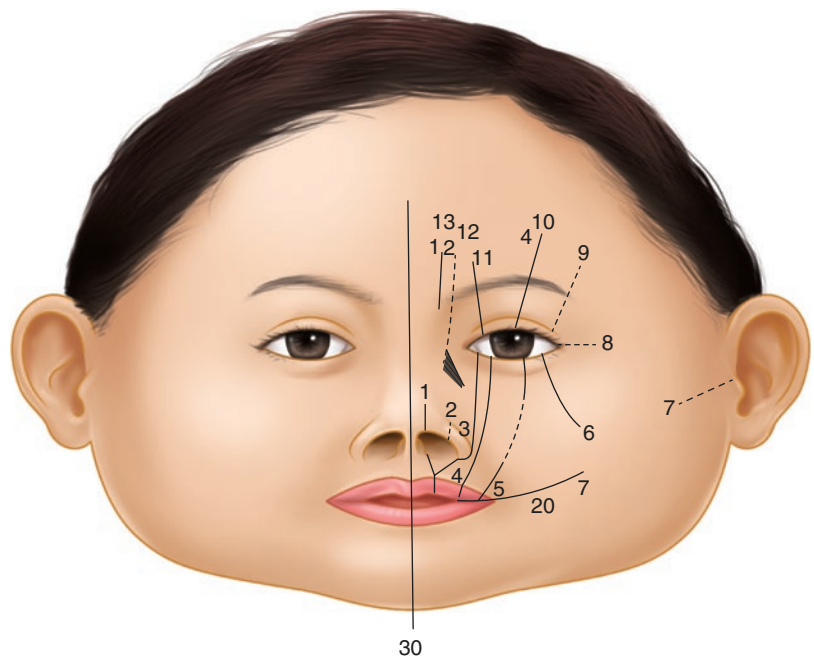


Fig. 12.2 Tessier's classification system

become progressively more severe by involving the mandible, tongue, chin, neck, hyoid bone, and even the sternum. The tongue is frequently bifid and bound to the mandible by a band of tissue. The cleft of the alveolus is located in the midline between the central incisors.

The Tessier *no.1 cleft* is a paramedian craniofacial cleft. The cleft passes through the soft tissues from the Cupid's bow region to the dome of the alar cartilage. If the no.1 cleft extends superiorly onto the frontal bone, it is referred to as the no.13 cleft. The olfactory groove of the cribriform plate becomes widened, resulting in hypertelorism. Inferiorly, the no.1 cleft continues through the alveolar bone.

The Tessier *no.2 cleft* is a paranasal location that crosses the soft tissue of the nose, the alar, and the lip. Distortion of the eyebrow occurs if the cleft continues into the frontal region as a no.12 cleft. The nasolacrimal system is not disturbed as in the no.3 cleft. Enlargement of the ethmoidal labyrinth results in hypertelorism. Usually, the glabella is flattened, and the frontal sinus is enlarged.

The Tessier *no.3 cleft* is a medial orbitomaxillary cleft. Through the bony skeleton, it traverses obliquely across the lacrimal groove. The frontal process of the maxilla is often absent. Through the soft tissue, the cleft passes across the lower eyelid, the alar base, the nasolabial fold, and the lip and alveolar ridge. The mildest form of this cleft is represented by a coloboma of the nasal ala. The vertical distance between the alar base and the medial canthus is disturbed, and the nasolacrimal duct is obliterated. The severest form of ocular involvement is microphthalmia. The Tessier no.11 cleft represents the superior extension of this cleft.

The Tessier *no.4 cleft* is a median orbitomaxillary cleft. Through the soft tissues, it traverses almost vertically the lip, eyelids, and eyebrow passing laterally to the alar base. The nasolacrimal canal and lacrimal sac remain intact. In the severest forms, there is anophthalmia. The cleft on the maxilla passes medial to the infraorbital foramen and produces a bony defect in the inferior orbital rim and floor, with consequently orbital dystopia. In the complete form, the orbital cavity, maxillary sinus, and oral cavity are all confluent. The Tessier no.10 cleft is the superior extension of this cleft.

The Tessier *no.5 cleft* is the rarest of the oblique facial clefts. The cleft of the lip is found medial to the angle of the mouth but not at the commissure. It courses upward across the lateral cheek to and between the eyelid. The vertical distance between the mouth and lower eyelid is decreased, resulting in a pulling of the upper lid and lower eyelid toward each other. Microphthalmia is infrequently present. The bony malformation parallels the path of the cleft. The alveolar portion of the cleft is found in the premolar region. Passing lateral to the infraorbital foramen, the cleft enters the orbital floor with prolapse of the orbital contents.

The Tessier *no.6 cleft* is characteristically recognized as the incomplete form of the Treacher–Collins–Franceschetti syndrome. The external ears can be almost normal, but a hearing deficit is often present. The antimongoloid slant of the palpebral fissures is milder. The bony malformations of this cleft set it apart from the complete form of the syndrome: the malar bone is present but hypoplastic with an intact zygomatic arch. The cleft runs between the hypoplastic malar bone and the maxilla in the region of the zygomaticomaxillary suture.

The Tessier *no.7 cleft* is the most common. It groups several anomalies (necrotic facial dysplasia, hemifacial microsomia and microtia, otomandibular dysostosis, unilateral facial agenesis, auriculobranchiogenic dysplasia, hemignathia and microtia syndrome, lateral/transverse facial clefts, and oro-mandibular-auricular syndrome). Goldenhar's syndrome is also comparable in many of its features but, in addition, involves epibulbar cysts and vertebral anomalies. The clinical expression of the no.7 cleft varies from a slight facial asymmetry with minimal auricular malformations to severe ear malformations. Hypoplasia of the maxilla, temporal bone, soft palate, and tongue has been seen. The parotid gland can be absent. The fifth and seventh nerves can be involved, along with their innervated musculature, represented by weakness of masticatory and facial expression muscles. As a result of the

hypoplastic maxilla and the reduced height of the mandibular ramus, there is a defect of the occlusal plane. In the complete form, the mandibular condyle and ramus can be missing.

The Tessier *no.8 cleft* is very rare. The soft tissue cleft begins at the lateral canthus and extends toward the temporal region. The lateral coloboma can be occupied by a dermatocele.

Tessier has noted that there is a unique bilateral *combination of clefts no.6–7-8*, known as Treacher–Collins syndrome, Franceschetti–Zwahlen–Klein syndrome, or mandibulofacial dysostosis. The hallmark of this syndrome is the absent malar bone. Soft tissue malformations result in coloboma of the lower eyelid with partial deficiency of the eyelashes; the eyelid coloboma and antimongoloid slant of the palpebral fissure; absence of the lateral orbital rim with associated lateral canthal dystopia; absence of the zygomatic arch, fusion, and hypoplasia of masseter and temporalis muscles, microtia with conductive hearing loss; and mandibular deficiency with retrognathia and open bite.

The Tessier *no.9 cleft* is a superolateral orbital cleft that continues into the frontotemporal cranium, traversing laterally the upper eyelid. This cranial cleft corresponds to facial cleft no.5.

The Tessier *no.10 cleft* is a central superior orbital cleft that extends across the roof of the orbit and the frontal bone. The soft tissue deformity is characterized by the central coloboma of the upper eyelid. The eyelid and eyebrow are divided into two portions. Its severest form occurs as a lack of eyelids. The no.10 cleft appears to be the more superior cranial equivalent of facial cleft no.4. Both clefts can have a coloboma of the iris.

The Tessier *no.11 cleft* is a superomedial orbital cleft. The coloboma of the upper eyelid can extend to the eyebrow and into the frontal hairline. It is the cranial equivalent of facial cleft no.3. It can pass lateral to the ethmoid bone with a cleft in the eyebrow and orbital rim, or it can pass through the ethmoid labyrinth, resulting in orbital hypertelorism.

The Tessier *no.12 cleft* is located medial to the medial canthus, passing through the frontal process of the maxilla and the nasal bone. This flattening results in telecanthus. The ethmoidal labyrinth is increased resulting in hypertelorism. The cleft in the soft tissues extends from the root of the eyebrows and into the frontal hairline. The cranial equivalent of the no.12 cleft is facial cleft no.2.

The Tessier *no.13 cleft* corresponds to the cranial extension of the no.1 facial cleft. The distinctive features are the widening of the olfactory grooves and cribriform plate, resulting in hypertelorism; an omega-shaped disruption of the hairline; and lateral displacement of the eyelid and eyebrow.

The Tessier *no.14 cleft*, as opposed to the no.0 cleft, is always associated with hypertelorism. The orbits tend to remain in the fetal position, the cranium is bifidum or displaced by a large medial frontal encephalocele, the crista galli is widened or duplicated, and the ethmoid bone prolapses caudally.

This completes the axial dysplasia of the craniofacial clefts proposed by Tessier [5–8], based on bone and soft tissue landmarks, which seems to have a direct relationship with neuromeric theory.

Key Point

Craniofacial clefts are among the most disfiguring of all craniofacial anomalies.

Tessier's classification is the most accepted classification system. It divided the clefts into 15 regions numbered 0–14 around the orbit, in relationship to the sagittal midline. Clefts 0–7 (facial cleft) are caudal to the orbital equator (the horizontal line drawn through the canthi); 9–14 (cranial cleft) are cephalad to the orbital equator; and the Tessier no.8 cleft coincides with the equator and passes laterally from the lateral canthus.

12.3 Cleft Lip and Palate

Cleft lip and palate is the most common congenital facial anomaly. The incidence ranges from 0.6 to 2.13 per 1000 births [4]. Cleft lip—with or

without cleft palate—is seen more commonly in males, while isolated cleft palate has a higher incidence in females. Asians have the highest incidence, while Africans have been found to have the lowest incidence. It may be associated with syndromes but more frequently occur sporadically. Cleft lip may be unilateral (right or left sided) or bilateral, complete or incomplete, with or without cleft palate. The most used classification systems are to follow:

– The Kernahan striped Y is the most used diagrammatic classification system that describes cleft anatomy and severity [11]. By convention, the primary palate consists of premaxilla, anterior septum, and soft tissues of the central part of the lip (philtrum). The secondary palate is separated from the primary palate by the incisive foramen and consists of the remaining hard palate, the soft palate, and the uvula [12]. The limitation of the Kernahan Y classification is that clefts of the secondary palate cannot be classified into right or left sides. So, the Y classification was modified into a better numeric system (Fig. 12.3), in which clefts of the primary palate anterior to the incisive foramen are numbered 1–5 and 11–15. Clefts of the secondary palate posterior to the incisive foramen are numbered 6–9 and 16–19 [13].

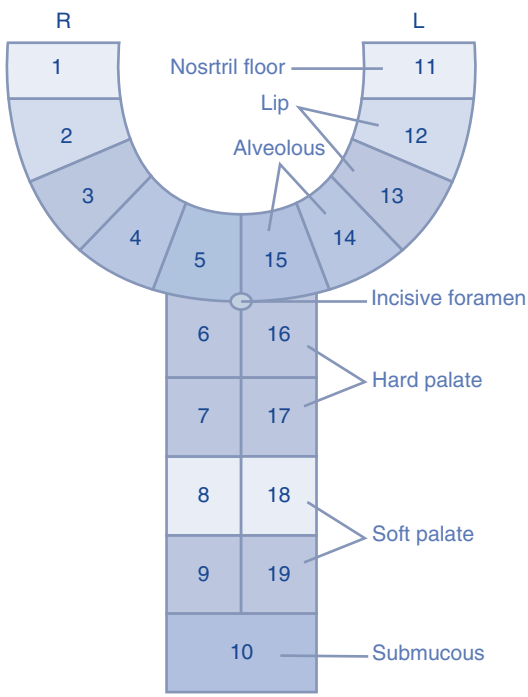


Fig. 12.3 Kernahan's striped Y classification modified

Berkowitz has suggested that the numerous morphologic varieties of cleft lip and palate may segregate into four categories: a) clefts involving the lip and alveolus; b) clefts involving the primary palate (lip) and secondary palate; c) clefts involving only the secondary palate; and d) clefts involving congenital insufficiency of the palate (velopharyngeal dysfunction, submucous cleft palate) [14].

Veau described a classification divided into four groups: (1) cleft of the soft palate; (2) cleft of the hard and soft palates up the incisive foramen; (3) complete unilateral cleft; and (4) complete bilateral cleft [15] (Fig. 12.4).

The American Association for Cleft Palate Rehabilitation divides all clefts into two major categories: prepalate (lip and alveolar process to incisive foramen) and palate (soft palate, hard palate to incisive foramen) [16].

Clinically, cleft lip presents several osseous and soft tissue dysmorphology: the premaxilla is projecting (and rotated in unilateral form); the lateral maxillary elements are retropositioned; the orbicularis oris muscle inserts into the alar wing; the philtrum is short; the nasal alar cartilage on the cleft side is displaced and flattened; the tip of the nose is deviated toward the noncleft side; the septum is dislocated out of the vomerine groove; the alar base is rotated; the columella is distorted; and vestibular lining is deficient.

Cleft lip and palate may show different severity ranging from a submucous cleft palate, where the mucosa is intact, but the muscles fail to fuse on the midline, to a complete cleft of the soft palate, hard palate, alveolus, and lip.

However, approaching this anomaly, it is mandatory to know the aberrant anatomy in alveolar and palatal cleft. The alveolar process is the ridge of the bone on the maxilla that provides support for the teeth. This bone develops with tooth eruption and resorbs when teeth are lost. Palate clefts form along the epithelial fusion plane between the premaxilla and the lateral segments of the

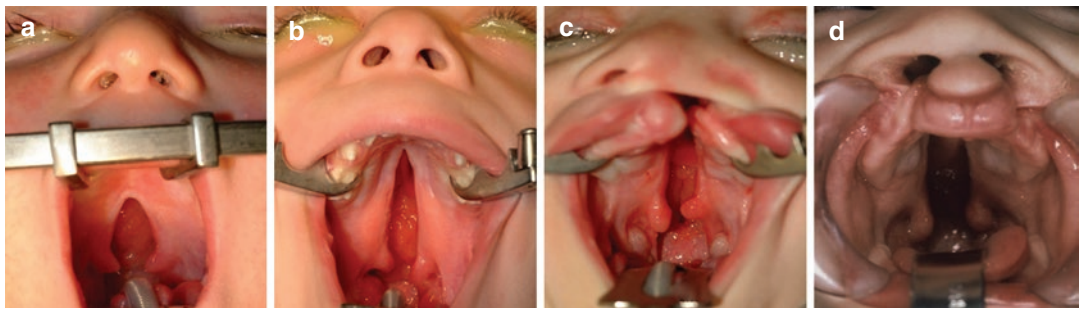


Fig. 12.4 (**a**) Cleft soft palate; (**b**) cleft and hard palate to the incisive foramen; (**c**) complete unilateral palate, alveolus and lip; (**d**) complete bilateral palate, alveolus and lip

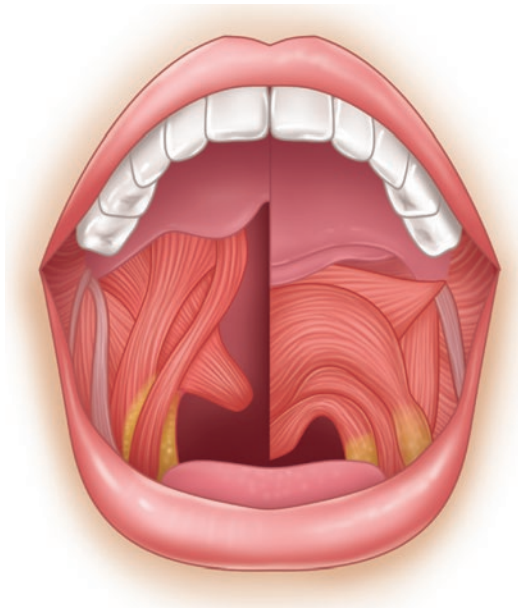


Fig. 12.5 Muscle displacement in the cleft soft palate

maxilla: this is the reason for the frequent absence of the lateral incisor on the cleft side [17].

In hard palate clefts, the vomer can be seen in the midline, inside the nasal cavity. In a unilateral cleft palate, the vomer remains attached to the noncleft side.

When a cleft of the soft palate is present, the muscles are displaced anterolaterally, along the cleft margins (Fig. 12.5), while the palate aponeurosis is displaced laterally [18].

Cleft lip can be diagnosed in the prenatal period by ultrasound, while the diagnosis of the cleft palate is usually made at birth. At diagnosis, it is essential to send parents to a cleft center for counseling about feeding and treatment plans. The cleft team will teach parents about feeding techniques to overcome the difficulties in creating negative pressure due to the direct communication between oral and nasal cavity. Moreover, they will become aware that their child will be at the center of the care of a multidisciplinary team, which will follow him from infancy to adulthood.

Submucosal cleft palate generally goes undiagnosed in the neonate; it is often detected incidentally after investigating for hypernasal speech. It determines a velopharyngeal insufficiency and can be associated with bifid uvula, translucent velar zone, presence of a bony notch in the posterior edge of the hard palate, otitis media, and speech impairment [19].

Key Point

Cleft lip and palate is the most common congenital facial anomaly. The range of severity varies from submucous cleft palate to complete cleft of soft and hard palate along with cleft of alveolus and lip.

Cleft lip can be diagnosed in the prenatal period by ultrasound, while the diagnosis of cleft palate is usually made at birth. Submucosal cleft palate can have a late diagnosis.

Several classification systems exist. The most important are Kernahan striped Y, Berkowitz, and Veau.

12.4 Craniosynostosis

Craniosynostosis is a craniofacial deformity caused by the premature closure of one or more of the cranial sutures. It represents one of the

major groups of congenital craniofacial malformations. Virchow, in 1851, was the first to coin the word *craniostenosis*. The term *craniosynostosis* has been introduced recently to describe the process of premature fusion, with craniostenosis being the result.

There are several different types of craniosynostosis. The simple form refers to the involvement of one suture being prematurely fused, whereas the complex form involves synostosis of two or more sutures [20]. All of them have a typical phenotypic expression (Table 12.1).

Craniosynostosis with single-suture synostosis includes metopic, coronal, sagittal, and lambdoid synostosis. These deformities generally appear to be isolated and therefore are named *nonsyndromic*. The isolated craniosynostosis form is present in patients who usually have no other abnormalities. The severity of the resultant deformity is directly proportional to the area of suture involved. The range of facial deformation can be minimal, as in the scaphocephaly malformation with premature closure of the sagittal suture, to greater, as noted in trigonocephaly with premature closure of the metopic suture.

Sagittal synostosis is the most frequent nonsyndromic craniosynostosis. It is known as scaphocephaly. It is more common in the male. Fusion of the sagittal suture impairs expansion of skull width, which is compensated by excessive skull length. This increase of the cranial anteroposterior diameter includes an expansion of the anterior and posterior fossae.

Unilateral coronal synostosis is the second most frequent nonsyndromic craniosynostosis. It is known as anterior plagiocephaly. It is more common in females and has a notable impact on facial growth. The frontal region is more deformed than the occiput, with recession of the forehead ipsilateral to the synostosis and protrusion contralaterally. The major facial deformity consists of right–left asymmetries and deviation of the midline (nose, lips, and chin).

Metopic synostosis is the third most frequent nonsyndromic craniosynostosis and is known as trigonocephaly. It is more common in the male. Patients are considered the most at risk for cognitive or behavioral impairment. The cranium has a triangular shape with a midfrontal keel, bifrontotemporal narrowing, and parietal-occipital protrusion. The face also is distinctive due to excessive narrowing of the interorbital space: orbital hypotelorism, epicanthal folds, and low nasal dorsum.

Complete or bilateral coronal synostosis is known as brachicephaly because of the short head shape. The cranium has a decreased anteroposterior diameter and an increased temporoparietal width. The facies are characteristic: the forehead is usually high with cephalad prominence that protrudes beyond the brow recession and is excessively broad. There is superior exorbitism due to the shortness of the anterior cranial base and orbits. Bilateral coronal synostosis can be nonsyndromic, although it is more commonly associated with syndromic craniosynostoses. It is more common in females.

Lambdoid synostosis is the less common nonsyndromic craniosynostosis. Generally, it is unilateral and is known as posterior plagiocephaly. It is more common in the male. The cranium is asymmetric and the primary dysmorphism is in the occiput. The mastoid projects more caudally. Frontal bone, eyebrows, and orbits have minor asymmetry with nasal and chin deviation. Posterior plagiocephaly must be differentiated from deformational plagiocephaly that is a positional skull deformity associated with nonsynostotic causes, most commonly with sleep position.

Key Point

Craniosynostosis results from a premature closure of one or more of the cranial sutures and has a typical phenotypic expression.

Craniosynostosis with single-suture synostosis includes metopic, coronal, sagittal, and lambdoid synostosis. These deformities generally are isolated and so are nonsyndromic; instead, syndromic craniosynostosis is characterized by multiple malformations. Nonsyndromic craniosynostosis is known as scaphocephaly, plagiocephaly, trigonocephaly, and brachycephaly, in order of incidence.

Deformational plagiocephaly is a nonsynostotic positional skull deformation associated most commonly with sleep position.

Table 12.1 Phenotypic expression of craniosynostosis

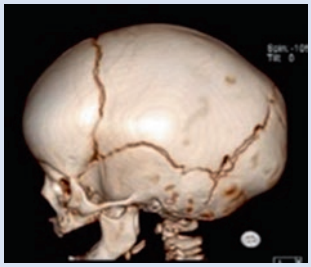
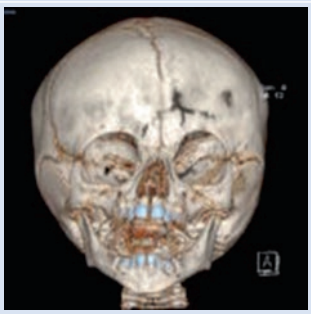
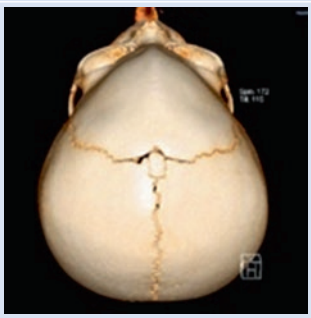
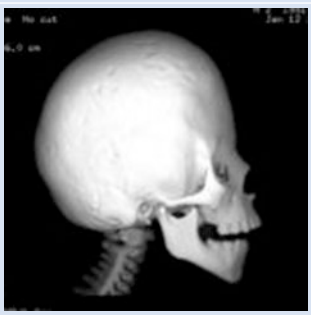
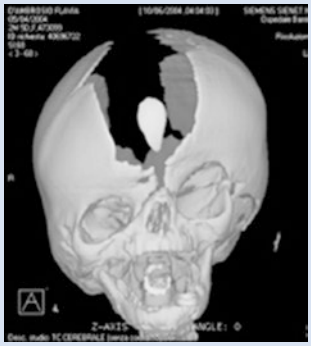
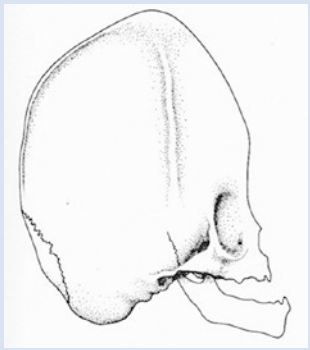
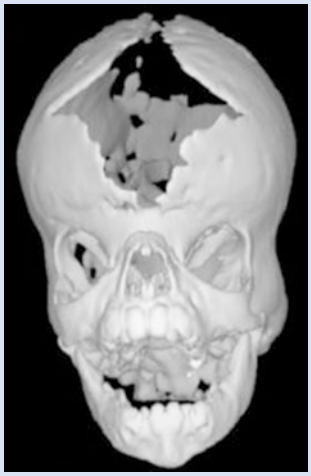
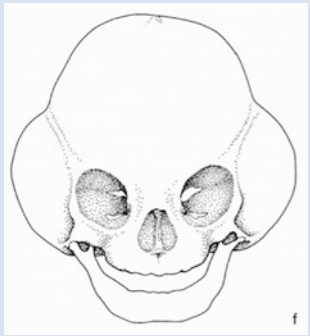
Name	Synostotic suture	CT features	Head shape	Incidence
Scaphocephaly	Sagittal		Boat head	1:5000
Plagiocephaly	Unilateral coronal (anterior plagiocephaly) Unilateral lambdoid (posterior plagiocephaly)		Twisted head	1:10000
Trigonocephaly	Metopic		Triangle head	1:15000
Brachycephaly	Coronal		Short head	1:20000

Table 12.1 (continued)

Name	Synostotic suture	CT features	Head shape	Incidence
Acrocephaly	Multiple		Peak head	>1:50000
Oxycephaly	Multiple		Point head	
Turricephaly	Multiple		Tower head	
Kleeblattschädel/ pansynostosis	All		Cloverleaf skull	

12.5 Craniofacial Syndromes

Craniofacial syndromes include syndromic craniosynostosis, facial syndromes, craniofacial microsomia, and frontonasal malformation. At present, there are over 150 craniofacial syndromes, with new syndromes being described every year [5]. A syndrome is traditionally characterized by multiple malformations that occur during fetal development. In genetics, a syndrome represents multiple malformations occurring in embryonically noncontiguous areas.

Many syndromes have multiple phenotypic expressions and different degrees of severity. Some craniofacial syndromes are readily identifiable by their appearance (e.g., Treacher–Collins–Franceschetti syndrome, craniofacial microsomia, Apert syndrome, and Crouzon disease), and their diagnosis is based on clinical observation and diagnostic imaging. For other syndromes, diagnosis is much more difficult (e.g., Stickler syndrome, 22q deletion including DiGeorge syndrome and velocardiofacial syndrome, Sathre–Chotzen and Jackson–Weiss syndromes), and genetic analyses are essential for correct assessment.

Children who have complex craniofacial anomalies require the skills of a variety of medical professionals for their assessment and treatment. The multidisciplinary team includes plastic surgeons, pediatricians, neurosurgeons, otolaryngologists, orthodontists, speech pathologists, social workers, orthopedics, ophthalmologists, geneticists, and other specialists. The team must be coordinated and act in a dedicated center.

12.5.1 Syndromic Craniosynostosis

Syndromic craniosynostosis occurs in patients with other primary defects of morphogenesis (as in Carpenter's syndrome, in which polysyndactyly and congenital heart defects accompany the craniosynostosis). The severity of the deformities is directly proportional to the area involved. The range of facial deformation goes from minimal to severe, as in the Kleeblattschadel deformity or craniofacial dysostosis syndromes, in which multiple sutures are involved [4].

Syndromic craniosynostosis may be classified as primary or secondary type. In primary craniosynostosis, the sutures prematurely fuse as a result of a genetic predisposition. In secondary craniosynostosis, suture closure is secondary to a known disorder, such as one of certain hematologic disorders (thalassemia), metabolic disorders (hyperthyroidism), or other malformations (microcephaly) [21]. This classification, proposed by Cohen, based on clinical similarities and genetic transmission, groups the anomalies into 11 chromosomal syndromes that have craniosynostosis as a variable feature and 57 known syndromes with craniosynostosis [21].

Crouzon's syndrome is one of the best-known syndromic craniosynostosis characterized by premature synostosis of the coronal suture and, at times, the sagittal-lambdoidal sutures. The deformity results in a foreshortened cranial base and a retropositioned frontal bone. The midface is hypoplastic and retruded, with exorbitism, mild hypertelorism, orbital proptosis, retropositioned soft palate, and airway obstruction. If the exorbitism is severe, exposure keratitis can result. Intelligence is usually normal, but if the malformation is severe, an increase in intracranial pressure can result, with concomitant secondary effects in cerebration and vision. This syndrome has an autosomal dominant inheritance pattern. It is caused by multiple mutations in the FGFR2 gene.

Apert's syndrome, or acrocephalosyndactyly, is one of the more severe and distinctive craniofacial syndromes. The coronal sutures are premature synostosis, resulting in brachycephaly; the sagittal and lambdoidal sutures can also contribute to the deformity. The face has a high flat forehead. The exorbitism is sometimes milder than that seen in Crouzon's syndrome, but there is a greater degree of hypertelorism. Divergent strabismus and exophoria are also present. The midface is hypoplastic. Soft palate cleft can occur, as well as a constricted palate. The occipital bone is flattened. Syndactyly of both the hands and the feet in a symmetric distribution is a hallmark of the syndrome. May be some degree of mental

retardation. This syndrome is generally sporadic, but it can be inherited in an autosomal dominant pattern.

Pfeiffer syndrome has facial features generally closer to the Crouzon syndrome, but the deformities are distinct. The coronal suture is the primary site of premature synostosis, resulting in the typical hypoplastic midface with a turribrachycephaly cranium. The hallmark of this syndrome is manifested by the digital anomalies, with the thumb and great toe being broad and directed in a varus direction. According to Cohen, three degrees of severity exist: Type I with mild hypertelorism and exorbitism, minimal proptosis, growth expectation generally good, and normal intelligence; Type II with more severe midface deficiency, severe proptosis, cloverleaf skull, hydrocephalus, and elbow ankylosis; Type III is similar to type II without cloverleaf skull deformity but with severe proptosis, neurologic impairment, and a limited life span. This syndrome has an autosomal dominant pattern with incomplete penetrance.

Saethre–Chotzen syndrome presents an acrocephalic cranial configuration as a result of premature synostosis of the coronal suture and a facial asymmetry (deviation of the nasal septum, low frontal hairline, and upper eyelid ptosis). The nose appears beaked, or there is an absence of the frontonasal angle. The limb anomalies associated are brachydactyly and syndactyly. This syndrome has an autosomal dominant pattern with high penetrance.

Jackson–Weiss syndrome presents craniosynostosis, midface hypoplasia, and anomalies of the feet. It is similar to all of the acrocephalosyndactylies; thus, the key for the diagnosis is molecular differentiation. It has an autosomal dominant inheritance.

Carpenter's syndrome presents variable craniosynostosis and complex facial deformities. The premature synostosis of the coronal suture causes an acrocephalopolysyndactyly deformity. When unequal sutural closures are present, there is an asymmetrical tower-shaped skull deformity. Polydactyly is present, and retardation and heart malformations can be present.

Kleeblattschadel deformity or cloverleaf skull is a severe form of pansynostosis where the skull appears trilobed secondary to the premature synostosis of varying combinations of the temporoparietal, coronal, lambdoidal, and metopic sutures. Hydrocephalus and hypoplastic midface with exorbitism are present. A high mortality rate is associated with this autosomal recessive anomaly.

Muenke syndrome, also known as FGFR3-associated coronal synostosis syndrome, is a genetic disorder characterized by coronal craniosynostosis (short skull with increased vertical height and very tall and wide forehead), midface hypoplasia (decreased growth of the midface), and hypertelorism (wide-set eyes).

Opitz syndrome, also known as oculo-genito-laryngeal syndrome and BBB/G compound syndrome, is a genetic condition characterized by facial anomalies (such as small jaw, ear abnormalities, prominent forehead, widely spaced eyes), trigonocephaly, cleft lip and/or palate (about ¼ of all children with this syndrome), hypospadias in males, and respiratory and heart defects. Brain malformations can be associated. There are two forms of inheritance: X-linked and autosomal dominant that is caused by a defect on the 22nd chromosome, so this form is classified as a part of the larger condition named 22q11.2 deletion syndrome.

12.5.2 Facial Syndromes

The facial syndromes include syndromic deformities without craniosynostosis.

Treacher–Collins or Franceschetti syndrome (also known as mandibulofacial dysostosis) has typical features (Fig. 12.6), with a deformity centered around the middle portion of the face, consistent with craniofacial cleft (Tessier no.6–8). The hallmark of this syndrome is the absent malar bone, with lower later orbit. Maxilla is caudally rotated; consequently, the micrognathic mandible rotates clockwise, producing a retrognathic mandible with an open bite. Soft tissue malformations result in a coloboma of the lower

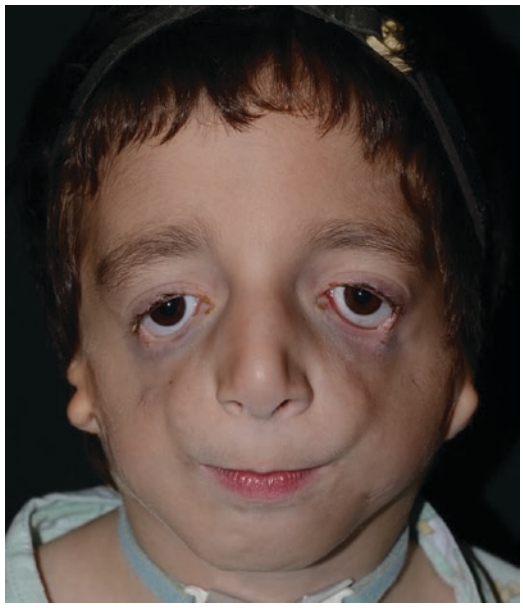


Fig. 12.6 Treacher–Collins–Franceschetti syndrome

eyelid and occasionally deficiency. The absence of the zygomatic arch results in a fusion and hypoplasia of the masseter and temporalis muscles, otic malformation, microtia, and mandibular deficiencies. The lack of bony zygomatic support results in the eyelid coloboma and the antimongoloid slant of the palpebral fissure and lateral canthal dystopia. This syndrome has an autosomal dominant inheritance with variable expressivity.

Pierre Robin sequence (PRS) is due to a cascade of events resulting in micrognathia, glossoptosis, upper airway obstruction, and predisposition to cleft palate. The first pathophysiologic event in utero is the hypoplasia of the mandible (microretrognathia) (Fig. 12.7), which is deficient in the sagittal plane; therefore, the tongue is displaced posteriorly (glossoptosis) with consequently airway obstruction. The persistence of the tongue between the palatal shelves prevents their fusion on the midline resulting in a U-shaped cleft palate.

PRS has an incidence of 1 in 8000–14,000 newborns and although the majority of cases may be associated with a syndrome, it may also occur as an isolated entity. Symptoms include varying

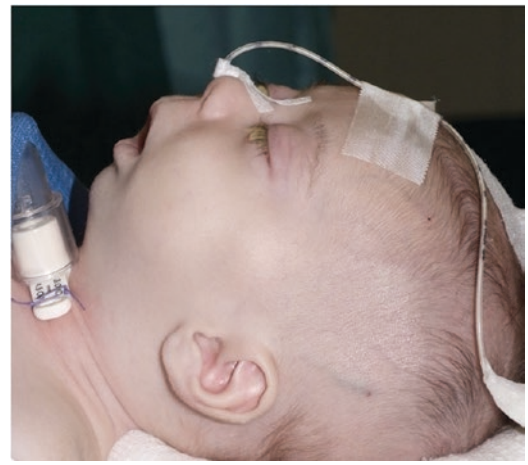


Fig. 12.7 Pierre Robin sequence

degrees of upper airway obstruction and feeding problems, possibly leading to subsequent life-threatening respiratory and cardiac sequelae and failure to thrive when not adequately treated [1].

When the anomalies of tongue and mandible result in moderate airway obstruction, most patients will respond to conservative therapy (prone or side positioning). In the case of severe airway obstruction, surgery must be performed early. This includes mandibular advancement with distraction osteogenesis or tracheostomy. Tongue to lip adhesion still has some indications in very selected cases. Cleft palate repair must be performed around 6 and 8 months of age. Language development and mandibular growth are carefully monitored for possible secondary surgery.

Stickler syndrome is an association of cleft palate and eye abnormalities, which include retinal detachment, cataracts, ocular hypertension, and severe myopia. These anomalies are progressive and can lead to blindness. Other features are a flat midface, hearing loss, and musculoskeletal involvement. It is a hereditary connective tissue disorder of fibrillar collagen with autosomal dominant inheritance.

22q deletion syndrome is an autosomal dominant syndrome associated with 22 chromosome abnormality that groups velocardiofacial syndrome and DiGeorge syndrome. Phenotypes include immunologic findings, hypocalcemia,

cardiovascular involvement, vertical maxillary excess with malar flattening and relative mandibular retrusion, narrow palpebral fissures, small ears, and complete or submucous cleft palate and velopharyngeal insufficiency. The most important feature to investigate in the case of palatal or pharyngeal flap surgery is the medial displacement of the carotid artery into the pharynx [22]. Finally, this syndrome is associated with learning disabilities and psychological/psychiatric problems. A close monitoring of development is needed.

Van der Woude syndrome is among the most common syndrome that is associated with cleft lip and palate. The diagnostic finding in Van der Woude syndrome is bilateral paramedian lower lip pits. It is autosomal dominant with variable expressivity.

Nager syndrome presents with micrognathia, external ear defects, conductive hearing loss, cleft palate, down-slanting palpebral fissures, high nasal bridge, hypoplastic/absent thumbs, and variable lower limb defects. It is often sporadic, although both autosomal recessive and dominant familial cases are reported.

Beckwith–Wiedemenn syndrome is a genetic disorder commonly characterized by overgrowth. It includes macroglossia (enlarged tongue), macrosomia (large birth weight and length), hemihypertrophy/hemihyperplasia of one side or one part of the body, hypoglycemia/hyperinsulinism, defects in the abdominal wall and organs, ear anomalies, and an increased risk of developing certain cancers (Wilms' tumor, hepatoblastoma, neuroblastoma, and rhabdomyosarcoma).

Parry–Romberg syndrome or progressive hemifacial atrophy is an atrophic disorder characterized by a progressive loss of the hemifacial soft tissues. It is more common in females and on the left side of the face. It is often accompanied by neurological abnormalities, including seizures. The typical onset of the disease is in the first or second decade of life (ages 5–15) and involves a slow progressive resorption of skin, subcutaneous fat, muscle, and occasionally bone. The causes are unknown.

12.5.3 Craniofacial Microsomia

Craniofacial microsomia (CFM) is the clinical association of mandible and ear anomalies with orbital and lower cranial region deformities (Fig. 12.8). Various names have been used to designate this condition, including oculoauriculovertebral syndrome, first and second branchial arch syndrome, otomandibular dysostosis, and lateral facial dysplasia [23].

In the literature, the incidence of CFM ranges 1:3500–26,550 live births, with a commonly quoted incidence of 1:5600 live births [24]. It is the second more common craniofacial deformity after cleft lip and palate. The etiology of CFM is heterogeneous. The prevailing theory is that CFM is a sporadic event, possibly linked to teratogens [25]. Other studies suggest a role for genetic transmission [26].

Variants are hemifacial microsomia (when orbital and cranial involvement are not included) and Goldenhar syndrome (or oculoauriculovertebral sequence):

– Hemifacial microsomia has a deformity centered around the lower face, in which there are

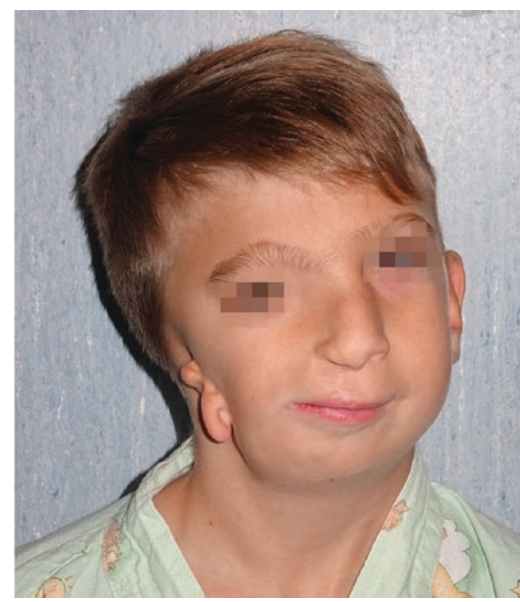


Fig. 12.8 Craniofacial microsomia

ear deformity, mandibular hypoplasia, involvement of the marginal mandibular branch of the VII cranial nerve, and soft tissue hypoplasia.

– Diagnosis of Goldenhar syndrome includes epibulbar dermoid and vertebral anomalies in association with the typical features of the craniofacial microsomia. Common in Goldenhar is also macrostomia, which may be the appearance of a lateral cleft of the lip.

The most conspicuous deformity in CMF is auricular malformations, mandibular hypoplasia, and craniofacial anomalies.

According to Marx, auricular malformations include microtia: grade I, distinctly smaller malformed ear with most of the characteristic components; grade II, vertical remnant of skin and cartilage, with atresia of the external meatus; grade III, the external ear is absent except for a small remnant, such as a misplaced deformed lobule. Other principal auricular anomalies are preauricular tags, conductive hearing loss, and middle ear (ossicle) defects.

Mandibular hypoplasia is characterized by a ramus hypoplastic or virtually absent, the body of the mandible curves upward to join the vertically reduced ramus. The chin is deviated to the affected side. Condyle malformation varies from minimal hypoplasia to complete absence. Condylar anomalies are constants and, consequently, pathognomonic of this syndrome (see Pruzansky classification of severity). The neuromuscular components are also distorted or deficient, and the occlusal plane is inclined.

Microphthalmia, coloboma, orbital dystopia, cranial base anomalies, cleft lip and palate, velum paresis, and velopharyngeal insufficiency have been reported, as well as dental hypoplasia, plagiocephaly, parotid gland hypoplasia, cranial nerve defects, and sensorineural hearing loss [27]. It can be bilateral in 5% to 30% of cases.

12.5.4 Frontonasal Malformations

Frontonasal malformation (Fig. 12.9) can be isolated or syndromic. It is also known as median cleft facial syndrome or median face syndrome, and it is comparable with Tessier 0–14 cleft. First named frontonasal dysplasia, successively fron-

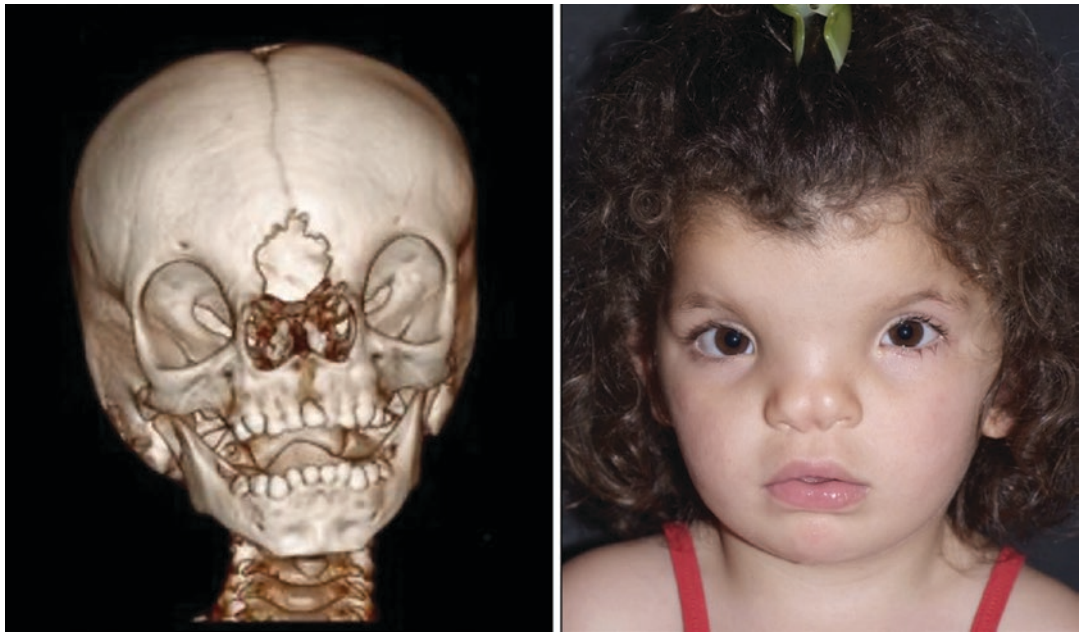


Fig. 12.9 Orbital hypertelorism and frontonasal malformation

tonasal malformation [10, 28], its universal feature is hypertelorism.

Hypertelorism is a malposition of the orbital structures with lateral orbital displacement (Fig. 12.9), greater interorbital distance (the bone measurement between the junction of the frontal lacrimal bones), greater outer orbital distance, greater intercanthal width, and widened nasal root (occasionally duplicate with a bifid septum).

Its syndromic form is craniofrontonasal dysplasia. It is a combination of frontonasal malformation and coronal craniosynostosis with varying extracranial manifestations, whereby hypertelorism and bifid nasal tip accompany frontal bossing and brachycephaly or plagiocephaly secondary to the synostosis. Other clinical expressions include anomalies in the hairline, central nervous system abnormalities [29], soft tissue syndactyly, nail grooves, shoulder and hip derangements, cleft lip and palate, and uncommon cardiac anomalies [30].

This is a familial disorder with an unusual X-linked pattern (all daughters of males-carriers are affected) [31].

Key Point

Craniofacial malformations may be syndromic or nonsyndromic, respectively, if they are associated with other malformations or isolated defects (e.g., cleft lip and palate, craniosynostosis, microtia).

Syndromic craniofacial malformations include the following:

- Syndromic craniosynostosis, such as *Crouzon disease*, *Apert* syndrome or acrocephalosyndactyly, *Pfeiffer* syndrome, *Saethre–Chotzen* syndrome, *Jackson–Weiss* syndrome, *Carpenter* syndrome, *Kleeblattschadel* deformity, *Muenke* syndrome, and *Opitz* syndrome.
- Facial syndromes, such as *Treacher–Collins or Franceschetti* syndrome, *Pierre Robin* sequence, *Stickler* syndrome, *22q* deletion (that comprises velocardiofacial and DiGeorge syndromes), *Van der Woude* and *Nager* syndromes, *Beckwith–Wiedemenn* syndrome, and *Parry–Romberg* syndrome.
- Craniofacial microsomia (mandible, ear anomalies, and orbital and lower cranial deformities) with its variants hemifacial microsomia (if orbital and cranial deformities are not included) and *Goldenhar* syndrome (or oculoauriculovertebral sequence, when epibulbar dermoid and vertebral anomalies are present).
- Frontonasal malformations, where hypertelorism and nasal deformities are the typical features (the only present in isolated frontonasal malformation); coronal craniosynostosis and extracranial anomalies are associated in the syndromic form (also known as craniofrontonasal dysplasia).

12.6 Microtia

Microtia affects the external ears and occurs once in every 1200–6000 births (the prevalence of microtia varies depending on the population studied; the higher incidence is in the Navajo population) [32, 33]. The majority of the patients also have conductive hearing loss.

External ear is composed of several important landmarks that begin to develop during the fifth week of gestation from the first (tragus, helical root, helix) and second (antihelix, antitragus, lobule) pharyngeal arches. These malformations range from minor irregularities in the contour and size to a complete absence of the ear (known also as anotia). Many classification systems have been proposed. The most popular are the four Hunter degrees (presence of all components but smaller size, presence of some recognized components, presence of some not recognized components, anotia) and the five Nagata types (lobule, small concha, concha, anotia, low hairline). The most

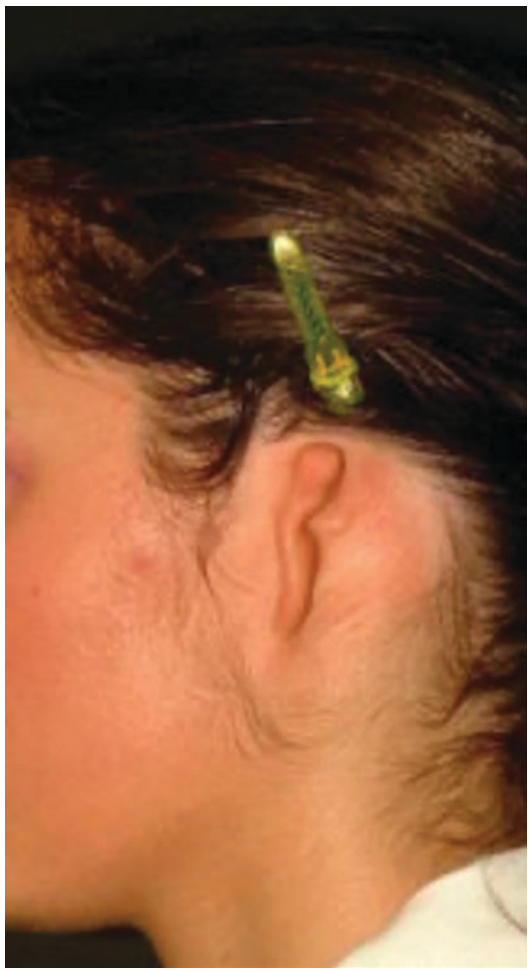


Fig. 12.10 Microtia lobular type

common form of microtia is represented by a lobule lying usually in a vertical position (Marx's grade III/Nagata's lobular type) (Fig. 12.10).

Microtia can occur isolated, as part of a genetic syndrome, or in association with other anomalies. The most common syndromes associated with microtia are craniofacial microsomia (including oculoauriculovertebral spectrum, Goldenhar syndrome/hemifacial microsomia), Treacher Collins, Nager, and 22q deletion syndrome (comprising DiGeorge). The most frequent dysmorphic features associated with microtia are mandibular hypoplasia, facial asymmetry, cleft lip and palate, anophthalmia/microphthalmia, macrostomia, polydactyly, holoprosencephaly, and epibulbar dermoids [34].

Microtia is more frequent in males. The ratio right-left-bilateral is 6:3:1. In most instances, the microtic lobule is displaced superiorly, although incomplete ear migration often leaves it in an inferior location. Approximately, one-third to half of the patients exhibit gross characteristics of hemifacial microsomia, although Converse et al. [35, 36] have demonstrated topographically that skeletal deficiencies exist in all cases [37].

Key Point

Microtia affects the external ear and has a phenotypic spectrum varying from hypoplasia to partial presence of recognized/not recognized ear components, up to anotia.

It is isolated or syndromic. The most common syndrome associated is craniofacial microsomia (including oculoauriculovertebral spectrum, Goldenhar syndrome, hemifacial microsomia).

12.7 Micrognathia

Micrognathia, also known as mandibular hypoplasia, is an anomaly in which the lower jaw is undersized. It may interfere with child's feeding and breathing and is linked to several craniofacial conditions, including cleft lip and palate, Pierre Robin sequence, Stickler's syndrome, hemifacial microsomia, Treacher Collins Franceschetti syndrome, and others.

In a child with a diagnosis of micrognathia, the craniofacial specialist evaluates if there is a cleft palate and/or facial asymmetries, the relationship between tongue and lower jaw and between upper and lower jaw, the presence of lingual frenulum, X-ray or CT scan of the face and head, and the sleep study.

On the basis of the severity and dysfunctions, therapies are nonsurgical (prone positioning, nasopharyngeal airways tube, noninvasive positive pressure ventilation) or surgical (mandibular distraction osteogenesis). If diagnosis and treatment are early, long-term outcomes for children with micrognathia are good. Additional surgeries

may be necessary depending upon jaw growth and development.

Key Point

Micrognathia or mandibular hypoplasia interfere with feeding and breathing.

It is linked to several craniofacial anomalies, such as cleft lip and palate, Pierre Robin sequence, Stickler's syndrome, hemifacial microsomia, Treacher Collins Franceschetti syndrome, and others.

12.8 Craniofacial Malformation Surgery

Craniofacial surgery is a teamwork that begins at the prenatal diagnosis or immediately after birth and continues until the end of facial growth (around 18 years of age). This means that craniofacial surgery is not confined to the operative treatment but includes all the activities connected to the correct development of the skull and face. It takes place in specialized pediatric centers with specific expertise in craniofacial malformations.

As Paul Tessier, father of the discipline, stated that craniofacial surgery consists in the transcranial approach to the orbits and maxilla, where transcranial means through the anterior cranial base. Tessier developed models for preoperative planning and established surgical techniques that permitted to treat many patients with varieties of congenital deformities. His teaching in Paris and worldwide spread the news rapidly. As a result, the craniofacial surgeons on every continent established their own teams.

Two fundamental aspects must be considered in craniofacial surgery: the surgical anatomy and the fourth dimension (growth over time) since craniofacial growth is a dynamic process that affects both form and function [38].

From a surgical anatomy point of view, the craniofacial area consists of two structures: the cranium and the face.

The cranium is composed of the vault and the base.

The vault is formed by the frontal bone, single and median, the two parietals, the upper part of the occipital bone, and the two temporal fossae. In the cranium of the newborn, the skeletal parts are separated from each other by the sutures (bands of connective tissue) and fontanelles (sites of suture junction between three or four bones).

The metopic suture (between the two frontal bones) closes before birth and disappears around the 15th month of life. The other sutures close slowly up to the 18th month (Fig. 12.11). They are the following:

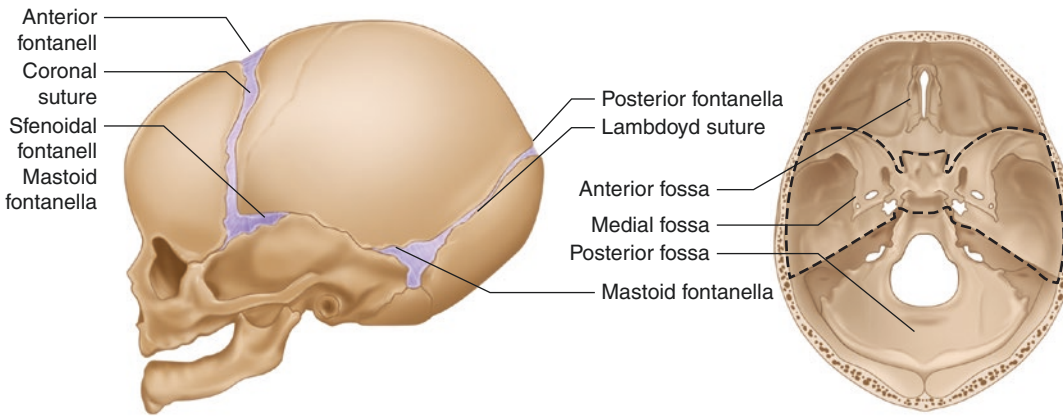


Fig. 12.11 Cranial sutures, fontanelle, and fossae

- Coronal (between frontal and parietal bones).
- Sagittal (between parietal bones).
- Lambdoid (between parietal and occipital bones).
- Parietosquamous (between parietal and temporal bones).
- Sphenofrontal and sphenotemporal (between cranium and face).

The fontanelles are placed at the four corners of the parietal bone and are named bregmatic, lambdoid, pteric, and asteric (Fig. 12.11).

The base is formed by the posterior, middle, and anterior fossae. These reproduce the tribasilar bone of Virchow (basiocciput, basisphenoid, and presphenoid). Each fossa accommodates a different part of the brain.

The anterior fossa is of particular interest in craniofacial surgery. It is a territory with an unpaired midline area leading to the nasopharynx and two paired lateral areas that are the orbital roofs. The anterior fossa is supported by the body of the sphenoid, articulating with the frontal bone and ethmoid bone. This fossa accommodates the anteroinferior portions of the frontal lobes of the brain. The ethmoid bone in particular contains the main foramina of the anterior cranial fossa for transit of vessels and nerves (I cranial nerve).

The middle cranial fossa consists of three bones, the sphenoid and the two temporals. It contains many nerves, vessels, and cranial structures crucial to its function. The middle cranial fossa consists of a central portion, which contains the pituitary gland, and two lateral portions, which accommodate the temporal lobes of the brain.

The posterior cranial fossa is the most posterior and deep of the three cranial fossae. It accommodates the brainstem and cerebellum. It is composed of three bones: the occipital and the two temporal bones. There are several bony landmarks and foramina present in the posterior cranial fossa for the passage of blood vessels or nerves (Fig. 12.11).

The face has sutures that unite the bones of the facial complex and the latter to the vault and cranial base. It is formed by 14 bones.

The centrofacial portion is a pyramid composed of the maxillo-ethmoidonasal complex. Deep inside, this centrofacial complex supports the velum and the palatopharyngeal muscle slings [39].

The orbits represent the upper third of the face and include four walls:

- Roof (superior): orbital part of the frontal bone, lesser wing of the sphenoid bone.
- Medial: orbital plate of the ethmoid bone, lacrimal bone, frontal process of the maxilla, greater wing of the sphenoid bone.
- Floor (inferior): orbital surface of the maxilla, zygomatic bone, palatine bone.
- Lateral: zygomatic bone, sphenoid bone.

The zygomatic bones continue inferolaterally and complete the upper two-thirds of the face.

The lower third of the face is formed by the alveolodental sector and mandible. It comprises the oral cavity.

The visible craniofacial surface is characterized by the hairy scalp in cranial portion and the hair-less skin in the face with typical hairy zones (eyebrow, mustache, and beard). Facial skin is lined by the mimic muscles innervated by the facial nerve.

Pearls and Pitfalls

- Craniofacial surgery is a teamwork that begins at the prenatal diagnosis or immediately after birth and continues until the end of facial growth (around 18 years old).
- It is not confined to the operative treatment.
- It takes place in specialized pediatric centers with specific expertise in craniofacial malformations.
- A fundamental aspect to be evaluated in this surgery is the fourth dimension (growth over time).

Key Point

The major scientific advance in craniofacial surgery is due to Tessier's study that permitted it to reach orbits and maxilla through the anterior cranial base.

Craniofacial surgeons must have a perfect knowledge of the surgical anatomy and awareness of the fourth dimension.

12.9 Cleft Lip and Palate Treatment

The management of cleft lip and palate patients is multidisciplinary, from infancy to adulthood. The cleft team includes plastic surgeons, pediatricians, geneticists, speech pathologists, pedodontists, orthodontists, otolaryngologists, ophthalmologists, social workers, psychologists, cleft nurses, and other specialties if there are associated pathologies. These health specialists are coordinated and work together in a cleft center.

Prenatal diagnosis of cleft lip is the first step in the management and is usually made in the second trimester by ultrasound. The diagnosis of cleft palate is commonly made at birth.

The second step is the parents' counseling about feeding and treatment (at the time of the prenatal diagnosis or at birth).

The third step is the evaluation of the newborn cleft baby by the cleft plastic surgeon, pediatrician, geneticist, and ophthalmologist for other systemic conditions (at 1–4 weeks from birth).

In the first year of life, cleft plastic surgeons perform the cheiloplasty and/or the palatoplasty; successively, they perform the alveolar bone graft around 7–10 years of age (timing relates to the eruption of canine); finally, rhinoplasty at 18 years old.

In a minority of cases, cleft plastic surgeons must also perform a lengthening palatoplasty or pharyngoplasty (to correct a velopharyngeal insufficiency, around 3–5 years old) and a LeFort I osteotomy with or without distraction osteogenesis (to advance the lower part of the maxilla to correct the maxillary hypoplasia, around 17–18 years old). Moreover, the fourth dimension (the growth over time) can affect the morphological result of primary surgery; therefore, secondary surgery may be necessary for some cleft patients.

In this period of life, from infancy to adulthood, the evaluation and monitoring by the ENT, speech therapist, dentist, orthodontist, and psychologist (and other specialists in the case of other associated pathologies) is mandatory.

The primary surgery of the first year of life includes myocheiloplasty (around 3–4 months old) and palatoplasty (around 6–9 months old). Gingivoperiosteoplasty at this age remains a controversial method of treatment, and few centers carry it out.

The surgical challenges in cleft patients are the deficiencies of soft tissue, cartilage, and bone (piriform area and maxilla); the availability of skin and muscle; the cleft width and type; and the deviation of tissues to the noncleft side (e.g., alar cartilage distortion in unilateral clefts).

In selected cases of very severe deviation of the premaxilla, a presurgical alveolar molding can be done. There is no international agreement on how to do it. Presurgical orthopedics is the technique of some cleft centers; lip adhesion is the technique of other centers; and external taping is the simplest technique for both presurgical molding of the maxillary and nonsurgical approximation of the alveolus. In this method, a strip of medical tape is placed across the cleft to approximate the upper lips, simulating effects of an adhesion cheiloplasty without stressing the tissues, without inducing inflammation or creating scar tissue (limits of the alternative methods of presurgical alveolar molding). This atraumatic method is adopted in our and many other cleft centers.

Myocheiloplasty: Lip measurements of anthropometric markings are a good method of evaluating lip deficiencies. The surgeon draws with a caliper the important anthropometric points of the Cupid's bow on the epidermis–vermilion junction line, the white roll, as described by Millard [40]; the vermilion–mucosa junction line, the red line [41]; the base of the ala;

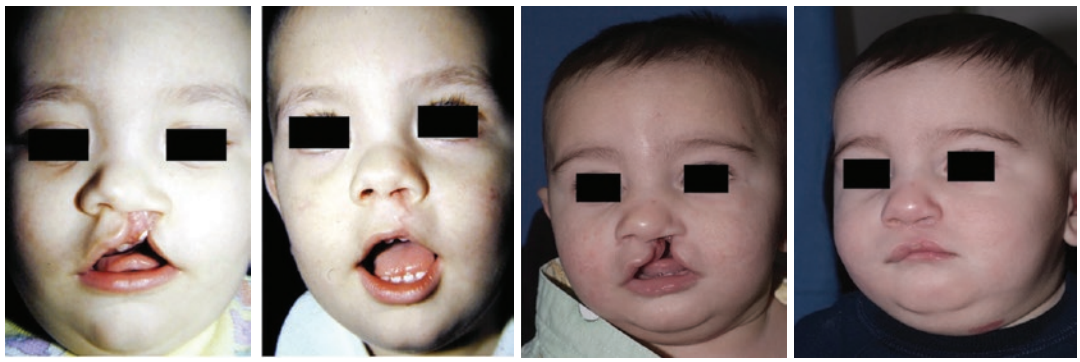


Fig. 12.12 Pre- and postoperative of Tennison–Randall technique; and pre- and postoperative of Millard technique

the commissures; the philtral column in cleft side and in noncleft side (in unilateral cleft lip); and the horizontal and vertical length.

Surgery was simple until the Tennison and Randall method. Indeed, this was the start of a more sophisticated repair with actual preservation and positioning of the Cupid's bow by using a triangular flap technique. In 1955, Millard presented his rotation-advancement technique, published in 1957. Since then, Tennison–Randall and Millard repairs (Fig. 12.12) have been the most popular types of reconstructions, with many modifications. Mostly, the Millard technique spans a lifetime of change and innovation. In the 50 years since the introduction of the rotation-advancement, many further refinements have been proposed, including those by Byrd, Cutting, Mohler, Mulliken, Stal, and others [42]. Recently, Fisher devised the anatomical subunit approximation technique, which is an evolution of geometric style repairs [43].

The key points in unilateral myocheiloplasty are the reconstruction of the Cupid's bow, orbicularis muscle release and approximation, complete mucosal and vermilion closure, definition of the alar groove, and the philtral column. In the Millard technique, there is the rotation of the noncleft side upper lip, the advancement of the cleft side upper lip, and the versatile C flap that can be placed laterally (beneath the ala) or medially (rotating into the columella).

Reconstruction of the orbicularis oris muscle in lip repair is essential to achieve a good appearance and function.

A dissection of the alar cartilage of the cleft side and alar transfixion sutures can complete the operation, and postoperative splinting of the nostril with a silicone conformer can limit the effects of wound contracture.

In bilateral cleft lip, the additional problems are the skin imbalance between prolabium and columella, the premaxilla does not connect to the lateral palatal shelves, the premaxilla is projected anteriorly, and there is the absence of muscle under the prolabium. Several techniques for bilateral cleft lip repair have been described. The Millard method adapted from bilateral cleft lip repair can be applied. Interesting and widespread is also the Mulliken approach [44]. Its markings for the operation include the standard anthropometric landmarks: subnasale, subalaris, labiale superius, crista philtri superioris, crista philtri inferioris, and the vermilion/mucosal junction (red line). On the prolabium, the philtral flap is designed. For the typical infant, this flap should be 2 mm wide superiorly, 4 mm wide inferiorly, and 6–7 mm in height, with sides drawn gently concave. Two flanking flaps should be drawn 2–3 mm in width on each side and deepithelialized. These flanking flaps improve the vascular supply of the philtral flap and may simulate the philtral ridge. Below the filter flap, the orbicularis oris muscle from the lateral elements is joined in the midline.

Small C-flaps are drawn on each side of the prolabium and are then approximated to the alar base flaps.

Mulliken completes the repair with bilateral alar rim incisions for placement of intercartilaginous and interdomal sutures.

In expert hands, both Millard and Mulliken techniques can give excellent results [45].

Pearls and Pitfalls

- Adequate rotation of the Cupid's bow is one of the most important aspects in achieving a good esthetic result, and reconstruction of the orbicularis oris muscle in lip repair is essential to achieve a good appearance and function.
- In expert hands, myocheiloplsty techniques can give excellent results, but it is also true that the fourth dimension can negatively affect the morphological result of primary surgery. In these cases, secondary surgery becomes necessary.

Palatoplasty: The goal of the cleft palate repair is to separate the oropharynx from the nasopharynx, obtain normalization of speech, improve otologic issues, and minimize the effects of surgery on midfacial growth. Anatomic variability of cleft palate influences the timing and sequence of surgical repair. Usually, if there is cleft palate with cleft lip and alveolus (complete cleft lip and palate), the repair of the hard palate will be done at the time of lip repair, while soft palate repair will be done later. If cleft palate involves only the secondary palate, reconstruction will be done at the same time for the hard and soft palate.

Optimal timing of palate repair must be balanced between optimal speech outcome and optimal maxillary growth. However, the primary goal is to attain a normal speech (primary goal). Good speech outcomes become more difficult to achieve with increasing age, whereas most maxillary growth problems can be addressed with orthodontic treatment and maxillary osteotomies.

The most important aspect of surgical anatomy is the emergency of the greater palatine neurovascular bundle from the greater palatine foramen through the lateral posterior hard palate.

Unilateral complete cleft lip and palate is characterized by direct communication between the entire length of the nasal passage and oropharynx. The nasal septum is deviated and buckled toward the cleft side. The absence of a portion of the inferior piriform aperture and the hypoplasia of the lateral nasal bony platform at the maxillary wall contribute to the cleft nasal deformity; the nasal base is depressed, the ala collapses, and the floor widens. The unilateral complete cleft is thus a full-thickness palatal defect of nasal mucosa, bony palate, velar muscles, and oral mucosa.

In bilateral complete cleft lip and palate, the premaxillary segment containing the central and lateral incisor roots is discontinuous from the alveolar arch. The abnormal anterior projection of the premaxilla complicates the lip reconstruction because of the greater tension on the soft tissues, risk of anterior fistulas with speech and nasal regurgitation problems, and midface growth deficiency (common sequela of bilateral cleft palate).

The levator palatini muscle runs longitudinally along the cleft margin before it inserts aberrantly into the posterior border of the hard palate (Fig. 12.5); this results in ineffective contraction and inability to close the palate against the posterior pharyngeal wall. Air escape through the nose during speech produces a characteristic hypernasal quality. In addition, aberrant levator positioning impairs the function of the tensor palatini muscle, which normally assists eustachian tube function [46].

In the cleft of the secondary palate, dentition is normal and symmetric and the levator palatini muscles are displaced as in the complete clefts. If submucous cleft palate is present, there is mucosal continuity with or without bifid uvula.

The purpose of the palate repair is to obtain complete nasal and oral tension-free closure and restoration of normal muscle anatomy.

The palatoplasty involves the reconstruction of two layers at the level of the hard palate (nasal mucosa and oral mucoperiosteum) and three layers at the level of the soft palate (nasal and oral mucosa, and muscles).

The techniques for hard palate closure use mucoperiosteal flaps, such as the methods of von Langenbeck, Bardach, and Veau–Wardill–Kilner. When the nasal mucosa is severely deficient and nasal approximation is not possible, the cleft plastic surgeon resort to vomer flaps.

Langenbeck introduced the mucoperiosteal closure of the secondary palate by harvesting of two advancement flaps elevated from lateral relaxing incisions that began posterior to the maxillary tuberosity, followed the posterior portion of the alveolar ridge, and maintained the anterior attachment. The oral layer is sutured after the closure of nasal mucosa (Fig. 12.13).

Bardach (also known as two-flap palatoplasty) modified the Langenbeck technique, extending the relaxing incisions along the alveolar margins to the edge of the cleft. In this way, in a unilateral cleft, the greater flap is shifted across the cleft and closed directly behind the alveolar margin (with decreased risk of fistula of the hard palate).

The pushback technique (known as Veau–Wardill–Kilner) is a three-flap palatoplasty based on a V–Y plasty principle with V incision, harvesting of three mucoperiosteal flaps and Y closure of the oral layer, after release and closure of the nasal tissue (Fig. 12.14). This method has the advantage of providing increased length for palate (favoring a better position for levator muscle), but it has the drawback of leaving large open areas anteriorly (that can result in contraction of maxillary arches anteriorly and increases the risk of fistulas).

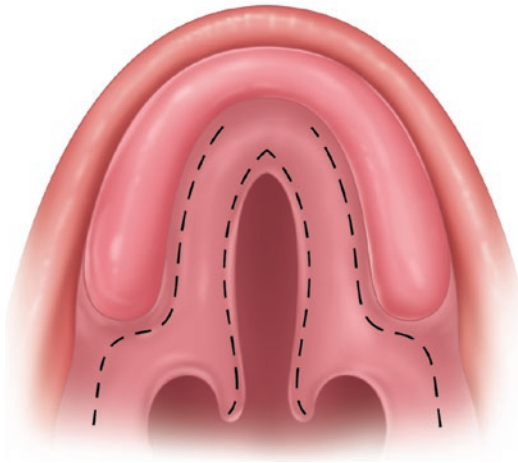


Fig. 12.13 Incision according to Langenbeck technique

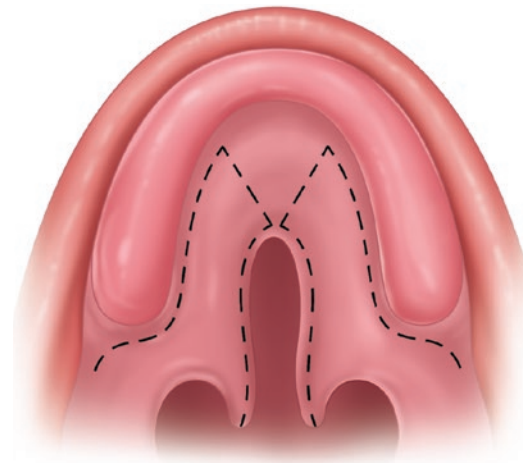


Fig. 12.14 Incision according to Veau–Wardill–Kilner

Vomer flap has been described as inferiorly and superiorly based to provide a single-layer closure, but many centers noted a high number of maxillary retrusion and fistulas. So, it is changed to a two-layer closure and a midline incision along the septum, harvesting two flaps that are reflected each one in the direction of the cleft margin in bilateral forms, or one flap in unilateral clefts, to close the nasal mucosa.

Techniques for soft palate reconstruction emphasize correction of the abnormal position of the levator palatini muscles, such as the methods of Furlow (double opposing Z-plasty) and Braithwaite–Cutting–Sommerlad (intravelar veloplasty), to reproduce the normal muscle sling.

Furlow first applied the Z-plasty principle to the palate repair (Fig. 12.15). His double opposing Z-plasty technique consists in the incision of a Z on the oral layer and a reverse Z on the nasal layer in order to obtain four flaps to transpose in opposite directions. The two posteriorly based flaps include the levator muscle. This technique

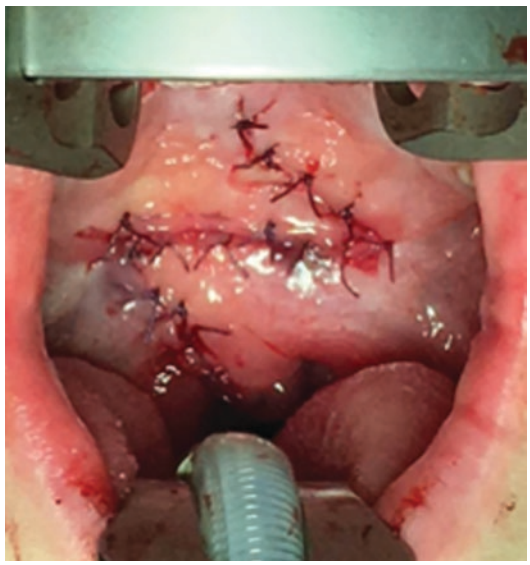


Fig. 12.15 Furlow's palatoplasty

provides complete nasal and oral closure to repair the levator muscle sling.

Intravelar veloplasty is the technique of the levator palatini dissection from both nasal and oral mucosa and reapproximation on the midline. Although Veau first advocated the muscle reapproximation, Braithwaite was the first to perform more extensive muscle dissection, Cutting to include the division of the tensor palatini tendon, and Sommerlad to propose the re-dissection of the levator in velopharyngeal insufficiency.

The surgical technique for submucous cleft palate is focused on the anatomic correction of the velar muscle diastasis. Although pharyngeal flaps and sphincter pharyngoplasty have been proposed as primary means of treatment, most surgeons focus on the repair of the abnormal levator muscle position. If a short palate or muscle hypotony is associated, intravelar veloplasty often cannot be sufficient to close the palate against the posterior pharyngeal wall. The Furlow double opposition Z-plasty is a successful procedure for these patients [47], which lengthens the velum improving the velo-pharyngeal function [48], and it avoids the potential for nasal obstruction and sleep apnea in these patients if a pharyngeal flap is used.

Pharyngoplasty, such as the Orticochea technique and Hynes, as well as buccinator flaps, is reserved to severe velopharyngeal dysfunction as secondary/tertiary surgery, in which is not sufficient the intravelar veloplasty re-repair or the Furlow redo.

Pearls and Pitfalls

- Reconstruction of the cleft palate is focused on the anatomic correction of the oronasal communication for hard palate and of the velar muscle diastasis (with attention for levator palatini position) in soft palate.
- Normal speech is closely related to the velar muscle function. The surgery must provide an adequate velar length and muscle position.
- Alveolar bone grafting must be coordinated with orthodontic treatment.

Alveolar bone grafting: Reconstruction of the cleft alveolus by bone grafting is important for stabilization of the maxillary arch; support for the roots of teeth adjacent to the cleft on each side; support for a prosthesis; closure of an alveolar fistula; and reconstruction of the floor of the piriform aperture.

Presurgical orthodontic expansion and alignment are necessary if the maxillary arch width must be restored. The bone graft then will stabilize and prevent relapse.

The ideal timing for bone grafting is before the eruption of the cuspid into the cleft. Iliac crest cancellous bone is the gold standard. The stabilization of the maxillary arch is also important for those patients with maxillary hypoplasia, which can have a benefit by distraction osteogenesis.

Secondary deformities are particularly common for lip and nose because all patients undergoing primary surgery within the first year of life have a long period of growth (fourth dimension) that may negatively affect the final result. So, secondary surgery of the lip and nose must be an integral part of the care of these patients.

Key Point

The surgical challenges in cleft patients are the following:

- Deficiencies of soft tissue, cartilage, and bone (piriform area and maxilla).
- Availability of skin and muscle.
- Cleft width and type.
- Deviation and distortion of the tissues.
- Projection of the premaxilla.
- Nasal deformity.
- The key points in myocheiloplasty are the following:
- Reconstruction of the Cupid's bow.
- Release and approximation of the orbicularis oris muscle.
- Complete mucosal and vermilion closure.
- Definition of the alar groove and the philtral column.

Millard rotation-advancement technique is the cheiloplasty most performed, modified, and innovated worldwide. The Mulliken method is widespread for bilateral cleft lip.

The purpose of the cleft palate repair is to do the following:

- Separate the oropharynx from the nasopharynx.
- Attain normalization of speech (primary goal).
- Improve otologic issues.
- Minimize effects of surgery on midfacial growth.

The most used palatoplasty is the techniques of Veau–Wardil–Kilner, Langenback, Bardach, Furlow, Sommerlad, intravelar veloplasty, and vomer flaps.

Alveolar bone grafting is needed to reconstruct the cleft of alveolus and piriform aperture.

Iliac crest cancellous bone is the gold standard.

Patients with maxillary hypoplasia may need distraction osteogenesis.

The care of secondary deformities is an integral part of the treatment. At the end of facial growth, rhinoplasty usually concludes the surgical treatment in many cleft patients.

12.10 Surgical Management of Craniosynostosis

The main goals of surgical treatment of craniosynostosis are protecting vision, reducing intracranial pressure, and improving appearance, by calvarial and supraorbital normalization. However, the primary indication is decompression. Renier's studies showed that nonsyndromic patients have a 14% incidence of elevated intracranial pressure before surgery [49]. Preoperatively, if the patient has multiple sutures involved, 45% has elevated intracranial pressures; Crouzon syndrome, 66%; and Apert syndrome, 44%.

Key Point

The primary goal of surgery for craniosynostosis is reducing intracranial pressure (to avoid late consequences, blindness, and mental retardation).

In nonsyndromic patients, individual cranial sutures may be fused, resulting in an abnormality of shape requiring cranial vault remodeling and fronto-orbital advancement. In syndromic craniofacial disorders, in addition to cranial suture abnormalities, the cranial base is abnormal, resulting in an abnormal retruded midface with exorbitism, orbital hypoplasia, and globe and corneal exposure. So, multiple interventions are needed.

The timing of surgery is important. Cranial vault remodeling is performed around 4–6 months of age. At an early age (<4 months), the bone is

more fragile; at a large age (>12 months), residual calvarial defects will fail to reossify [50]. Moreover, later procedures delay the potential benefits of early decompression.

For coronal craniosynostosis, this means bilateral fronto-orbital advancement with frontotemporal remodeling. Metopic synostosis is also treated with bilateral fronto-orbital advancement with frontotemporal remodeling.

Sagittal synostosis is treated with strip craniectomy (removal of the synostosed suture) and cranial vault remodeling to correct anterior–posterior lengthening with narrow bitemporal width (e.g., inverted Greek *p*).

Midface hypoplasia is treated around 4–6 years by monobloc advancement of the midface or Le Fort III.

Syndromic craniosynostosis with orbital hypertelorism, typical of Crouzon and Apert, needs at least three surgical stages. The first is the correction of the coronal craniosynostosis (brachycephaly or plagiocephaly) around 4–6 months of age. The second is the correction of the hypertelorism and upper third of the nose, around 4–6 years old. The third stage of reconstruction follows the end of facial development (i.e., Le Fort I, rhinoplasty and/or genioplasty, around 18 years old).

Abnormalities of facial growth can persist in syndromic patients, so minor revision or even secondary advancement may be required.

Pearls and Pitfalls

- Main goals of surgery of craniosynostosis are decompression, protecting vision, normalizing cranial and facial dysmorphism, and improving consequently psychosocial adjustment.
- Cranial vault remodeling must be performed around 4–6 months of age.
- At an early age, the bone is more fragile.
- At a large age (>12 months), residual calvarial defects will fail to reossify and could compromise the potential benefits of early decompression.
- Midface hypoplasia is treated around 4–6 years by monobloc advancement of the midface or Le fort III. When the forehead requires concomitant advancement, the monobloc is the procedure of choice.
- Syndromic craniosynostosis with hypertelorism need at least three craniofacial surgical stages:
  - The correction of the coronal craniosynostosis (around 4–6 months of age).
  - The correction of the hypertelorism and upper third of the nose (around 4–6 years old).
  - The reconstruction at the end of facial development (i.e., Le fort I, rhinoplasty and/or genioplasty, around 18 years old).

The most severe syndromic forms can need an early bone distraction of the bony posterior fossa. Moreover, they require multiple interventions to correct the associated malformations. The anomalies of the hands, such as syndactyly, may be corrected after 6 months of age.

12.11 Management of Craniofacial Syndromes

Treatment of craniofacial syndromes is very complex and controversial because of the complexity of the deformities. Surgery is centered on preventing intracranial hypertension and reestablishing symmetry and facial proportions, but the correction of the abnormal facial skeleton often requires multiple surgical interventions. Nevertheless, these may still not completely correct the deformity. The aim is a normal social life for children and parents. The staged approach should be performed at intervals coinciding with facial growth and social development.

In syndromic craniosynostosis, the staged treatment comprises the surgical steps as follows:

- In the neonatal period, the airway can be sustained by tracheostomy, and, in very selected cases, early monobloc fronto-facial advance-

ment can be performed. Nutritional issues can necessitate alternative enteral feeding or gastrostomy. A shunt can treat hydrocephalus when present. Early cranioplasty is debated. Surgeons who perform anterior vault remodeling with fronto-orbital advancement after 6 months of age may first expand the posterior skull earlier in life (3–6 months of age) if there is severe progressive turribrachycephaly.

This is the typical protocol for Apert or Crouzon patients:

- Age 4 months: poster fossa expansion through distraction osteogenesis.
- Age 12 months: fronto-orbital advancement if ocular proptosis still present.
- Age 6–8 years: Monobloc fronto-facial advancement, with or without facial bipartition, through distraction osteogenesis (which is gold standard for children with deficient supraorbital rim, short anterior cranial base and orbits, retruded maxilla, and class III anterior open bite) (Figs. 12.16 and 12.17); Le Fort III osteotomy through distraction osteogenesis is an alternative in few selected cases (Fig. 12.18).
- Age 15 years: Le Fort I osteotomy through distraction osteogenesis.
- Age 18–20 years: possible redo of Le Fort I osteotomy through distraction osteogenesis.

- At the age of skeletal maturity, improving facial appearance can be achieved through rhinoplasty, genioplasty, bone graft augmentation, fat graft, and other ancillary procedures.

In Treacher–Collins–Franceschetti syndrome (bilateral Tessier no.6–8 craniofacial cleft), there is great controversy about the timing of surgical treatment, and multiple protocols are published. Tessier stated that it is better to delay major reconstruction until the age of 6–10 years because resorption of bone grafts is more severe in this than in other malformations. A staged approach to reconstruction is more appropriate:

- During infancy, lower lid reconstruction (if the lid insufficiency does not allow the eyelid closure) and ear reconstruction (to treat microtia) can be performed.
- Bone graft on the midface and orthognathic surgery are deferred until late adolescence or early skeletal maturity.
- Rhinoplasty and fat grafting generally conclude the treatment.

In less severe Pierre Robin sequence, the first treatment is the prone positioning until 6 months to allow neuromuscular adaptation and mandibular growth. In the more severe forms, the airway obstruction imposes an early mandibular lengthening by distraction osteogenesis, performed to prevent tracheostomy. Tracheostomy is reserved for syndromic patients or for those with associated anomalies such as tracheomalacia. Tongue–lip adhesion could be indicated in a few selected cases but actually almost abandoned. If cleft palate is present, the correction is performed between 6 and 9 months of age.

In craniofacial microsomia and hemifacial microsomia, the treatment is centered around the three major components of the syndrome: ear, mandible, and soft tissue.

Reconstruction of external ear is performed by costal cartilage (especially in Europe) or polyethylene implant (mainly in the United States), as explained in the next section.

The major difficulty in major reconstruction planning is the mandible. Mandibular distraction osteogenesis has been a major advance in providing an opportunity for early skeletal reconstruction so that soft tissue reconstruction can proceed at a relatively early age. Mandibular distraction can be employed at any age from the neonate to the adult. The technique involves complete osteotomy of the mandible with the application of intraoral distraction devices (extraoral devices are now almost abandoned) that can be activated at the rate of 1 mm/day. Mandibular distraction can be secondly repeated.

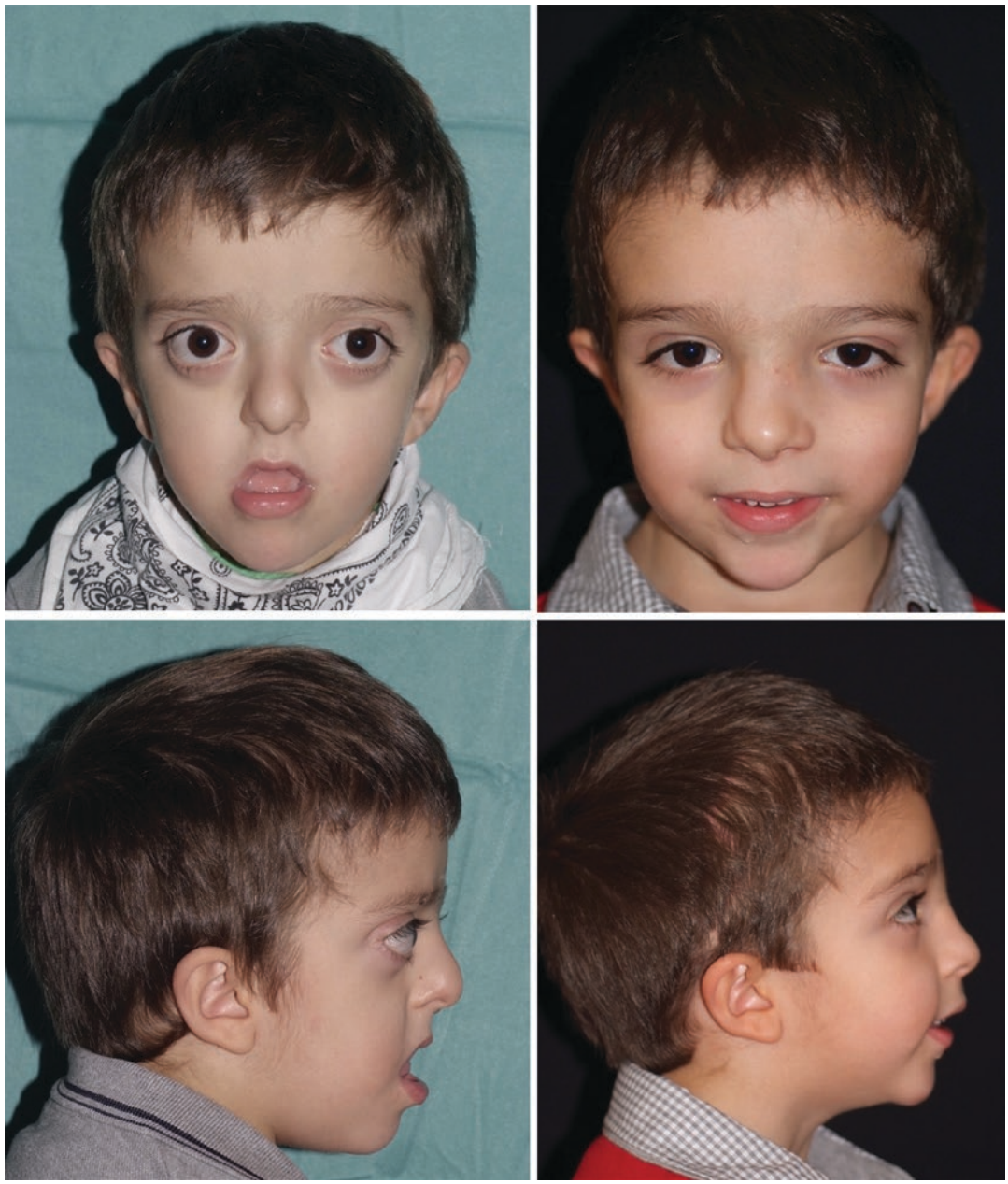


Fig. 12.16 Monobloc fronto-facial advancement, pre- and postoperative

Maxillo-mandibular distraction is also possible by performing a concomitant LeFort I osteotomy and placing an internal device that proceeds as a mandibular distraction. These procedures must be coordinated with orthodontic treatment. When absent, the ramus of the mandible can be reconstructed by a costochondral graft or free fibula flap.

The treatment more accepted for soft tissue is fat grafting.

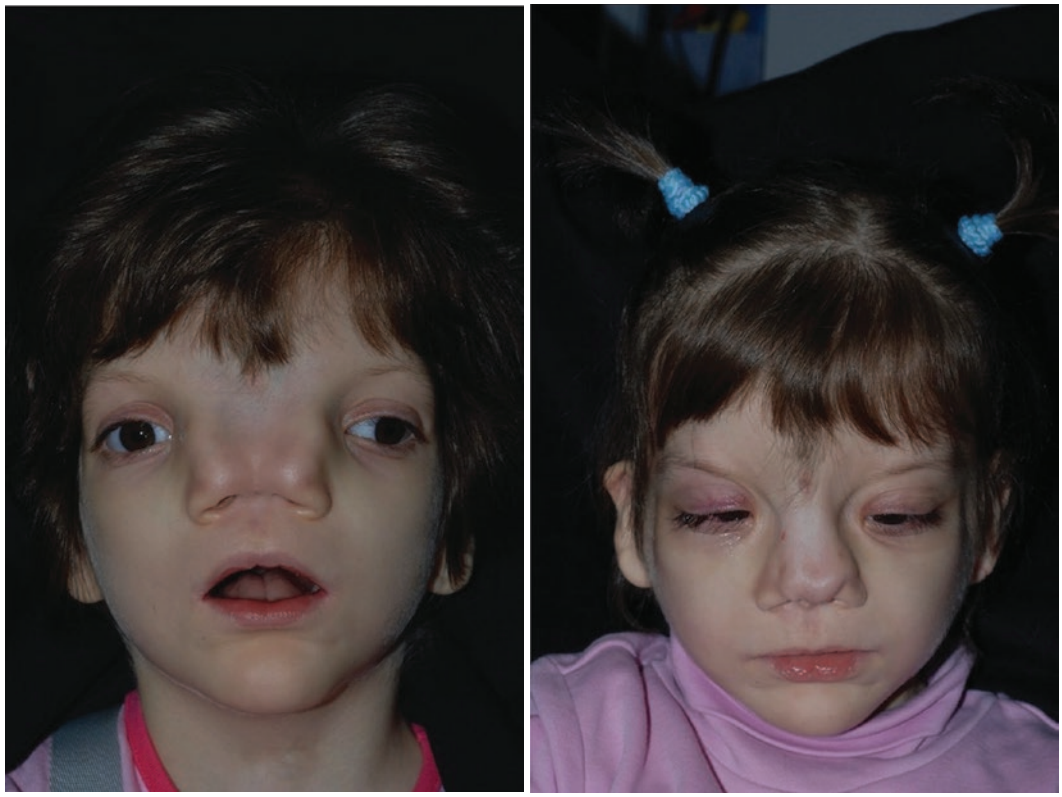


Fig. 12.17 Facial bipartition, pre- and postoperative

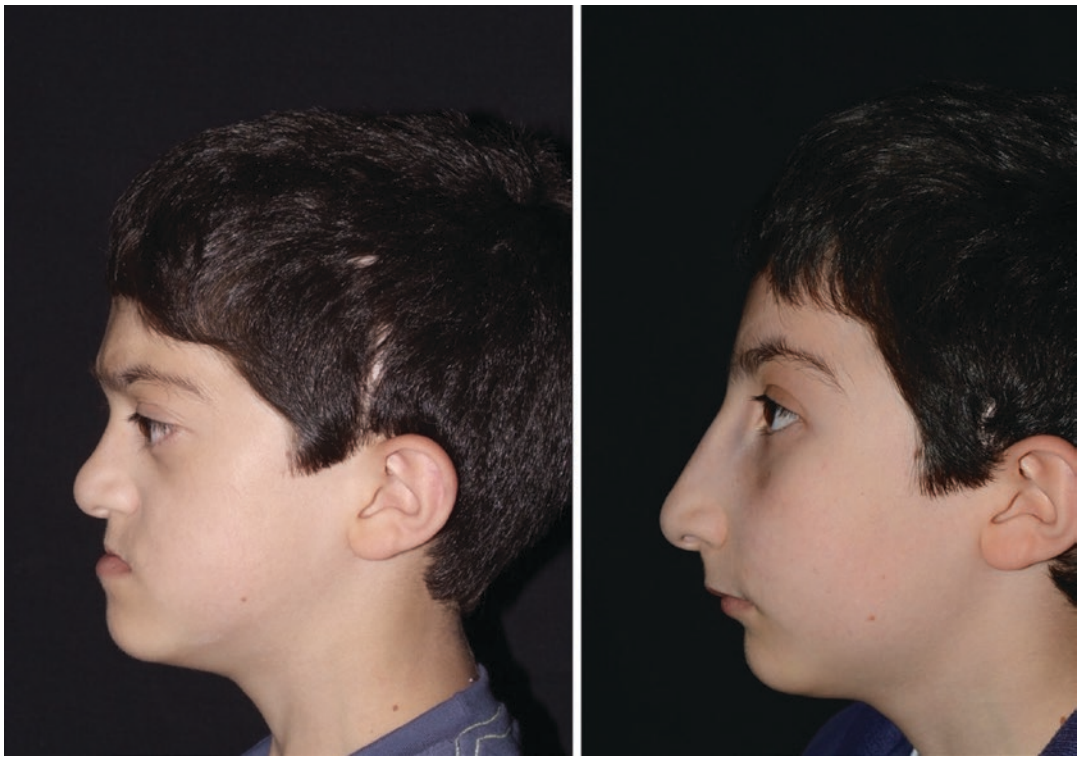


Fig. 12.18 LeFort III osteotomy and advancement, pre- and postoperative

12.12 Ear Reconstruction

Total ear reconstruction for microtia is performed by autologous costal cartilage or porous polyethylene implants. Among the major difficulties in reconstruction of microtia is the short position of the hairline. This is related to the soft tissue deficiency and the underlying skeletal asymmetry and can require the positioning of a skin expander for hairline repositioning before ear reconstruction. In both techniques, the lobule is reconstructed from the microtic ear.

The reconstruction by cartilage requires the harvesting of VI, VII, VIII, and, in some cases, IX costal cartilages. These are sculpted and united to create the three-dimensional contours of the ear (on the model of the contralateral ear) and are placed under local skin flaps (Fig. 12.19).

Autologous reconstruction of microtia with a sculpted costochondral graft is classically performed in staged procedures, as originally described by Tanzer. Then Brent, Nagata, and Firmin modified the methods to achieve finer results in fewer stages. Today this reconstruction is performed in two steps: (1) cartilage sculpting and inset; and (2) restoration of the retro-auricular sulcus. Nagata recommends waiting until 10 years of age to allow the rib cartilage to achieve adequate cartilage volume and stiffness.

The reconstruction by porous polyethylene, first described by Reinisch, can even be performed at a younger age (e.g., 5 years old). The techniques consist in the insertion of the implant (after union of a base and a helicoidal rhyme, on the model of the contralateral ear), raising of the superficial temporal fascia flap, and harvest full-thickness skin grafts (Fig. 12.20).

In expert hands, both techniques produce good results, but both have important limitations. The gold standard of the ear reconstruction will be reached when 3D printing of autologous cartilage will be available.

12.13 Glossectomy for Macroglossia

Macroglossia is defined as a tongue that in the resting position protrudes beyond the teeth toward the alveolar ridge. It is a typical feature of the Beckwith–Wiedemann syndrome (97%) and may cause a functional and esthetic abnormality with problems in speech, chewing, swallowing, and suction. Moreover, it can cause upper airway obstruction and obstructive sleep apnea syndrome.

Therefore, children with macroglossia should have formal evaluations for potential effects on feeding, speech, and sleep. This evaluation determines the indication of the partial glossectomy, which is the reduction of less than one-half tongue. The simplest approach is transoral.

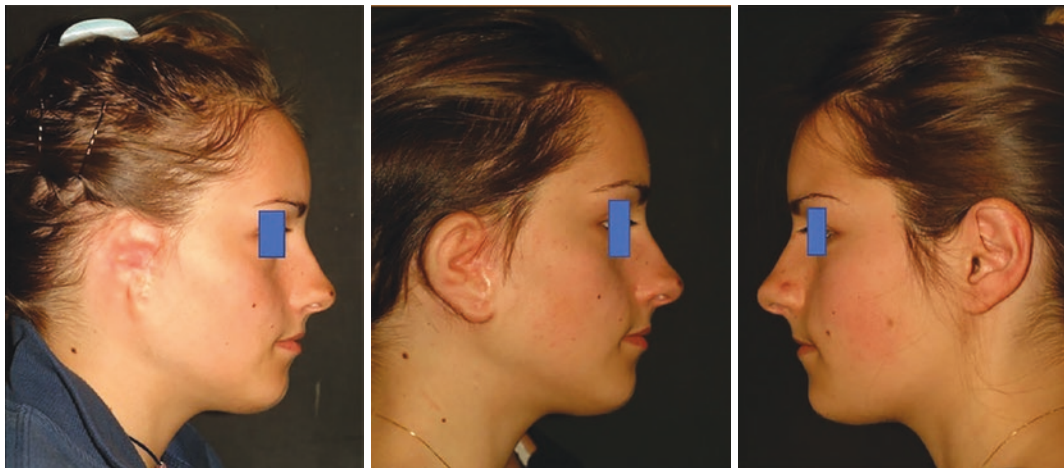


Fig. 12.19 Ear reconstruction by cartilage: pre- and postoperative, and contralateral ear

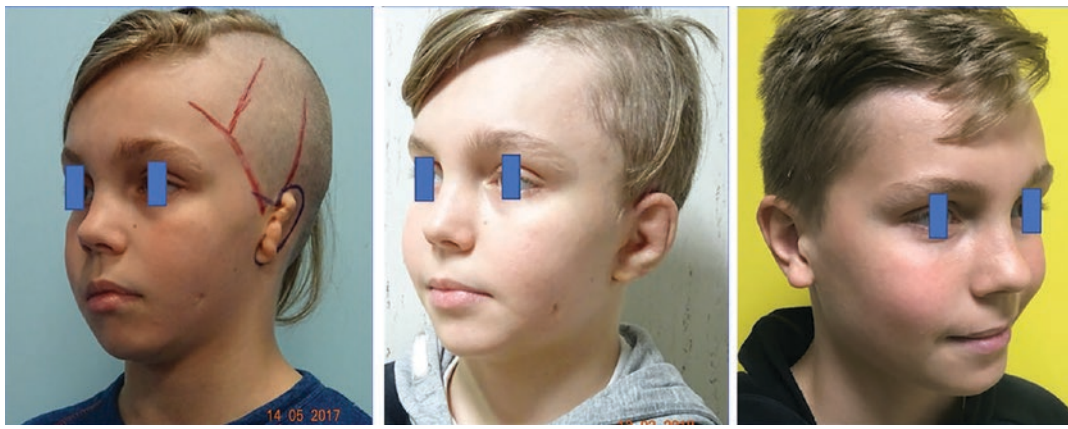


Fig. 12.20 Ear reconstruction by polyethylene and superficialis temporal fascia: pre- and postoperative, and contralateral ear

In the procedures most widely used, the tongue is removed on the midline with mucosal and muscle incisions, central reductions, and wedge resections. Among these techniques, Obwegeser described a central reduction technique that includes incisions in the apex and in the middle part of the tongue, which promotes the longitudinal and transversal reduction, even if it has as a limitation the maintenance of the tongue height.

Take-Home Message

- Craniofacial malformation evaluation and treatment require the skills of a dedicated multidisciplinary team, coordinated in a cleft and craniofacial center.
- Craniofacial malformations develop between the fourth and eighth weeks of gestation. Diagnosis of anomalies is prenatal with ultrasound or at birth. These children must be addressed to a pediatric cleft and craniofacial center.
- Majority of patients with craniofacial malformations have no mental deficiencies, and an appropriate staged surgical correction is fundamental for normal social life and interaction.
- Primary surgery has to be precise, keeping the fourth dimension in mind.

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Malformations of the Hand

13

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13.1 Introduction

Congenital anomaly of the hand is an area that not every hand surgeon engages in routinely. How do hand surgeons set priorities when dealing with congenital anomalies of the hand? Congenital anomalies are often complicated structural abnormalities, so the question of priority would really deserve close scrutiny. Before every surgical intervention, an analytical prioritization would help significantly to achieve a functional restoration. The relationship between structure and function of the hand is so intimate that in any structural correction of the hand, the priority should be on the functional restoration rather than a simple structural correction. In other words, with the exception of pure cosmetic corrections under very special circumstances, functional restoration or improvement overrules structural corrections. Functions of the hand should not be defined vaguely; these have been identified and labeled pretty well in the past. These functions include three different types of grip: power, diagonal, and hook; three different types of pinch: tip pinch, side pinch, and palp pinch, fulfilling different demands on physical activities, sensory feeling, and, lastly, expression. All surgical planning should pay full attention to the functional goal we want to achieve. Although the physical ability of the individual has a lot to do with the functional achievement based on intact hand structure, one still has to observe that structural integrity is not everything. By that, we are talking about the length and position of the digits, the mobility and stability of the joints, the strength of the components, and the sensation of the tactile parts. Without a proper length and favorable position, no digit could function. Without stability and mobility, no joint could function. Without reasonable strength, no hand could function properly, and, without sensation, a hand would not be able to protect itself, not to mention precision performance. These components need to be considered together. For example, good length without stability or mobility is meaningless.

Key Points

Congenital differences of the upper limb occur in approximately 0.16–0.18% of live births. Approximately 10% of these infants will have a partial or complete absence of the involved limb, leading to serious loss of function.

Because limb formation occurs concurrently with other organ development, it is

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important to be aware of associated abnormalities, including cardiac, hematopoietic, or tumorous conditions. Communication with the pediatrician is important in establishing a comprehensive diagnosis and for staging and planning any reconstructive procedures. A multidisciplinary approach will provide superior outcomes by addressing all aspects of the physical and emotional state of both the patient and the family.

Because congenital anomalies of the upper limb are a significant challenge, the hand surgeon or reconstructive surgeon, as the team leader and primary decision-maker, has a unique opportunity to positively and directly affect the child's growth and development.

A child achieves bimanual palmar grasp by the age of 9 months and learns three-digit pinch between 1 and 2 years. Patterns of hand–eye coordination have been established by age 3. Therefore, successful technical reconstruction may fail to alter already established fixed functional or psychological patterns if the reconstruction is not completed by approximately 4 years of age. Ideally, the reconstruction should be completed by school age to allow for easier social transitioning [1].

13.2 Principles Governing Pediatric Management

It would be wrong to consider children as small adults. Correction of deformities needs to take into consideration the age and the growth, not only the structural dimensions. Although growth plates and growing epiphysis are vulnerable to injury, it did not mean that they could not be touched. Perhaps as long as the epiphyseal plate is untouched, the epiphysis could be cut flat and stitched to its adjacent component in an attempt to achieve linear fusion, trying not to affect the optimal growth. Similarly, enlarged or abnormally faceted epiphyses could be shaved to give more congruent articulating surfaces without affecting the ultimate growth of the components handled. Tada and Yonenobi used this technique extensively in the Duplex thumb to bring more satisfactory alignment of the retained component after sacrificing the unwanted component. Young children do not tolerate pain and limitations of activities. Henceforth, dressing has to be double safe and better protected, pinning has to be secure and hidden, and casts need to go up one proximal joint (e.g., including the elbow) in order to avoid loosening. Taking care of the postoperative child should include paying attention to his psychological needs. The hand often reflects the mind. The hand is an important body image second only to the face. It is therefore easy to understand how a structurally abnormal hand could significantly affect a child. If possible, correction should be completed by school age [2]. It would be wrong to assume that severe psychologic disturbances exist only in children with severe anomalies and not in those who are not so seriously affected (duplication or syndactyly). In fact, the actual outcome of possible psychologic disturbances depends on environmental conditions, individual circumstances, and immediate family support. It should be mandatory for every child with a hand anomaly to receive a proper psychological assessment [3].

Radiologic images (perhaps inaccurate imaging of a growing child, unossified epiphyses) need to be interpreted with extra caution and with a sound knowledge of ossification centers; otherwise, fractures and displacements could be misdiagnosed. Likewise, correct interpretation about length issues cannot be accurately given. The varieties of imaging have expanded extensively in recent years so that congenital anomalies could acquire many benefits. Although conventional radiography and angiogram still served routinely for structural identification and delineation of vascular patterns, disappointments are not uncommon. Ultrasonic examinations could help in recognizing inflammation conditions such as tendonitis. The same device and technique could be useful to help identify thickened soft-tissue structures and to differentiate tissue planes

between the normal and abnormal tissues. Conventional tomography and computed tomography of the radioulnar joint and the wrist are used in patients with persisting complaints or doubtful findings on plain radiographs and difficult anatomical situations. Suspected ligamentous injuries of the wrist, including tears of the triangular fibrocartilage complex, are evaluated by wrist arthrography or magnetic resonance imaging, the latter requiring a highly skilled imaging and interpretation technique. Magnetic resonance imaging is the method of choice for the detection of osteonecrosis. The use of real-time sonography allows a reliable diagnosis of the cystic or solid nature of soft-tissue tumors and accurate estimation of their volume and their precise 3-dimensional localization. Sonography facilitates the location of foreign bodies and appears as a new promising technique for the evaluation of tendons [4].

Key Points

In children, the neurovascular bundle is much more stretchable than in adults. However, structural anomalies could well be associated with neurovascular anomalies. Awareness is much more important than special investigations, which cannot be taken as routine.

Tips and Tricks

To correct the alignment, very often the surgeon has to deal with joint surfaces and epiphyseal articulations. It is important to remember that as long as the growth plate is not touched, growth disturbance will not occur. If desired, therefore, the cartilage end could be shaved. Surgery these days tends to become gadget driven and gadget dependent. Surgical procedures should be followed closely, step by step. However, surgery performed for children with anomalies demands extra flexibilities on the operating table. Immediate decisions have to be made whether to stretch the neurovascular tissues or not; perhaps whether to end the surgery for a two-staged maneuver or to continue on to completion; whether to attempt perfection or to accept some defects; whether to use a fixation device or rely on casting alone; and so forth.

13.2.1 Reconstruction of Congenital Differences of the Hand

Expansion of the discipline of hand surgery and heightened interest in congenital problems have resulted in major advances in the treatment of congenital hand anomalies over the past 25 years. Increased experience with congenital anomalies of the hand has expanded the hand surgeon's knowledge of patterns and relationships between different anomalies, resulting in new methods of classification and more logical approaches to treatment. The principles of treatment of the more common anomalies, such as syndactyly, established by prior generations of hand surgeons have been refined in details of technique. New technologies, such as distraction lengthening and free vascularized transfers, have allowed the surgeon to treat new problems and old problems in new ways. In spite of our successes, much remains to challenge hand surgeons in this new millennium, especially in the construction of joints and the expanding field of fetal surgery.

13.2.1.1 Timing of Treatment

Treatment options and timing of treatment depend on the anomaly, although most advocate that surgical correction should be performed within the first 2–3 years of life to allow for maximal growth, development, and use. In addition, early treatment improves scarring and decreases the psychological impacts of congenital hand syndromes. Despite that, early operative procedures prove to be technically challenging. Noninvasive treatment options may be advisable in the first 1–2 years of life as the child grows.

These options include splinting, stretching, physical therapy, and prosthesis for increased function and cosmesis [1].

13.3 Epidemiology

Congenital hand conditions are common, occurring in 2.3 per 1000 of total births or 0.16% –0.18% of the population of the United States, with incidence varying according to region and ethnicity. Ekblom et al. reported a worldwide incidence of 21.5 per 10,000 live births. Lamb et al. and Giele et al. reported the overall prevalence of congenital hand anomalies to be 11.4–19.7 per 10,000 live births. Of the anomalies included, failure of differentiation is the most commonly reported, followed by failure of duplication and failure of formation anomalies. Polydactyly is the most common individual diagnosis. Although overall only slight variation exists in the prevalence of major anomalies among different regions or ethnic populations, there are exceptions. For example, ring constriction syndrome is 4 to 6 times more prevalent in Japan than in Scotland. Ulnar polydactyly is more common among those of African descent. In general, males are more likely to be affected by congenital hand anomalies than females with an overall ratio of 3:2. The prevalence of congenital hand anomalies increases with maternal age. Mothers older than 40 years are twice as likely to have a child with hand deformity than mothers younger than 30 years, 5–20% of upper limb anomalies occur as a part of a known syndrome, and 50% occur bilaterally. Up to 17% of patients will present with multiple upper limb anomalies, and up to 18% of patients will die before the age of 6 years because of other concurrent congenital disorders [5].

Because limb formation occurs concurrently with other organ development, it is important to be aware of associated abnormalities, including cardiac, hematopoietic, or tumorous conditions. Communication with the pediatrician is important in establishing a comprehensive diagnosis and for staging and planning of any reconstructive procedures. A multidisciplinary approach will provide superior outcomes by addressing all aspects of the physical and emotional state of both the patient and the family.

Therefore, successful technical reconstruction may fail to alter already established fixed functional or psychological patterns if the reconstruction is not completed by approximately 4 years of age. Ideally, reconstruction should be completed by school age to allow for easier social transitioning.

13.4 Embryology of Limb Development

During embryonic development, the upper extremity develops from the arm bud, a mass of mesoderm-derived mesenchyme covered by ectoderm. The Hox genes (HoxA, HoxB, HoxC, and HoxD) are responsible for regulating limb development in the human embryo. Sonic hedgehog, fibroblast growth factor, and Wnt-7a are some of the known signaling proteins that control Hox gene expression. Hox gene products act on competent mesenchymal cells within the limb bud, guiding these cells to form condensations at the appropriate time and location. These condensations form the precartilaginous skeletal foundation of the limb. The limb must form simultaneously across three anatomical axes: proximal to distal axis, dorsal to palmar axis, and anteroposterior (preaxial/ postaxial) axis. The apical ectodermal ridge forms as a thickening of ectoderm at the leading edge of the limb bud and, through its interactions with the underlying mesenchymal cells, is responsible for proximal to distal differentiation of the limb. The dorsal ectoderm helps to control the dorsal to palmar axis of differentiation, leading to distinct flexor and extensor surfaces of the hand and arm. The zone of polarizing activity is a condensation of mesenchymal cells on the preaxial surface of the limb bud. This zone signals the anteroposterior formation of the limb bud by setting up a gradient of signaling proteins along this axis. The arm bud begins as an outgrowth from the ventrolateral wall of the developing embryo and appears at approxi-

mately 30 days' gestation. Located opposite the fifth through seventh cervical somites, the arm bud precedes lower extremity development throughout embryogenesis. At 33 days' gestation, blood circulation develops within the bud, which has established a flipper-like appearance. By 38 days, blood vessels have become apparent growing from proximal to distal, and a constriction marks the separation of the forearm from the upper arm. Finger development is apparent by day 44, with five distinct mesenchymal separations. By day 52, the digits are completely separated because of apoptosis of the intervening mesenchymal tissue. This orderly resorption of tissue occurs through the release of lysosomal enzymes as cells migrate toward the digital condensations to participate in chondrogenesis. By approximately the seventh week of gestation, the limb bud rotates 90 degrees on its long axis with the elbow positioned dorsally. By the eighth week of gestation, embryogenesis is complete. After the eighth week, the small but completely formed upper limb continues to grow in size and primary ossification centers replace areas of cartilage to complete development [6–10].

13.5 Classification

Several classification schemes for congenital upper limb malformations have been conceived. The current classification scheme has been agreed on by the American Society for Surgery of the Hand and the International Federation of Societies for Surgery of the Hand and was first published by Swanson. This classification comprises seven groups based on abnormalities of embryogenesis: failure of formation of parts, failure of differentiation of parts, duplication, overgrowth, undergrowth, constriction ring syndrome, and general skeletal abnormalities. Many of these groups are further subdivided by the anatomical level of the malformation. In this chapter, the International Federation of Societies for Surgery of the Hand classification scheme is used to organize the discussion on congenital hand surgery [11–13].

13.5.1 Failure of Formation of Parts: Transverse Arrest

13.5.1.1 Transverse Deficiencies

Transverse deficiencies of the upper limb may occur at any level from the shoulder to the phalanges. Transverse arrest most commonly occurs at the level of the proximal third of the forearm and at the wrist. Digital appendages, or nubbins, are often found at the end of the limb. Transverse deficiencies are usually isolated, unilateral, and sporadic. These defects are thought to be the result of vascular disruption at some point during embryogenesis of the upper limb. Transverse deficiency differs from constriction ring syndrome; the latter tends to be hypoplastic at the same level in that proximal parts.

13.5.2 Proximal Transverse Deficiencies

With proximal transverse deficiencies, treatment is usually a prosthetic device. These devices may be static or dynamic and may be controlled by remaining skeletal structures or myoelectric impulses. For children with transverse deficiency at the wrist or metacarpal level, a volar paddle prosthesis may act as a post against which the remaining carpus or metacarpals may be flexed. In bilateral deficiencies, children often become adept at using their lower extremities to perform activities of daily living. Surgical options for proximal transverse deficiencies may include removal of functionless digital nubbins, stump revision to allow for prosthetic fitting, and excision of excess or functionless parts. In children with bilateral deficiencies and visual impairment, the Krukenberg procedure is advocated. This procedure separates the distal ulna from the radius, allowing for the opposition of the two bones during supination of the forearm.

Key Points

Prosthetic devices are the treatment of choice for children with proximal transverse deficiencies.

13.5.3 Transverse Arrest of the Digits Distal to the Metacarpal Level

Transverse arrest of the digits distal to the metacarpal level, sometimes referred to as symbrachydactyly, has been treated by conventional techniques of distraction lengthening and nonvascularized toe phalangeal bone grafting. Metacarpal or phalangeal lengthening uses the principles of distraction osteogenesis to form new bone. A distractor is placed spanning a metacarpal or phalangeal osteotomy or corticotomy, and the bone is distracted 0.5–1 mm per day for 3–6 weeks until the desired digit length is achieved. The bone gap may consolidate with regenerate bone or may require secondary autogenous or allograft bone grafting. Transverse deficiencies of the digits may also be treated with nonvascularized toe phalangeal bone grafting from the proximal phalanges of the second, third, or fourth toe. Up to 1.5 cm of length can be achieved with each proximal phalanx graft. Whether the epiphysis of a toe phalangeal bone graft continues to grow remains controversial. It has been recommended that toe phalangeal bone grafts should be performed before 15 months of age, that the bone should be harvested extraperiosteally, and that the collateral ligaments and tendons should be reattached to provide the optimal conditions for the physis to remain open and thus maintain growing potential. Free microvascular toe-to-hand transfer is becoming an increasingly accepted method for treatment of these patients. The first toe-to-hand transfer was performed by Nicoladoni in 1897 for a traumatic thumb amputation and required multiple stages to preserve the blood supply to the transferred toe. In 1955, Clarkson reported the first series of congenital toe-to-thumb transfers with 15 transfers in six patients. Because multiple stages required immobilization of the hand to the foot, the procedure fell out of favor. The first successful microvascular toe-to-hand transfer was reported by Cobbet in 1969 and led to the possibility of free toe transfers for congenital malformations. The first toe-to-hand transfer to reconstruct a congenital anomaly was performed by O'Brien et al. in 1978. In 1995, Vilkki reported a series of 18 successful congenital toe transfers, with an 11-year follow-up proving that toe transfer was beneficial in this population. Several congenital anomalies have been treated with toe transfer, including transverse deficiency, longitudinal deficiency, traumatic amputation, vascular malformations, and constriction ring syndrome. Studies have shown that growth potential is retained in the transferred toe. Epiphyseal plates remain open, and bone growth is comparable to that of the corresponding toe on the contralateral foot. A long-term study of toe-to-hand transfers in post-traumatic deformities has shown good hand function and acceptance of the transferred digit up to 20 years after the procedure. Transverse deficiency of the thumb is an ideal indication for free microvascular toe-to-hand transfer. Unlike longitudinal thumb deficiencies, the proximal thumb remnant tends to retain some normal anatomy, including a mobile carpometacarpal joint, thenar muscles, and proximal stumps of the flexor pollicis longus and extensor pollicis longus tendons. In such cases, a microsurgical second toe-to-thumb transfer is a better option than pollicization of the index finger. In children with a thumb but the absence of all four fingers or with the complete absence of all five digits, bilateral second toe transfers can be performed. The two toe transfers can provide three post pinch to a remaining thumb or one toe transfer can be used to reconstruct the thumb and the other toe transfer can be used to create a digit for pinch activity. The child's family should be carefully counseled regarding the limitations and potential complications before proceeding with this extremely difficult reconstruction [14, 15].

Tips and Tricks

- Toe phalangeal bone grafts should be performed before 15 months of age.
- The bone should be harvested extraperiosteally.
- The collateral ligaments and tendons should be reattached.

13.5.4 Failure of Formation of Parts: Longitudinal Arrest

13.5.4.1 Radial Longitudinal Deficiency

Radial longitudinal deficiency, or radial club hand, involves approximately 1 in 30,000 to 1 in 100,000 live births and is more common in boys than in girls and affects Caucasians more often than other races. The deformity is bilateral up to 50% of the time and, when unilateral, affects the right side more often than the left (Fig. 13.1a, b).

Radial longitudinal deficiency is often found in association with other malformations of the hematopoietic, cardiac, genitourinary, and skeletal systems, including Fanconi anemia, TAR syndrome (thrombocytopenia, absent radius), Holt–Oram syndrome (cardiac defects), and the VATER association (vertebral anomalies, anal atresia, tracheoesophageal fistula, renal defects). Radial longitudinal deficiency has been classified into four types based on the severity of the involvement of the radius. Thumb hypoplasia is often present, ranging from slight to total absence. The scaphoid and trapezium may also be absent. Radial sided digits often exhibit a flexion deformity or camptodactyly. The small finger is often unaffected, with relatively normal function. Short, fibrotic muscles run along the radial side of the forearm and insert into the ulna, causing severe bowing. The ulna may also be short, and the distal humerus is often hypoplastic, leading to stiffness of the elbow. Both the radial artery and radial nerve may be absent. The median nerve is always present and courses superficially below the skin in the radial concavity, making it prone to injury during operative exposure. Radial longitudinal deficiency results in very poor function in the affected hand because of the flexed position of the radially deviated hand, loss of wrist support, poor flexor/extensor tendon excursion, hypoplasia of the thumb, and stiffness of the elbow. These deformities increase with age, leading to deteriorating function. Psychologically, the appearance of the hand can be quite troubling for both the child and the parents. For these reasons, treatment should be done immediately after birth and consists of passive stretching exercises and serial casting to begin, centralizing wrist and hand on the remaining ulna. Contraindications to treatment include older patients who have adapted to their deformity and children with stiff elbows. In these circumstances, the radial angulation of the hand and carpus makes feeding and hygiene possible in the presence of a stiff elbow. Surgical treatment of radial longitudinal deficiency attempts to improve the appearance and function of the hand by stabilizing the carpus on

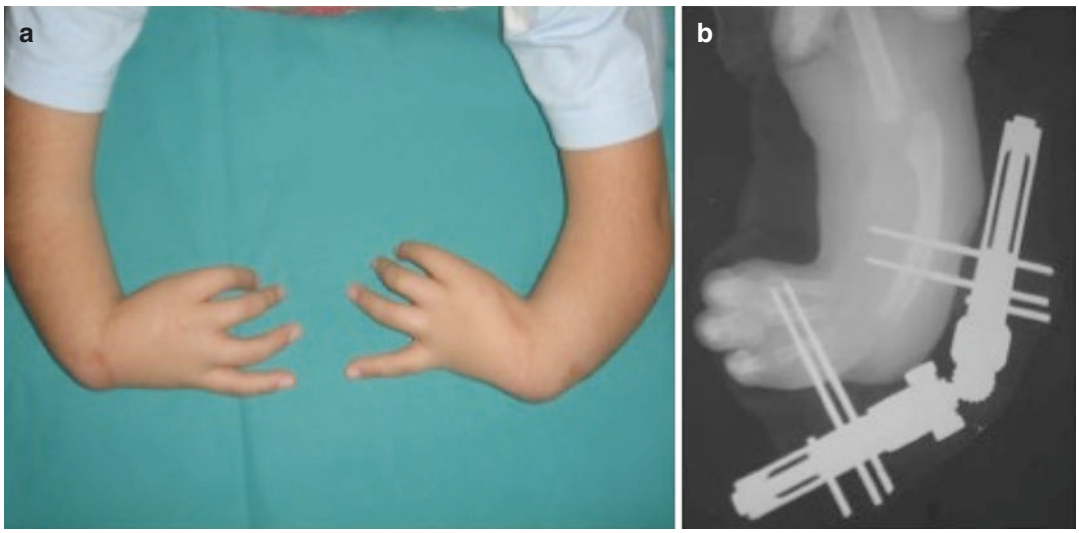

Fig. 13.1 Radial longitudinal deficiency; (**a**) clinical picture, (**b**) post-operative x-ray

the end of the ulna. Historically, centralization of the carpus over the ulna and bone grafting of the absent radius have been attempted, but centralization of the carpus only on the ulna remains the definitive treatment. Centralization is usually performed in the first year through a Z-plasty incision over the radial aspect of the wrist to release the tight skin envelope. After identifying the median nerve, the carpus is freed from the radial fibrotic muscle mass and then centralized over the ulna after transecting the brachioradialis, flexor carpi radialis, and extensor carpi radialis longus tendons. The lunate may need to be excised to fit the carpus over the end of the ulna. A longitudinal Steinmann pin is used to hold the middle finger metacarpal bone and carpus over the ulna for several months. Radial deforming tendons such as the flexor carpi radialis may then be transferred to the extensor carpi ulnaris to help rebalance the carpus [2].

Tips and Tricks

Buck-Gramcko has advocated radialization of the carpus in which the deformity is overcorrected to the ulnar side by placing the ulna along the axis of the index finger metacarpal bone. Preoperative distraction may be performed initially to allow the carpus to be radialized or centralized without the need for resection of carpal bones. If significant ulnar bowing is present, a corrective osteotomy or multiple osteotomies may also be performed and fixed with the same Steinmann pin to help straighten the long axis of the forearm.

13.5.4.2 Ulnar Longitudinal Deficiency

Ulnar longitudinal deficiency occurs in 1 in every 100,000 live births. The deformity is often sporadic and does not have the syndromic associations of radial longitudinal deficiency. However, approximately 50% of the patients will have some type of musculoskeletal abnormality, including the contralateral upper limb or the lower limbs. There is a clinical spectrum from hypoplasia of the ulna with an intact epiphysis to total absence of the ulna with radiohumeral synostosis. In all cases, a fibrous anlage tether replaces the missing ulna and inserts into the ulnar aspect of the carpus or the distal radius epiphysis. The flexor carpi ulnaris is absent, the ulnar and median nerves are present, but the ulnar artery is often absent. Unlike radial longitudinal deficiency, the wrist is stable, allowing for relatively normal digital function. The radial head may be dislocated, leading to pain or loss of function at the elbow. With the most severe deficiencies, the humerus is internally rotated and the forearm pronated, compromising the positioning of the hand. Treatment of ulnar longitudinal deficiency consists of serial casting to improve the wrist and elbow positions. Excision of the anlage is indicated for greater than 30 degrees of angulation or when the deformity is progressive. The anlage is approached through a lazy-S incision and resected off from the carpus or distal radius. Kirschner wires may be used to hold the wrist in a neutral position. Tendon transfers are not required; however, in severe bowing, a radial osteotomy may be required to help straighten the long axis of the forearm. When there is a loss of function at the elbow, the proximal radial head is resected, and a one-bone forearm is created by osteosynthesis of the distal radius to the proximal ulna. In the case of radiohumeral synostosis, a derotational osteotomy of the humerus may be required to place the hand into a more functional position. Arthroplasty of the elbow is not advised because of the low likelihood of success [16].

13.5.4.3 Central Ray Deficiency

Central ray deficiency, or cleft hand, was originally classified as either typical or atypical. Typical (true) cleft hand is caused by failure of development of the central digit of the hand, the middle finger, including the metacarpal bone, which leads to a deep V-shaped cleft. The border digits are occasionally involved in syndactyly with a tight first web space. Transverse bones separating the index and ring fingers are often present. Atypical cleft hand is now considered to be a variant of symbrachydactyly. The central digits of the hand are shortened or absent, with

vestigial nubbins remaining. The "cleft" is broad and flat, unlike the V-shaped cleft of typical central ray deficiency, usually leaving a thumb and ulnar border digits. Cleft hand is usually inherited as an autosomal dominant trait, with reduced penetrance and variable expressivity among family members. There may be associated abnormalities, including cardiac, visceral, ocular, auditory, and musculoskeletal, including cleft feet. Manske and Halikis have classified cleft hands based on the involvement of the first web space, which is the most predictive factor of hand function and therefore helps guide surgical treatment. Flatt described cleft hand as a "*functional triumph but a social disaster*." Treatment is directed at closing the cleft to improve the appearance of the hand and to treat any syndactyly that may exist. Transverse bones are removed from within the cleft, as these will continue to grow and push the cleft farther apart with age. If the ulnar border digits are syndactylized, they can be released at the time of cleft closure [17–20].

Tips and Tricks

The Snow–Littler procedure may be used to release the first web space syndactyly by releasing the thumb from the index finger and then transposing the index finger ray onto the middle finger metacarpal remnant, thereby achieving web release and cleft closure simultaneously. Alternatively, closure of the cleft by transposition of the index finger into the middle finger position as described by Miura and Komada could be used and may be technically simpler.

13.5.5 Undergrowth

13.5.5.1 Hypoplastic Thumb

Hypoplastic thumb may also be characterized as a variant of radial longitudinal deficiency and is often associated with radial club hand. Children with a hypoplastic thumb may begin to develop a widening of the second web space to achieve rudimentary pinch between the index and middle fingers. Children with a complete absence of the thumb may develop pronation of the index finger for the same reason. Therefore, treatment is often recommended by the second year to establish more normal prehensile patterns. The Blauth classification is used to categorize thumb hypoplasia. Type I is a slightly shorter normal functioning thumb and does not require any treatment. Types II and IIIA, in which the carpometacarpal joint is stable, can be treated with deepening of the first web space and a tendon transfer to improve opposition. The web space is deepened by a traditional four-flap Z-plasty procedure [21].

The Huber transfer uses the abductor digiti minimi to recreate the thenar eminence and replace the hypoplastic intrinsic muscles. The flexor digitorum superficialis from the ring finger may also be transferred through a window in the transverse carpal ligament to restore thumb opposition. Types IIIB, IV, and V require complete reconstruction because of an unstable or absent carpometacarpal joint. Index finger pollicization is the treatment of choice for these children (Fig. 13.2a, b) [22].

Pollicization was originally described by Littler and modified by Buck-Gramcko. In this technique, skin flaps are designed to widen the web space between the new thumb and middle finger. The index finger is elevated as an island flap on its radial and ulnar neurovascular pedicles, dorsal veins, and tendons. An osteotomy of the second metacarpal bone at the level of the distal epiphyseal plate is performed, and the metaphyseal flare at its base and the intervening shaft are removed. The finger is pronated between 140 and 160 degrees, and the metacarpal bone is placed in 45 degrees' abduction palmar to the base of the index finger metacarpal bone. The metacarpal head then becomes the new carpometacarpal joint. The first dorsal interosseus muscle is reattached to become the abductor pollicis brevis, the first palmar interosseous muscle becomes the adductor pollicis, the index extensor digitorum communis functions as the abductor pollicis longus, and the extensor indicis proprius becomes the extensor pollicis longus [23].

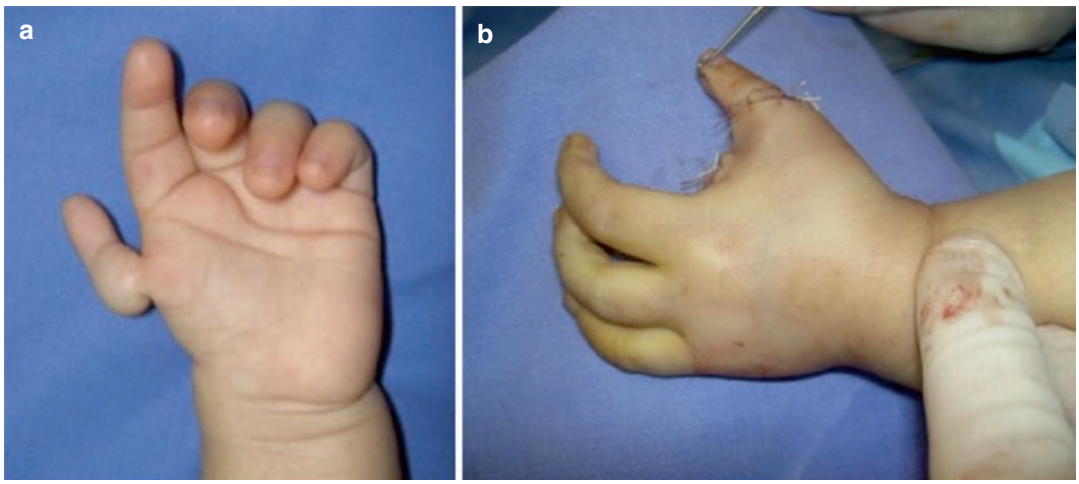

Fig. 13.2 Hypoplastic thumb; (**a**) pre-operative picture, (**b**) Pollicization: immediate post-operative result

13.5.6 Failure of Separation of Parts

13.5.6.1 Syndactyly

Syndactyly results from failure of digital separation and is one of the most common congenital hand malformations. It occurs in approximately 1 in 2000 births and is common in white male children. It occurs bilaterally in 50% of cases, and 10–40% of these cases show a family history of inheritance as an autosomal dominant trait. Inherited forms are associated with genetic defects involving particular candidate regions on the second chromosome. In isolated syndactyly, the third web space is most commonly affected, whereas the first web space is the least commonly affected. Syndactyly is classified as either complete or incomplete and as either simple or complex, depending on the degree of skin and/or bone involvement. In complete syndactyly, the web extends out to the nails, whereas incomplete syndactyly stops short of the fingertips. Simple syndactyly involves only the soft tissues, whereas complex syndactyly involves the phalanges, most commonly involving the fusion of the distal phalanges. Syndactyly associated with other anomalies such as polydactyly, constriction rings, toe webbing, brachydactyly, spinal deformities, and heart disorders is termed complicated syndactyly (i.e., Apert syndrome). Surgical release of syndactyly is recommended early to allow normal growth of the digits and normal grasp and pinch. Timing of syndactyly release is based largely on surgeon preference, although most begin the separation by 12 months of age with the goal of finishing all releases by the time the child is of school age. Early release of syndactyly involving the first web space, complex syndactyly involving the distal phalanges, and syndactyly producing a flexion contracture of the longer digit may require release by 3–6 months of age. Syndactyly involving more than one web space, such as in Apert or Poland syndrome, requires a decision on the sequence of staged releases because usually only one side of a digit should be released at one time to avoid vascular compromise of the digit that would occur if both sides of the digit were released simultaneously. The border digits, thumb, and small finger are usually released first, followed by the central three digits several months later. In complete syndactyly, the web space is reconstructed with a proximally based dorsal rectangular flap. The design of interdigitating skin flaps must be planned carefully, and triangular, zigzag, and rectangular incisions have all been used. Separation will not usually provide sufficient skin to resurface the circumference of each digit, and thus skin grafts are required. Full-thickness skin grafts are preferred to split-thickness grafts, as they are less prone to contracture. In incomplete syndactyly, various other techniques, including simple Z-plasty, four-flap Z-plasty, or double-opposing Z-plasty

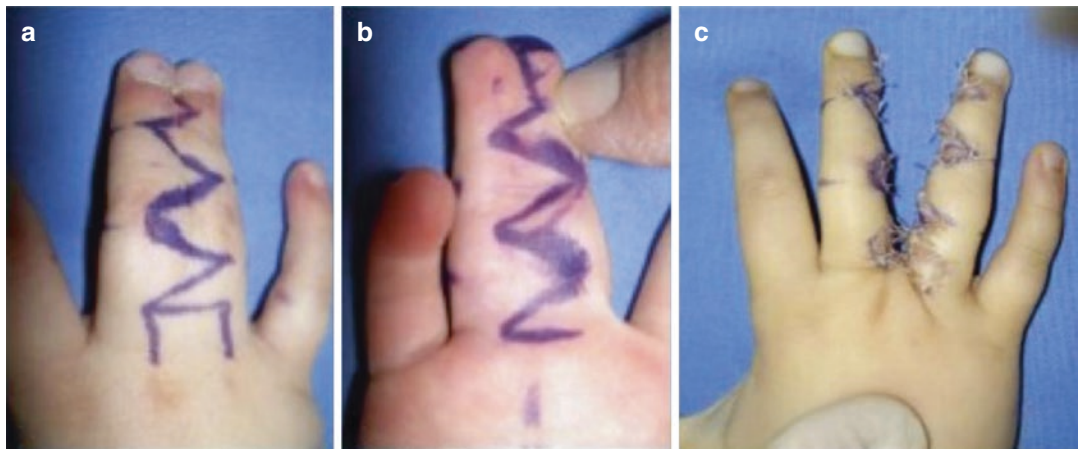

Fig. 13.3 (**a**, **b**) preoperative drawing, (**c**) immediate postoperative result Syndactyly

(Fig. 13.3a, b, c), may allow separation of the digits and deepening of the web space without requiring full-thickness skin grafts [24–28].

Key Points
Surgical release of syndactyly should be performed as early as possible to allow normal growth of the digits and normal grasp and pinch.

13.5.6.2 Radioulnar Synostosis

Congenital proximal radioulnar synostosis results from the failure of developing cartilaginous precursors of the forearm to separate late in the first trimester. It is bilateral in 60% of all patients. The incidence is unknown, and in most cases, it occurs sporadically, but it can be inherited as an autosomal dominant trait with variable penetrance. Children usually present between 2 and 6 years of age, with the absence of forearm rotation and a slight elbow flexion contracture. Children are often at school age before a diagnosis is made; this is due to the fact that the wrist has the ability to compensate for the lack of pronation/supination of the forearm. Clinical suspicion warrants radiographs of the forearm, which reveal the proximal radioulnar synostosis. The radial head is often subluxed or dislocated. Surgical management depends on the severity of the synostosis and the resulting functional impairment. Extreme pronation or supination that interferes with function is an indication for surgery. In addition, a forearm fixed in greater than 60 degrees of pronation generally requires surgery. Derotational osteotomy either at the site of synostosis or in the diaphysis of the radius and ulna to fix the forearm in neutral or slight pronation has been advocated. However, resection of the synostosis and interposition of autologous tissue or allograft between the radius and ulna is favored. However, separation is tenuous, as the synostosis tends to recur. Many interposition materials, to place, at the time of separation have been studied, including synthetic materials, autologous tissues, and allograft tissue. Synthetic materials, such as silicone and polyethylene sheeting, and autologous tissues (i.e., nonvascularized or vascularized tissue), such as free fat grafts, radial forearm fascial flap, and free lateral arm adipofascial flap, have been used. In addition, some surgeons have recommended perioperative irradiation, although this is usually used for post-traumatic radioulnar synostosis [29, 30].

Key Points
Extreme pronation or supination that interferes with function is an indication for surgery.

Surgery is recommended when the forearm is fixed in pronation >60°.

13.5.6.3 Symphalangism

Symphalangism is the term used to describe the failure of interphalangeal joint development and fusion of the proximal phalanges to the middle phalanges and was first described by Cushing in 1916. This condition represents 1% of all congenital upper extremity anomalies and is frequently transmitted as autosomal dominant. Flatt and Wood classified symphalangism as true symphalangism without additional skeletal abnormalities, symphalangism associated with symbrachydactyly, or symphalangism with syndactyly. Clinically, there is the absence of motion, and there are not skin creases in the affected digits. The proximal interphalangeal joint does not develop with growth. The affected fingers do have some flexion, as the metacarpophalangeal and distal interphalangeal joints are present and have a normal range of motion. Attempts have been made to reconstruct or replace the proximal interphalangeal joints, but results have not been favorable. If a child has a poor grasp secondary to symphalangism, a wedge of bone can be removed from the level of the proximal interphalangeal joint and the phalanges fused in 45 degrees of flexion.

13.5.6.4 Duplication (Polydactyly)

Polydactyly can occur on the preaxial (radial) or postaxial (ulnar) side of the limb or centrally, with postaxial polydactyly being the most common type. Preaxial polydactyly is more common in white population, and postaxial polydactyly is more common in African Americans. The supernumerary digit in postaxial polydactyly is either well developed (type A) or rudimentary and pedunculated (type B). Those that are rudimentary and represent a small nubbin of tissue can be managed by ligating the base of the pedicle in the nursery. This will lead to necrosis of the nubbin, which will eventually fall off. The more developed type A digits require formal surgical ablation and may require reattachment of the ulnar collateral ligament at the metacarpophalangeal joint or the abductor digiti quinti tendon. Preaxial polydactyly or thumb duplication occurs in 8 in 100,000 births (Fig. 13.4).

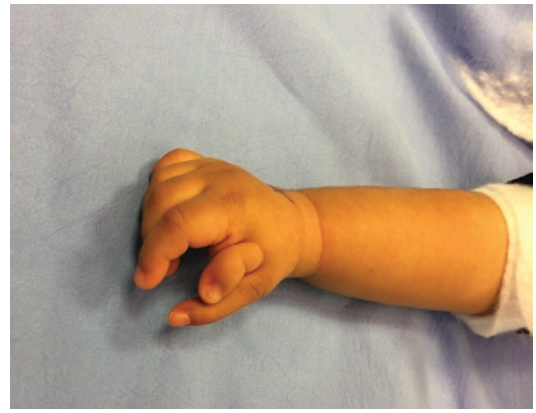

Fig. 13.4 Preaxial polydactyly or thumb duplication

Both the radial and ulnar duplicated thumbs show some degree of hypoplasia, although the radial duplicate is usually more affected. Wassel has categorized thumb duplication into seven types. Type I is characterized by a bifid distal phalanx, whereas type II is a duplication at the level of the interphalangeal joint. Type III is a bifid proximal phalanx, and type IV, the most common, is a duplication at the level of the metacarpophalangeal joint. Type V is characterized by a bifid metacarpal, and type VI is a duplication at the level of the carpometacarpal joint. Type VII describes thumb polydactyly with an associated triphalangeal thumb. Treatment of thumb polydactyly is based on the type of duplication. Types I and II can be treated with either resection of the radial duplication or central resection (Bilhaut operation) from each of the duplicated thumbs while preserving their outer portions. Unbalanced thumbs are generally managed with resection of the radial duplication, and balanced thumbs are managed with central resection. Treatment of duplication types III and IV must be individualized. In general, the best phalangeal portions of both thumbs are incorporated to create the best thumb. The radial duplication is usually amputated, as it is less developed, followed by radial collateral ligament reconstruction of the metacarpophalangeal joint and reattachment of the thenar muscle insertion to the radial base of the proximal phalanx of the remaining thumb. Treatment of types V and VI involves amputation of the radial duplication along with intrinsic muscle

reattachment and collateral ligament reconstruction if necessary [31–34].

Osteotomies may occasionally be required to realign the metacarpal with the proximal phalanx. Central polydactyly is a duplication involving the index, long, or ring finger. This is the least common type of polydactyly and may occur in isolation or as part of a syndrome. Duplication of the ring finger is the most common, followed by the long and index fingers. Central polydactyly may be hidden within concomitant syndactyly, which is termed synpolydactyly (Fig. 13.5a, b).

Treatment depends on the extent of involvement. A fully formed and functional central polydactyly does not necessarily require excision. Central polydactyly that is partially formed and/or has limited motion may require a ray resection. Given the potential spectrum of abnormality, the neurovascular bundles must be meticulously dissected so as not to compromise the remaining central digits [35].

13.5.7 Overgrowth

13.5.7.1 Macrodactyly

Macrodactyly, or gigantism, describes enlargement of all components of an affected digit and represents 1% of all congenital hand anomalies. Most cases are sporadic, without evidence of inheritance, 90% of cases are unilateral, and the index finger is most commonly involved. Several mechanisms have been proposed, including abnormal innervation leading to unimpeded growth, increased blood supply to the digit, and an abnormal humeral mechanism stimulating growth. There seem to be two forms of macrodactyly: the static type, which is noted at birth and in which the affected digit grows at the same rate as the other digits; and the more common progressive type, in which the digit is large at birth and grows disproportionately. Macrodactyly may be associated with hypertrophy of the median, ulnar, or digital nerves, which may result in symptoms of compression neuropathy that may require

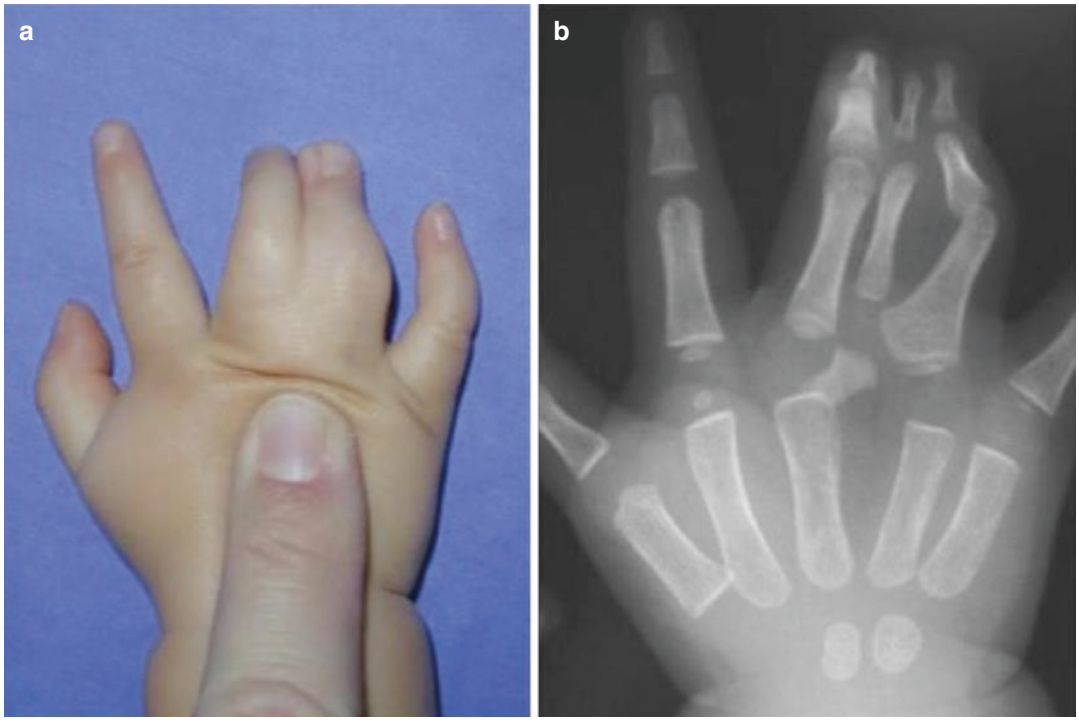

Fig. 13.5 Synpolydactyly; (**a**) clinical picture, (**b**) x-ray

decompression. Macrodactyly is extremely difficult to treat, but surgical intervention is often necessary, as the digit(s) lack function and may interfere with other normal digits. In addition, children with macrodactyly are subject to teasing and social embarrassment [36–38].

Key Points

Surgical options include debulking of the digit and/or disrupting further growth by obliterating the epiphyseal plates. Given the difficulty of treating this anomaly and the mediocre functional results, amputation should be strongly considered when only one or two digits are involved. If amputation is not warranted or if the parents refuse, staged debulking may be considered.

13.5.8 Congenital Constriction Ring Syndrome

13.5.8.1 Constriction Rings

Constriction rings may encircle a single digit or multiple digits or the entire limb of a newborn, causing varying degrees of vascular and lymphatic compromise. Constriction rings occur in 1 in 15,000 births. The constrictions may be either circumferential or incomplete and may occur anywhere on the body, although the limbs are most commonly affected. The cause of this condition is not fully understood. According to the intrinsic mechanism, it is caused by a vascular disruption in the embryo. According to the extrinsic mechanism, amniotic disruption causes the release of amniotic bands that encircle and strangulate the limb or parts of a limb in utero. Patterson classified constriction rings into four types. Type 1 is a mild transverse or oblique digital groove. Type 2 is a deeper groove with an abnormal distal part. Type 3 is characterized by incomplete or complete syndactyly of the distal parts, which is termed acrosyndactyly. Type 4 is a complete amputation distal to the constriction. Treatment of a digit or limb threatened at birth by distal ischemia caused by a proximal constriction ring requires urgent release of the ring.

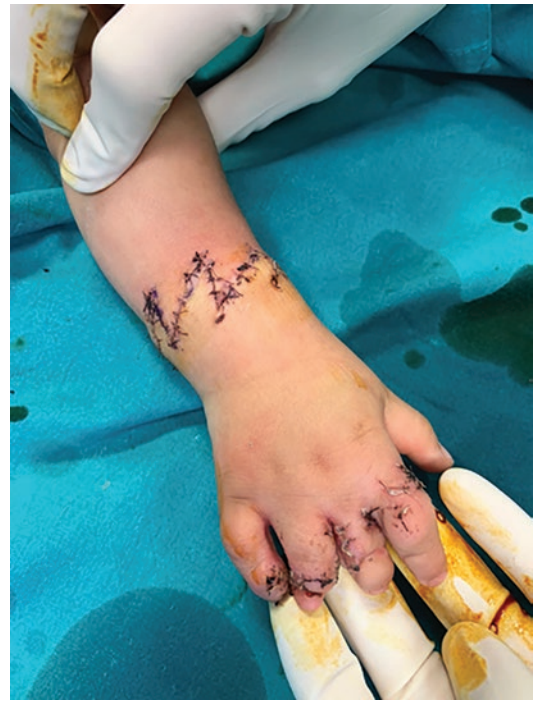

Fig. 13.6 Constriction ring, immediate post-operative result

Constriction rings may also affect the underlying nerves, necessitating decompression. In addition to releasing the constriction ring, the skin and subcutaneous tissues are rearranged with multiple Z- or W-plasties (Fig. 13.6). Some surgeons advocate the release of constriction rings in two stages. Half of the circumference of the ring is excised at the first stage, and the skin is lengthened with multiple Z-plasties. The remaining 50% of the constriction ring is released in a similar manner at a second stage [39–41].

Tips and Tricks

Constriction rings may be successfully released circumferentially around a limb or digit in a single stage.

If the constriction rings have transected extensor or flexor tendons, reconstruction with tendon grafts and/or tendon transfers may be necessary.

Amputation may occasionally be required.

13.5.9 Flexion Deformities

13.5.9.1 Camptodactyly

Camptodactyly is a flexion deformity of the proximal interphalangeal joint that occurs most commonly in the small finger, although other fingers may be affected. The metacarpophalangeal and distal interphalangeal joints are not affected. This flexion deformity occurs in less than 1% of the population, and most patients are asymptomatic and do not seek treatment. Two-thirds of the cases are bilateral, although the degree of flexion may not be symmetrical. The pathogenesis of this deformity remains unknown, although every structure surrounding the proximal interphalangeal joint has been implicated, including the skin and subcutaneous tissues, the ligaments (collateral, transverse, and oblique retinacular ligaments), the volar plate, the flexor tendons, the lumbricals, the interossei, and the extensor apparatus. Camptodactyly has been divided into three types. Type I deformities are the most common and are limited to the small finger. These become apparent during infancy and affect boys and girls equally. Type II deformities do not become apparent until preadolescence (ages 7–11) and affect girls more than they affect boys. Type II camptodactyly does not generally improve and may progress to a severe flexion deformity. Type III deformities are more severe, involving multiple digits of both extremities, and are generally associated with a variety of syndromes. Treatment of camptodactyly depends on the severity of the deformity. Initially, physical therapy and splinting (static and dynamic) may be used to extend the finger. If the contracture progresses to greater than 60 degrees of flexion, surgery may be indicated. This includes exploration and release of any abnormal structure found limiting proximal interphalangeal joint extension, including skin, fascia, ligaments, and/or tendons. Transfer of the flexor digitorum superficialis to the extensor apparatus has been described to decrease proximal interphalangeal joint flexion and increase proximal interphalangeal joint extension [42–45].

13.5.9.2 Congenital Clasped Thumb

Congenital clasped thumb (also known as isolated congenital thumb-palm deformity) represents a spectrum of thumb anomalies. It is more often bilateral and is seen in boys twice as often as in girls. The mild form is caused by the absence or hypoplasia of the extensor mechanism. Moderate to severe forms are related to joint contractures, collateral ligament abnormalities, first web space contracture, and thenar muscle hypoplasia. A clasped thumb is commonly found in arthrogryposis or its associated syndromes. In the classification system proposed by McCarroll and expanded by Mih, type I clasped thumb is flexible and has absence or hypoplasia of the extensor mechanism; type II clasped thumb is more complex, with additional findings of joint contracture, collateral ligament abnormality, first web space contracture, and thenar muscle abnormality; and type III clasped thumb is associated with arthrogryposis or its associated syndromes. The initial treatment of clasped thumb involves serial casting in extension and abduction for 3–6 months. The goal of surgical management is to bring the thumb out of the palm and restore grasp by addressing any or all of the abnormalities of the thumb web space, intrinsic muscle contracture or deficiency, extensor tendon deficiencies, and joint stability [46–49].

13.5.9.3 Arthrogryposis

Arthrogryposis (also known as arthrogryposis multiplex congenital) is a syndrome of nonprogressive joint contractures that is present at birth. Multiple variants of arthrogryposis vary in presentation and severity, and the cause is unknown. This may affect all joints in all limbs. Commonly, the wrist and fingers are flexed and the thumb adducted and flexed into the palm. Treatment should be individualized to achieve independent function. Manipulation of the deformities by a hand therapist shortly after birth may improve the range of motion and overall outcome. If progress is not achieved by 6 months of age, surgical management should be considered. Delaying surgery until after 1 year of age makes improvement more difficult, as the contractures become more

severe. Most surgeons advocate one-stage procedures that address the bone, joints, and soft tissue, as this gives the best results [50–52].

13.5.10 Pediatric Trigger Finger

Key Points

Trigger thumb is one of the most common pediatric hand conditions and responds universally to simple surgical release.

Trigger fingers are more complex, often owing to systemic conditions or anatomical abnormalities, and consequently require a wide and ample treatment.

13.6 Trigger Thumb

The etiology of trigger thumb in children remains uncertain. The main accredited hypothesis is that there is an anatomical mismatch between the diameter of the tendon sheath and the diameter of the flexor pollicis longus (FPL) tendon.

The condition normally presents with fixed flexed thumb interphalangeal joint (IPJ), with the presence of a small nodule on the volar face of the metacarpophalangeal joint (MPJ), Notta nodule. Sometimes it is possible to find some cases in which the thumb is fixed in an extended position, with no IPJ active flexion.

The relatives find the condition accidentally because the triggering is painless.

Sometimes it is supposed to be the result of a trauma or of a subluxation, but normal radiograms and ultrasound exclude it. Moreover, the presence of Notta nodule is diriment.

Regarding treatment, there is no unique direction.

Normally, instructions vary from a first period of 3–6 months of splinting to open surgical release in cases of splinting failure.

Exploring the literature, some authors suggested that all the therapeutic attitudes could be considered correct and could in some way lead to problem resolution. They analyze results of simple observation, versus stretching and exercises, versus night splinting with or without daily exercises versus open surgery and find out that all the series lead in some way to different percentages of clinical resolution, evidently in different periods of time treatment.

Anyway investigating correctly the data, it is evident that splinting or observations or stretching leads to a complete resolution preferentially in mild cases, and normally resolution is obtained with longer treatments.

On the contrary, open surgery leads in the majority of cases to recovery in a shorter time with really low rate or no complications.

Normally relatives willingly accept the period of orthesis to try to have a simple way toward resolution. Anyway usually, due to little compliance of the babies and to a long treatment, relatives usually switch happily to surgical solutions.

Surgery is quite simple; it could be performed under slight sedation and local anesthesia. It is performed through a small transversal incision at the MPJ volar surface of the thumb, the identification of the tight A1 pulley, and its surgical release. Often, it is possible to identify the Notta nodule, but once the pulley is open, no procedures are required on the nodule. Immediately after the complete pulley release, the finger shows a complete extension of IPJ [53, 54].

13.7 Trigger Finger

Pediatric, or congenital, trigger finger presents as a digit, other than the thumb, that locks in flexion.

As pediatric trigger thumb, although described as congenital by some authors, there are no clear records of this condition being present at birth. It has been reported as presenting between the ages of 3 weeks and 11 years. Many papers suggest that the pathological cause is due to anatomical anomalies, but this does make it hard to explain why the condition is not present at birth.

The management of this condition has varied from conservative splinting to operative exploration and correction of the offending structures.

In the literature, there is confusion on outcomes of splinting in trigger finger due to the fact that papers often compare the conservative treatment of trigger thumb and trigger finger together.

What is clear from the literature is that etiology of congenital trigger finger is different from congenital trigger thumb and adult conditions. It is reported that anatomic mechanical condition, such as mutual relationships among flexor digitorum profundus (FDP)) and flexor digitorum superficialis (FDS), or anatomical anomalies of pulleys, causes and sustains the triggering. The application of the operative principles applied in pediatric trigger thumb and adult trigger finger consisting in releasing of the A1 pulley only could lead to insufficient results.

Children who present with trigger fingers could have an underlying condition responsible for the triggering. Triggering has been associated with mucopolysaccharidosis, juvenile rheumatoid arthritis, Ehlers–Danlos syndrome, Down syndrome, and central nervous system disorders such as delayed motor development [55].

Surgery is quite often indicated, and a stepwise approach through Bruner's incision is therefore necessary.

Surgery could be performed under soft sedation and local anesthesia. The surgical approach allows the possibility to have a complete view of the flexor apparatus; both tendon structures and the pulley system must be carefully analyzed, and triggering must be evoked during surgery in order to be sure that the procedure undertaken has eliminated each possible cause of tendon friction [56].

13.7.1 Physiotherapy

Aristotle defined the hand "the tool of tools." The hand is for an individual a work, communication, and cognitive tool, right from the prenatal life: through touch, we learn, discover, get excited, and communicate.

The rehabilitation of the child involves not only the little patient but also his family and all of the medical staff who will take care of his health as a team.

The protagonist of the rehabilitation project is not just the hand but the whole little patient in the harmonious development of the evolutionary stages happening in the family context.

The hand therapist builds an ad hoc path using his knowledge, cultural background, and experience, but above all his own creativity and imagination because it is important not to forget that the patient in this case is a child.

In the specific area of pediatric hand affected by congenital malformation, rehabilitation must be offered in the form of a game, with suggestive activities that try to involve and stimulate the little patient. Playing thus becomes a fundamental tool that the hand therapist has at his disposal; it must therefore meet criteria not only of functionality but also of attractiveness and stimulus requirements for the attention and involvement of the child.

This is where the therapist has to use all his creativity. There is no pathology-dependent or predetermined activity for everyone, but, depending on the goal you want to achieve, the most suitable game is identified. Many times observation and play turn out to be the key to rehabilitation, always implementing new strategies and proposals that attract the attention of the young patient and that respect the developmental and cognitive stages reached.

Pediatric hand rehabilitation is not just "playing" or "gymnastics," as it is often defined, but a methodology that develops and supports the child's skills within specific and individualized paths.

Treatment of upper limb malformations, therefore, is part of a broad and rich context that aims at the well-being of the child in his whole being.

13.7.2 Psychological Aspects

Hands have a central role in social and emotional relationships because they vehicle emotionality; they are the protagonist in nonverbal communi-

cation, but they are also constantly visible to others as well as to their owner. When a person faces trauma or malformation problems, this last aspect is really important from a motivational point of view: the subject cannot avoid confronting his/her own difficulties and reactions raised in the social context.

Whether originated, the pathology of the upper limb affects and modifies many areas of individual life and requires an important psychological effort of acceptance and adaptation.

The relationship between patient and health specialists grows and shapes in this difficult context, especially when patients are children.

Several observations proposed by psychologists, surgeons, and physiotherapists working on this topic highlight the need for a synergistic approach involving different professionals.

Emotional manifestations are common reactions to stressful events, and in most situations, they can find support and reach acceptance within the proposed therapeutic protocol. However, if such emotions become stable and do not spontaneously evolve and resolve, it is essential to evaluate the duration and intensity of these emotions and their impact on quality of life and therapeutic protocol. It is essential that the psychologist attends during the first consultation and then, subsequently, is available to the patient or her/his family throughout the therapeutic protocol.

The interview with the psychologist allows the patient to face emotional aspects, helping the child's parents or the patient to expose and understand doubts and perplexities. Usually, uncertainties concern aspects strictly related to the therapeutic options and protocol, but patients and parents are also worried about life situations involving social skills, general child development—if the patient is a child, and educational aspects.

The whole family is included in the therapeutic pathway starting from the psychological interview following the first medical examination with the surgeon and all the following access to the medical care before and after surgery and at follow-ups.

As expected, even the young patient must be involved; this can be done in many different ways according to his/her age, since, based on it, the relevant main topics will be different.

During the interview between psychologist and parents, it is really important to discuss this topic in order to help parents in accepting the child's questions and supporting him/her during the inclusion in new contexts, for example, by talking and explaining to teachers and educationists.

The attention of the psychologist must therefore always be directed to the whole family system and its subsystems: the individual, the couple, interpersonal, and the sibling systems.

A multidisciplinary approach is essential considering the complexity of congenital hand conditions and hand diseases. The team has to deal carefully and respectfully with the patient and the family, keeping in mind their needs.

This requires that many professionals integrate together in order to provide a complete and adequate response to a patient's needs and not only to his/her malformed or traumatized hand.

13.8 Conclusions

Congenital differences of the upper limb represent a significant and unique challenge for the hand surgeon. In all cases, the ultimate goal is to provide a functional limb that can be integrated into the child's overall development. This goal may be met surgically or through specialized therapy and rehabilitation. Every case is unique, and each patient (and parent) will have a different capacity to adapt. These differences should be taken into account before embarking on a long, often difficult reconstructive course. It should be made clear from the outset that the child will never have a "normal" hand. Once realistic expectations have been set, reconstruction and/or rehabilitation can commence.

Pearls and Pitfalls

Proximal Transverse Deficiencies

Treatment is often a prosthetic device.

Surgical options are only to improve stump as removal of functionless digital nubbins.

Transverse Arrest of the Digits Distal to the Metacarpal Level

The objective of treatment is to create a pinch and grip. Distractions lengthening of metacarpal or phalangeal and nonvascularized toe phalangeal bone grafting are performed mostly in the case of oligodactyly or hypoplastic digits. In the case of monodactyl, adactyl, or transverse deficiency of the thumb, free microvascular toe-to-hand transfer could be the best option.

Nonvascularized toe phalangeal bone grafting should be performed before 15 months of age. The bone should be harvested extraperiosteally, and the collateral ligaments and tendons should be reattached.

Free microvascular toe-to-hand transfer, providing pinch to the adactylous hand by microsurgical toe transfer, is accomplished in two stages: first with a digit in the thumb position and then with a digit positioned for pinch using the second toe transfer most commonly.

Failure of Formation of Parts: Longitudinal Arrest

Radial Longitudinal Deficiency

Radial longitudinal deficiency is often found in association with other malformations. Thumb hypoplasia is often present, ranging from slight to total absence.

Treatment takes place step by step. First of all, the rigidity is corrected, then the wrist deviation, and lastly the thumb hypoplasia.

Treatment starts immediately after birth and consists of passive stretching exercises and splinting.

In the case of persistence of significant stiffness, soft tissue distraction is made with an external fixation device. Around 1 year of age, centralization or radialization is performed.

Centralization consists of the centralized carpus over the ulna after transecting radial fibrotic muscle and bands. The new position of the wrist is fixed by a pin through the middle finger metacarpal bone, carpus, and the ulna. Removal of the lunate and tendon transfer as flexor carpi radialis to extensor carpi ulnaris could be performed according to the degree of wrist stiffness and deviation. Lastly, pollicization of the ring finger is made to give a pinch.

Ulnar Longitudinal Deficiency

Treatment consists of serial casting to improve the wrist and elbow positions. For greater than 30 degrees of angulation, excision of the anlage (fibrotic bands) is indicated and K-wires may be used to hold the wrist in a neutral position. In the case of elbow stiffness, the proximal radial head is resected and a one-bone forearm is created by osteosynthesis of the distal radius to the proximal ulna. In the case of radiohumeral synostosis, a derotational osteotomy of the humerus may be required to place the hand into a more functional position.

Central Ray Deficiency

Treatment is directed to closing the cleft, creating a wide first web space and treating any syndactyly that may exist to improve the appearance of the hand. To achieve this, different surgical techniques are described.

The Snow–Littler procedure may be used to release the first web space syndactyly by releasing the thumb from the index finger and then transposing the index finger ray onto the middle finger metacarpal remnant, thereby achieving web release and cleft closure simultaneously [57].

Miura and Komada propose a simpler closure of the cleft by transposition of the index finger into the middle finger position [58].

Hypoplastic Thumb

Treatment of hypoplastic thumb depends on the grade of hypoplasia. Type I does not require any treatment. Types II and IIIA are treated with deepening of the first web space and a tendon or muscle transfer to improve opposition. Types IIIB, IV, and V require an index finger pollicization because there is an unstable or absent carpometacarpal joint.

Failure of Separation of Parts

Syndactyly

Surgical release of syndactyly should perform as early as possible, mostly in the case of syndactyly between 4° and 5° digits and 1° and 2° digits, to allow normal growth of digits and normal grasp and pinch. The goal of all surgical techniques is the reconstruction of the web space with a dorsal flap and separation of the digits using an interdigital zig-zag flap.

Duplication (Polydactyly)

Polydactyly can occur on the preaxial (radial) or postaxial (ulnar) side of the limb or centrally.

In each group, the treatment depends on the type of duplication. Except for rudimentary and pedunculated digits, treatment consists in ablation of supernumerary digit and rebalance of the dominant digit.

Overgrowth

Macrodactyly

Surgical options include debulking of the digit and/or disrupting further growth by obliterating the epiphyseal plates. Given the difficulty of treating this anomaly and the mediocre functional results, amputation should be strongly considered when only one or two digits are involved. If amputation is not warranted or if the parents refuse, staged debulking may be considered.

Congenital Constriction Ring Syndrome

The constrictions may be either circumferential or incomplete and may occur anywhere on the body, although the limbs are most commonly affected.

To release the constriction ring, multiple Z- or W-plasties are set up. The procedure could be done in one step by the release circumferentially or into two steps. When the constriction ring affects, an arm is important to release the fascia.

Trigger Thumb

Trigger thumb is one of the most common pediatric hand conditions and responds universally to simple surgical release.

Trigger fingers are more complex, often owing to systemic conditions or anatomical abnormalities, and consequently require a wide and ample treatment.

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14 Malformations of the External Genitalia

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Background

The development of the external genitalia is of particular interest because of the high incidence of malformations, 1 in 125 live male births [1].

Male and female external genitalia play a main role in human reproduction, and any anatomical anomaly or functional disorder may interfere with fertility, urinary continence, and renal function. Proper function of male and female external genitalia requires precise anatomical organization of penile and clitoral erectile bodies, the penile urethra, and precise somatic, sympathetic, and parasympathetic innervation of penis, clitoris, and vulva [2].

14.1 Introduction

The high incidence of genital malformations has led to a significant increase in interest in this medical field. In particular, genital surgery is an important topic in the field of both genital abnormalities and pediatric plastic surgery.

There are several genital malformations that can occur in both male and female gender, and it is clear that the correct clinical setting has a fundamental role in the prognosis of these young patients.

Among the most classic examples are hypospadias and epispadias: penile abnormalities that can be framed as two sides of the same coin, in which there is a developmental defect of the urethral canal and consequently the outlet of the latter. They manifest themselves with an anomalous localization of the urethral meatus on the ventral face of the shaft in the hypospadias and on the dorsal portion in the epispadias.

The huge scientific literature produced about the surgical procedure is essentially based on common concepts of plastic surgery, such as local flaps, vascularized flaps, and skin or mucosa grafts.

It must be remembered, however, that patients who undergo surgery are of pediatric age and that the nature of the various abnormalities often presents itself with important tissue deficiencies making the work of the surgeon not easy.

14.2 Embryology

The anatomical organization of male and female external genitalia emerges during embryonic and fetal development, and the developmental biol-

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ogy of external genitalia is critical to understand and repair all the possible malformations [3, 4].

The genital system is embryologically and anatomically connected with the urinary system. Both develop from a common mesodermal ridge (intermediate mesoderm), and initially the excretory ducts of both systems end in a single opening: the cloaca.

However, female and male genitalia have different functions; the female one produces oocyte and protects and nourishes the offspring until birth; the male one produces and deposes sperm.

The genital apparatus consists of three distinct organs, and all of them go through an indifferent stage: gonads (testicles in males and ovaries in females), the external genitalia, and the genital ducts.

14.2.1 External Genitalia

Development of the external genitalia is a complicated process involving a constellation of individual morphogenetic events. External genitalia consists of the penis, clitoris, labia majora and minora, and scrotum [5].

14.2.2 Indifferent Stage

In the third week of development, mesenchymal cells originating in the region of the primitive streak migrate around the cloacal membrane to form a pair of slightly elevated cloacal folds that merge cranially into a single protuberance: the genital tubercle (GT), made up by all three germ layers. Caudally these folds develop into the urethral folds anteriorly and the anal folds posteriorly.

The first stage of genital development, independent of hormones, consists in forming a urethral plaque in the midline of the genital tubercle. This occurs during the eighth and 12th weeks of gestation in both male and female fetuses.

The development of the urinary and genital system depends on the interaction between the epithelial and mesenchymal layers that provide a continuous guide to regulate the evolution of the structures.

During this process, other changes occur on both sides of the urethral folds, forming two tissue elevations, the genital bulges. These swellings will become the scrotal swellings in the male and the labia majora in the female.

At the end of the sixth week, it is not yet possible to determine the sex of the fetus (Fig. 14.1).

14.2.3 Different Stage

Sex differentiation starts between the eighth and ninth weeks of gestation when the complicated process begins. This phase involves many genes, but the essential one is found in the Y chromo-

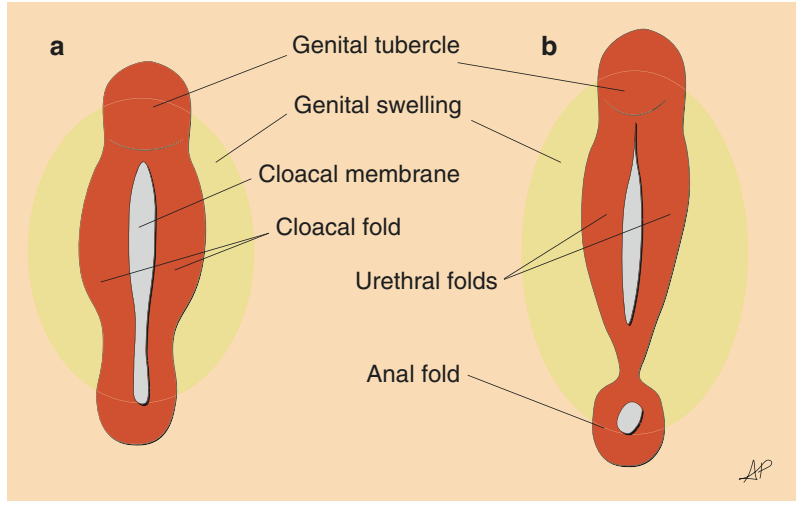


Fig. 14.1 The indifferent stage consists in the development of mesenchymal cells around the cloacal membrane. (**a**) The cloacal folds form the genital tubercle cranially; (**b**) caudally the folds make the urethral folds anteriorly and the anal folds posteriorly. (Illustrations by Angelica Pistoia))

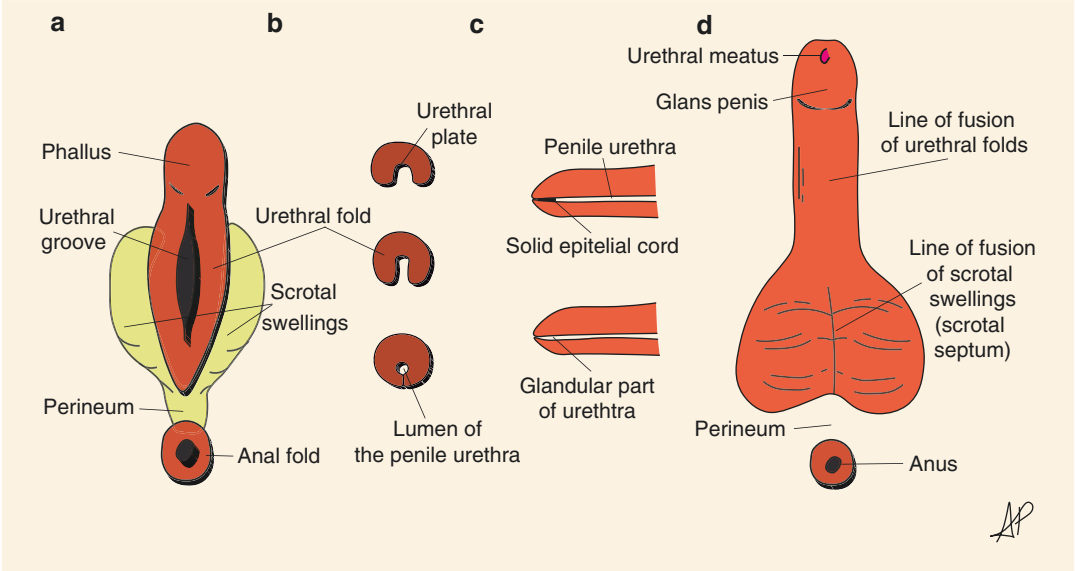


Fig. 14.2 Development of male external genitalia. (**a**) Differentiation of the genital tubercle, the urethral groove, urethral fold, and scrotal swellings; (**b**) frontal vision of the urethral folds closing over the urethral plate; (**c**) creating the penile urethra from proximal to distal and the solid epithelial cord that forms the external urethral meatus; (**d**) final aspect of penis. (Illustrations by Angelica Pistoia)

some, the SRY gene (sex determination region on Y). The product of this gene is a transcription factor that initiates a cascade of activation of several other genes, such as *SF1* (*steroidogenesis factor*) and *SOX9* that stimulate the differentiation of Sertoli and Leydig cells in the testicles. The SRY protein is the factor that determines testicular differentiation [2], hormone production, and therefore the development of the male sex [6]: Leydig cells differentiate in the testis and begin to secrete testosterone that stimulates the development of mesonephric ducts (vas deferens epididymis). *MIS* (*Mullerian inhibitor substance*) produced by Sertoli cells in the testicles causes the regression of paramesonephral ducts (female duct system). *Dihydrotestosterone* is responsible for the masculinization of genital tubercle, ductus Wolffiano, and urogenital sinus (UGS), stimulating the development of external genitals, penis, scrotum, and prostate.

14.2.3.1 External Genitalia in Male

After androgen production, one of the first signs of masculinization is the increase in the distance between the anus and genital structures (known as anogenital distance), followed by a rapid lengthening of the genital tubercle, which is now called phallus. During this lengthening, the urethral folds are stretched to form the lateral walls of the urethral groove without reaching the glans. The epithelial lining of the furrow, which originates in the endoderm, forms the urethral plate.

At the end of the third month, the two urethral folds close over the urethral plate, from proximal to distal to form a large, diamond-shaped urethral furrow inside the penis shaft (opening hinge), until they merge on the middle (closing hinge), creating the penile urethra.

The most distal portion of the urethra is formed during the fourth month, when the ectodermal cells of the tip of the glans penetrate inward and form a short epithelial cord, which then turns into a lumen, forming the external urethral meatus (Fig. 14.2).

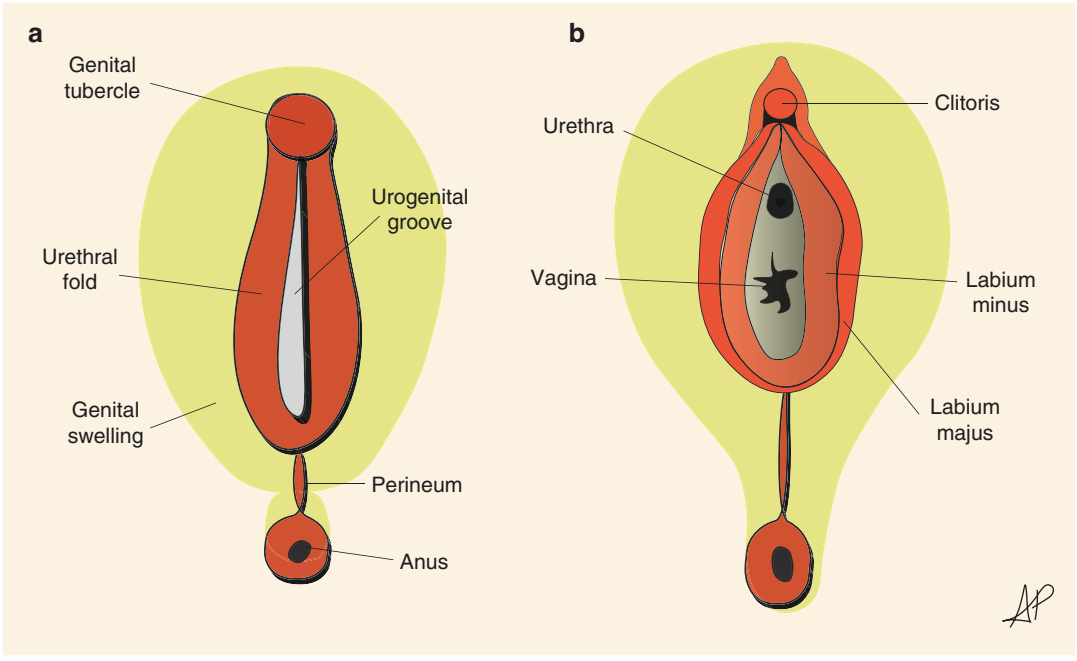
The scrotal genital swellings arise in the groin region and move caudally during development. Each swelling forms half of the scrotum and is separated from each other by the scrotal septum.

Toward the end of the second month, the urogenital mesentery, which binds the testicle to the

posterior abdominal wall, becomes ligamentous in the lower portion forming the caudal genital ligament. In the lower part of the testicle, a mass of mesenchymal cells, rich in extracellular matrices, called gubernacle, ends in the inguinal region between the oblique abdominal muscles. The peritoneum forms an eversion on each side of the midline in the ventral abdominal wall. This evagination, the processus vaginalis (which covers the testicle and becomes the tunic vaginalis), follows the course of gubernaculum testis into the scrotal swellings and is accompanied by the muscle and fascial layers of the body wall form the inguinal canal. Thus, the transversalis fascia forms the internal spermatic fascia, the internal abdominal oblique muscle gives rise to the cremasteric fascia and muscle, and the external abdominal oblique muscle forms the external spermatic fascia. The testicle descends through the inguinal ring, and the canal closes at birth or shortly afterward. Normally, the testicles reach the inguinal region around the 12th week of gestation and migrate through the inguinal canal at week 28 reaching the scrotum at the 33th week. The process is influenced by increased intra-abdominal pressure due to the growth of organs, hormones, including androgens, and MIS.

14.2.3.2 External Genitalia in the Female

Estrogens stimulate the development of the external genitalia of the female. The genital tubercle elongates only slightly and forms the clitoris; urethral folds do not fuse, as in the male, but develop into the labia minora. Genital swellings enlarge and form the labia majora. The urogenital groove is open and forms the vestibule. During the third and fourth months of gestation, errors in ultrasound sex identification are possible because the GT is larger than in the male during the early stages of development. Errors in production of or sensitivity to hormones of the testes lead to a predominance of female characteristics under the influence of the maternal and placental estrogens (Fig. 14.3).



14.3 Development of female external genitalia. (**a**) Genital tubercle enlargement and anus spacing; (**b**) the genital tubercle becomes the clitoris, the urethral folds become the labia minora, and the genital swellings the labia major. In the urogenital groove, there are the urethral meatus and the vagina opening (Illustrations by Angelica Pistoia)

Key Point

Indifferent Stage

- *From week 3 of gestation:*
  Development of the genital tubercle, urethral folds, anal folds, urethral plate, and genital swelling.

  Different Stage
- *From week 9 of gestation:*
  Development of the penis, urethral meatus, and scrotum
  Development of clitoris, labia minora, labia majora, and vestibule.

14.3 Risk Factors

Genital malformation, including hypospadias, represents the second most common male birth defect after cardiac malformations. During the past 50 years, hypospadias incidence has doubled along with other male reproductive problems. However, our understanding of basic genitalia development in general, including hormone-mediated genital differentiation, is still very limited. A complete understanding of genetic pathways governing genital development and masculinization and how perturbations of these pathways lead to genital malformations will have important applications to improve global health [7].

The increase in hypospadias incidence along with other male dysgenesis in developed countries raises the possibility that environmental factors, such as fetal exposure to endocrine disruptors, may contribute to the development of hypospadias [8].

Endocrine disruptors are chemical compounds found in the environment, including industrial and agricultural compounds, and even natural products found in plants. These compounds, also called xenobiotics, can interfere with human physiology by binding to hormone receptors and altering gene expression during development. Quite a number of xenobiotics structurally resemble estrogen and can bind to the ER and affect target gene expression. Exposure to these compounds has been linked to cancer, the steady decline of sperm counts, premature onset of puberty, and abnormal development of the reproductive tract [9].

The effects of androgens and estrogens on genitalia development are well known, and in the case of disbalance, different entities can be seen within the spectrum of congenital anomalies like hypospadias, micropenis, and ambiguous genitalia [10].

14.4 Main Malformations

External genitalia malformation can be divided into female and male defects.

- Female Malformation:
  - Ambiguous genitalia (genitalia not clearly male or female).
  - Imperforate hymen.
  - Labial adhesions.
  - Genital organs joined together (fusion abnormalities).
- Male Malformation:
  - Hypospadias.
  - Epispadias.
  - Micropenis.
  - Ambiguous genitalia (genitalia not clearly male or female).
  - Phimosis.
  - Cryptorchidism.

Hypospadias is a condition of mispositioning of the urethral meatus on the ventral surface of the penis.

Epispadias is a rare abnormality (1/30,000 births) in which the urethral meatus is found on the dorsum of the penis. Although epispadias may occur as an isolated defect, it is associated in the extreme form with exstrophy of the bladder [11], where the mucosa is exposed to the outside (Fig. 14.4). Normally the abdominal wall in front of the bladder is formed by primitive streak mesoderm, which migrates around the cloacal membrane. When this migration does not occur, rupture of the cloacal membrane extends cranially, creating exstrophy of the bladder.

Micropenis occurs when there is insufficient androgen stimulation for the growth of the exter-

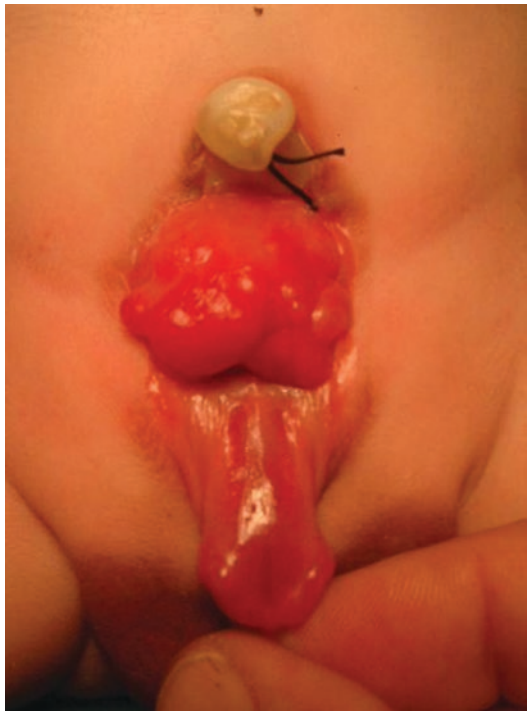


Fig. 14.4 Example of severe epispadias associated with exstrophy of the bladder. Courtesy of Prof. Pietro Bagolan

nal genitalia. Micropenis is usually caused by primary hypogonadism or hypothalamic or pituitary dysfunction. By definition, the penis is 2.5 standard deviations below the mean in length as measured along the dorsal surface from the pubis to the tip, with the penis stretched to resistance. Bifid penis or double penis may occur if the genital tubercle splits.

In 97% of male newborns, testes are present in the scrotum before birth. In most of the remainder, descent will be completed during the first 3 months postnatally. However, in less than 1% of infants, one or both testes fail to descend. The condition is called cryptorchidism and may be caused by decreased androgen (testosterone) production. The undescended testes fail to produce mature spermatozoa, and the condition is associated with a 3% to 5% incidence of renal anomalies.

Phimosis is a condition in which the prepuce cannot be retracted over the glans penis. It could be further defined as physiologic, as in infancy and childhood, because of the natural adhesions that exist between the prepuce and the glans; or pathologic from inflammatory or traumatic injury to the prepuce, resulting in an acquired inelastic scar that prevents retraction [12].

Paraphimosis is a condition in which the foreskin is left retracted because of entrapment of the tight prepuce proximal to the corona. The glans engorges, and the prepuce becomes edematous because of lymphatic and venous congestion. This could happen because boys have been encouraged to retract the foreskin for physiological phimosis by parents or medical staff. In some cases, circumcision is indicated considering the recurrence of the event.

Tips and Tricks

It is important to note that many severe hypospadias or micropenis cases are also accompanied by malformations in other parts of the urogenital and anorectal tracts.

This is predictable because the rectum, urethra, vagina in females, and the external genitalia all derive from a common embryonic structure, the cloaca.

Abnormal development of cloaca-related structures causes a spectrum of inborn defects from isolated hypospadias to complex urogenital-anorectal malformations such as OEIS (omphalocele, exstrophy, imperforate anus, and spinal defects).

14.4.1 Hypospadias

The development of external genital malformations is an important field of interest for medical and surgical studies, partly justified by the high incidence of one of these diseases such as hypospadias: a congenital defect of the penile urethra with an incidence of approximately 1:200–1:300 male births [13, 14].

Hypospadias is a condition characterized by mispositioning of the urethral meatus on the ventral side of the penis and is the second most common genital anomaly after undescended testes in male newborns [15].

Nowadays, hypospadias is often classified by the position of the urethral meatus in posterior, middle, and anterior according to *Duckett*'s classification. Nearly 70% of hypospadias are either glandular or distally located on the penis and are considered mild forms, while the remainder are more severe and complex [16].

14.4.2 Etiology

Many hypotheses have been proposed concerning the etiology of hypospadias. The results of an abnormal penile and urethral development are multifactorial and heterogeneous with several genetic and environmental determinants.

Monogenic and chromosomal defects are present in approximately 30% of cases, although the genetic factors contributing to hypospadias remain unknown in 70% of cases.

Most hypospadias occurs as an isolated condition but sometimes is associated with other anomalies including uni/bilateral cryptorchidism and micropenis [10], suggesting a deficiency of hormonal influences during embryogenesis.

The absence or the insensitivity to androgens is ascertained among the causes, and all patients with *5α-reductase* mutations develop hypospadias [17]. Moreover, other genes like *sonic hedgehog*, *fibroblast growth factors*, *bone morphogenetic proteins*, *homeobox genes*, and *the Wnt family* have been proposed to be implicated in the normal development of male external genitalia [18]. In addition, other risk factors have been pointed out such as pregnancy age <20 or >35 years, preterm birth, fetal growth restriction, primipara, maternal and passive smoking, oral progesterone, cold or fever during pregnancy, and exposure to high temperature in early pregnancy [19].

14.5 Clinical Evaluation

Hypospadias is generally defined as an abnormal ventral opening of the urethral meatus whether or not associated with ventral curvature of the penis and a ventrally deficiency of the foreskin around the glands [20] (Fig. 14.5).

The subcoronal position is the most common, and it is considered a mild form while proximal cases are more severe. In the latter scenario, hypospadias can masquerade a disorder of sex development [21], especially if associated with an undescended testes, or other nephrourological malformations.

Therefore, in such situations, it is appropriate to refer to an endocrinologist for a genetic and hormonal screening and have ultrasonography of the genitourinary tract [22].

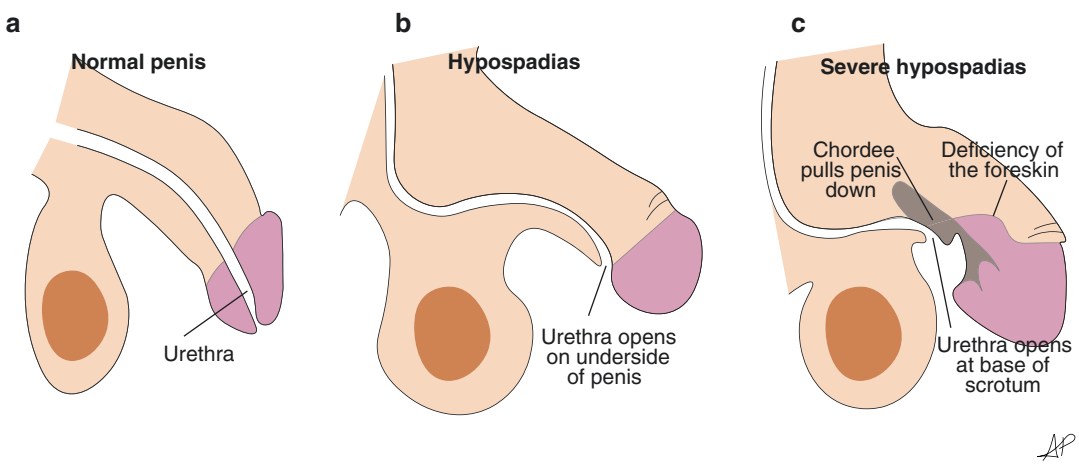


Fig. 14.5 Lateral vision of normal anatomy of urethra (**a**), distal hypospadias (**b**), and severe hypospadias (**c**) with proximal opening of the urethral meatus, curvature of the penis due to the Chordee and deficiency of the foreskin (Illustrations by Angelica Pistoia)

Moreover, the middle and posterior forms are those which most frequently occur with chordee (it derives from the Greek word chorda, which means "string" or "rope") and indicates the ventral curvature of the penis [23].

Clinical symptoms are variable and depend on the severity of the malformation. In mild hypospadias with a urethral meatus located on the glans, a normal urinary flow can be maintained. In the case of stenotic meatus, weak urinary flow can occur. Children with proximal hypospadias with penile curvature might not be able to void while standing. A penile curvature in children can create long-term psychosexual outcomes and inhibit sexual intercourse in adulthood [24].

Special variations of hypospadias are the following:

1. Hypospadias sine hypospadias: ventral curvature of the penis and a normal position of the meatus with a distorted foreskin [16].
2. *Megameatus intact prepuce* (MIP): a coronal lying meatus adjacent to a nonclosed glans with a very wide open navicular fossa and a normal developed circular prepuce [25].

14.6 Classification

The anatomic classification of hypospadias is basically focused on the level of the meatus, but, ideally, it should embrace the condition of glans (cleft, incomplete cleft, or flat), condition of the prepuce (complete or incomplete), chordee (presence or absence of penile curvature), rotation of the meatus, and scrotal transposition (if present).

Many classifications have been proposed based on meatal position:

- Smith's classification (1938): first degree locates the meatus from the corona to the distal shaft; second degree from the distal shaft to the penoscrotal junction; the third degree is from the penoscrotal junction to the perineum.
- *Schaefer and Erbes* (1950): glanular from the subcorona out; penile from the corona to the penoscrotal junction; perineal from there down.
- *Browne* (1936): subcoronal, penile, midshaft, penoscrotal, scrotal, and perineal varieties.
- *Duckett* (1966): anterior (glanular), coronal and subcoronal, middle (penile), and posterior hypospadias (penoscrotal, scrotal, and perineal) [26]

Fortunately, the prevalence of position of the urethral meatus has different incidence, and the complex forms represent only 15% of all cases [27].

Key Point
Prevalence of the position of the urethral meatus:

1. Anterior or distal represents 60–65% of cases.
2. Middle represents 20–30% of cases.
3. Posterior represents 15% of cases.

14.7 Treatment

The goal of hypospadias repair is to achieve cosmetic and functional normality, restoring the correct anatomy of the urethral meatus and removing the curvature of the penis.

Reasons for treating hypospadias include spraying of urinary stream, inability to urinate in standing position, curvature leading to difficulties during intercourse, fertility issues because of difficulty with sperm deposition, and decreased satisfaction with genital appearance [28].

Meatal position alone is generally used to identify the severity of hypospadias but also size of the penis, defect of the foreskin, size of glans and urethral plate, level of division of the corpus spongiosum, presence of a curvature, and anomalies and position of the scrotum have a significant impact on the outcome of surgical correction [16].

Currently, hypospadias surgery is recommended between 6 and 18 months of age and, in

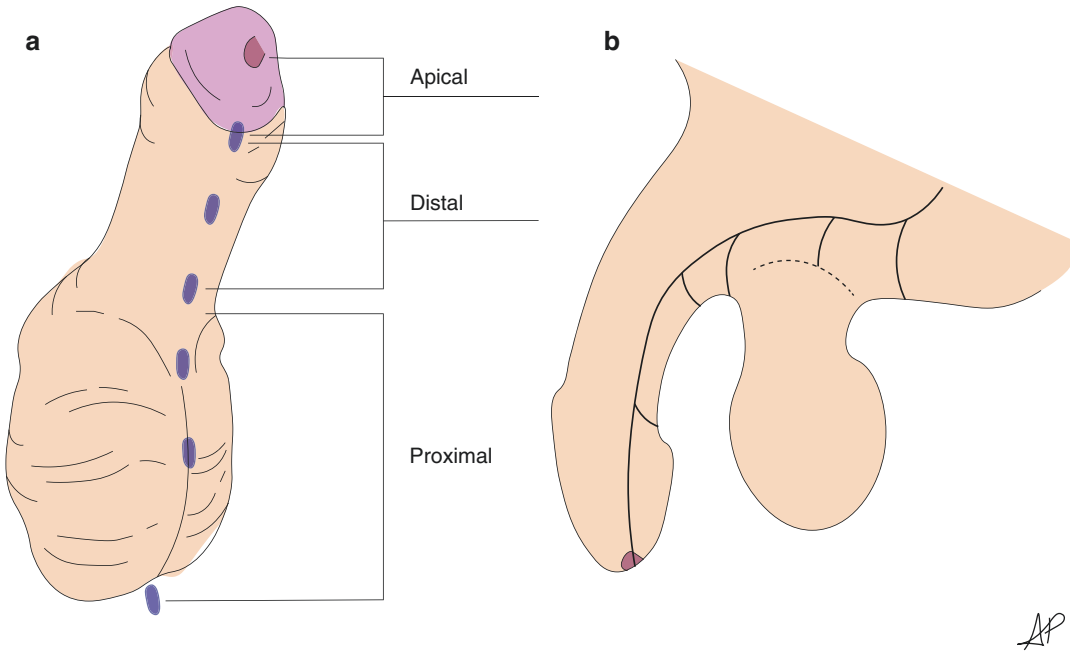


Fig. 14.6 (**a**) Classification of hypospadias based on anatomic location of the urethral meatus; (**b**) lateral vision of urethral path in different types of hypospadias (Illustrations by Angelica Pistoia)

most cases, can be performed in a single-stage operation that includes meatal advancement and glanuloplasty (MAGPI), glans approximation procedure, and tubularization of the urethral plate (TIP). Sometimes, for complex form, a two-stage operation is required, like penoscrotal or perineal hypospadias [29].

Many techniques have been proposed for hypospadias treatment, but no one is still universally accepted; at OPBG Hospital, a clinical distinction is commonly made based on the position of the ectopic urethral meatus on the ventral face of the penile shaft. This differentiation aims to have a specific surgical indication for each form. Therefore, a distinction is made between apical hypospadias, from the normal position of the meatus to the balanic groove; distal hypospadias, from the balanic groove to the distal third of the penis; and proximal hypospadias, which includes the other forms where the meatus is located on the proximal part of the penis, at the penoscrotal junction, at the middle of the scrotum, or at the perineal level (Fig. 14.6).

Each category has, at the OPBG, a surgical technique of the first choice carried out in a single time:

1. Apical hypospadias uses the technique of sliding and advancement.
2. Distal hypospadias uses urethroplasty according to Mathieu;
3. Proximal hypospadias uses the preputial island flap of Standoli.

In scrotal and scroto-perineal forms, the reconstruction takes place in two or three surgical stages: the first stage consists in the pull out of the cavernous bodies according to a modification of Jacques van der Meulen's technique; at the second stage, the urethroplasty is performed with the inner layer of the preputial skin; and at the third stage, the termino-terminal anastomosis between the original ectopic meatus and the reconstructed urethral canal is performed. If conditions permit, the second and third stages can be done at the same time.

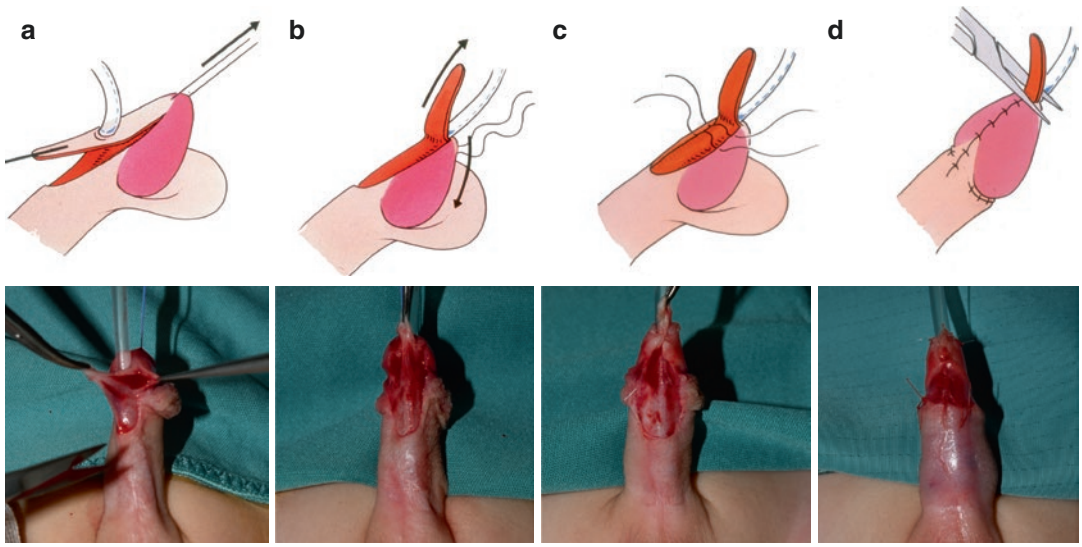


Fig. 14.7 Sliding and advancement technique. (**a**) Incisions along the urethral plate; (**b**) urethral plate is released and advanced to the apex; (**c**) and (**d**) glanduloplasty and skin closure

Some of the most common and used procedures are shown in the following.

14.8 Sliding and Advancement

Two parallel incisions are made along the urethral plate of the glans and then extended around the external urethral meatus. The identified urethral plate is then released and advanced to the apex of the glans, and at the same time, the glans is slid back. The procedure is completed by glanduloplasty and preputial skin remodeling (Fig. 14.7).

14.9 Mathieu Urethroplasty

A rectangular flap based on the external urethral meatus is raised and tilted upward, preserving the vascular pedicle. The flap is then sutured along the previously prepared urethral plate to reconstruct the ventral wall of the neo-urethra. The procedure is completed by glanduloplasty and preputial skin remodeling (Fig. 14.8).

14.10 Standoli Preputial Island Flap

A rectangular island flap is raised from the external layer of the preputial skin, vascularized by the vessels running inside the dartos. This flap is then rotated ventrally and used to form the ventral face of the new urethral canal by suturing it on the two margins of the previously prepared urethral plate. In the case of complex hypospadias, as in the penoscrotal or scrotal forms, the flap is completely tubulized to form the entire neo-urethra and anastomosed end to end to the original urethra by a flute beak suture (Figs. 14.9 and 14.10).

The preputial island flap can also be raised using all the preputial tissue, both the inner and outer layer: the so-called double island flap.

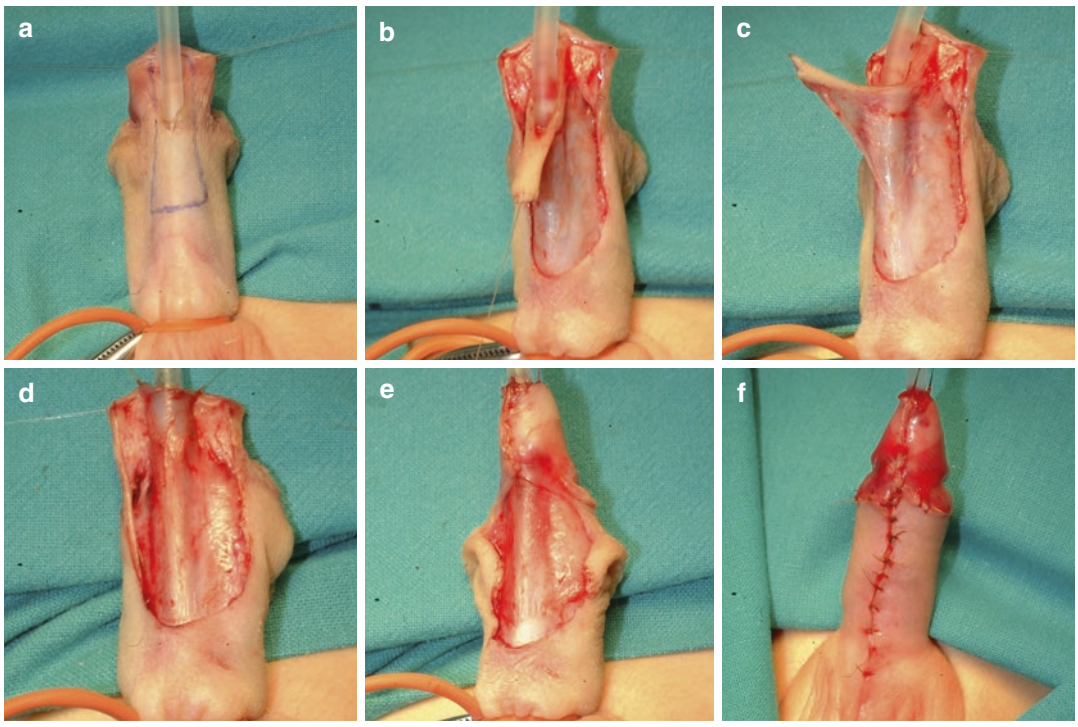


Fig. 14.8 Mathieu urethroplasty. (**a**) Flap design; (**b**) flap is raised keeping the vascular pedicle intact (**c**); (**d**) flap sutured in place; (**e**) glanduloplasty; (**f**) end of procedure

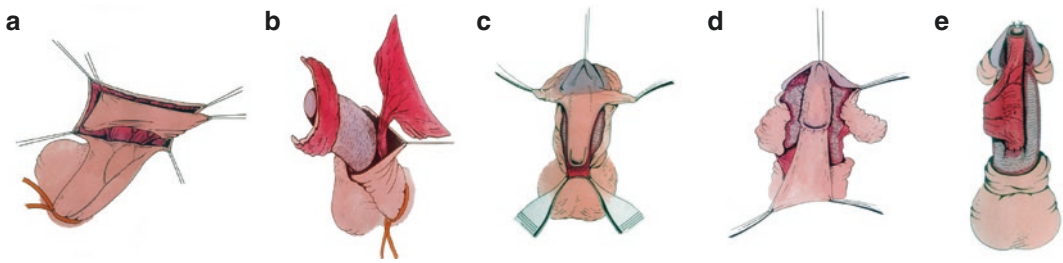


Fig. 14.9 Standoli preputial island flap. (**a**) Incision of the preputial flap; (**b**) flap mobilized with its pedicle; (**c**) preparation of the urethral plate; (**d**) flap being sutured; (**e**) urethroplasty completed

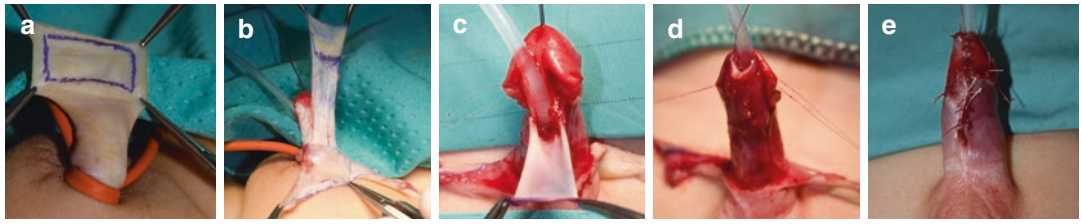


Fig. 14.10 Standoli preputial island flap. (**a**) Preputial flap design; (**b**) dissected flap; (**c**) flap sutured on the urethral plate; (**d**) urethroplasty completed; (**e**) glanduloplasty and skin closure

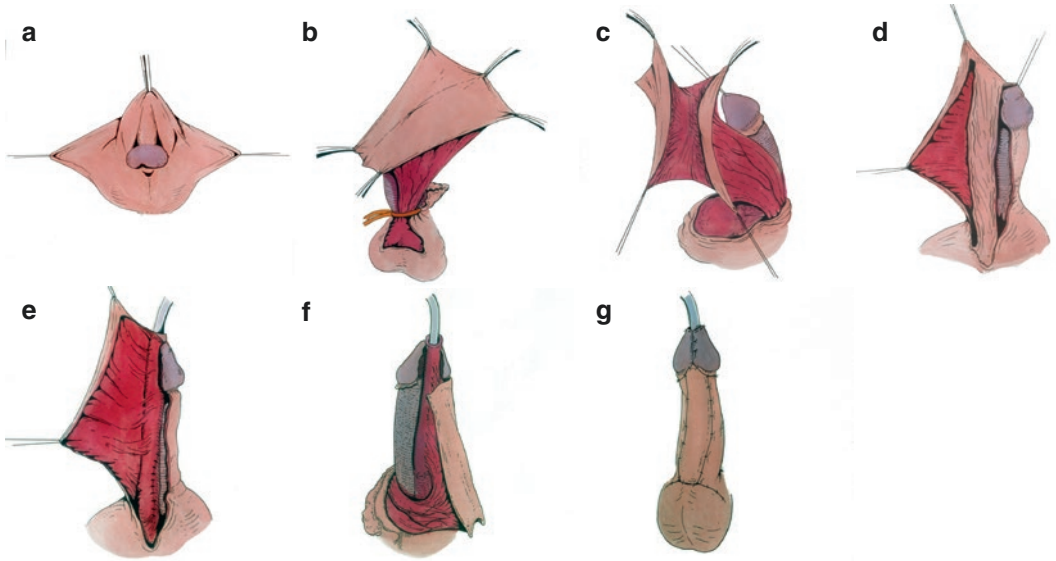


Fig. 14.11 Standoli double island flap. (**a**) Penoscrotal hypospadias; (**b**) dissection of the whole preputial flap; (**c**) separation of the outer and inner layer; (**d**) ventral rotation of the flap; (**e**) creating the neo-urethra with the inner layer; (**f**) outer layer of prepuce ready for ventral skin coverage; (**g**) end of the procedure

In this case, the inner layer will form the urethral canal, while the outer layer will provide adequate skin coverage of the ventral aspect of the penile shaft (Fig. 14.11).

14.11 Snodgrass One-Stage Repair

Tubularized incised plate (TIP) hypospadias repair was first described in 1994 [30], subsequently becoming one of the most commonly used operations for distal cases [31].

The technique starts with two incisions; one extending along the edges of the urethral plate from the tips of the glans, and the second a circumferential incision. The urethral plates are outlined, and a longitudinal relaxing incision is made from the meatus to its distal tip, extending deeply close to the corpora cavernosa [32]. Finally, the urethral plate is tubularized to create the neourethra.

Vascularized pedicled flap is elevated from the inner surface of dorsal prepuce up to the base of the penis and mobilized over neourethra to create an intermediate barrier layer between neourethra and surface skin layer.

An infant feeding tube is secured to the glans penis for 10–12 days, as drainage of urethral discharge [33] (Fig. 14.12).

14.12 Braka Two-Stage Repair

Modern hypospadias operations are mostly single-stage procedures but, for selected indications, Bracka's two-stage procedure can be used.

The first stage is to create a new and adequate urethral plate. The existing plate is excised, the glans is clefted, and the resulting defect is covered with a skin graft from the inner layer of the prepuce (Fig. 14.13).

After 3–6 months, once the graft is stable, the second stage consists of tabularizing the reconstructed urethral plate to form a neourethra. After the formation of the neourethra, a protective dartos fascia flap is positioned over the entire suture line as a "waterproof" layer [34] (Fig. 14.14).

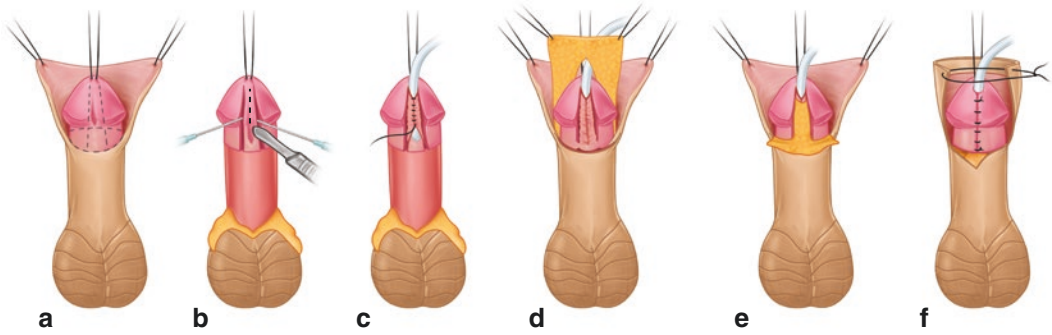


Fig. 14.12 Snodgrass tubularized incised plate (TIP) steps. (**a**) and (**b**) incisions; (**c**) urethral plate is tubularized from the neomeatus; (**d**) and (**e**) dartos pedicle flap dissected from preputial and transposed to cover the neourethra; (**f**) glansplasty and skin closure (Illustrations by Angelica Pistoia)

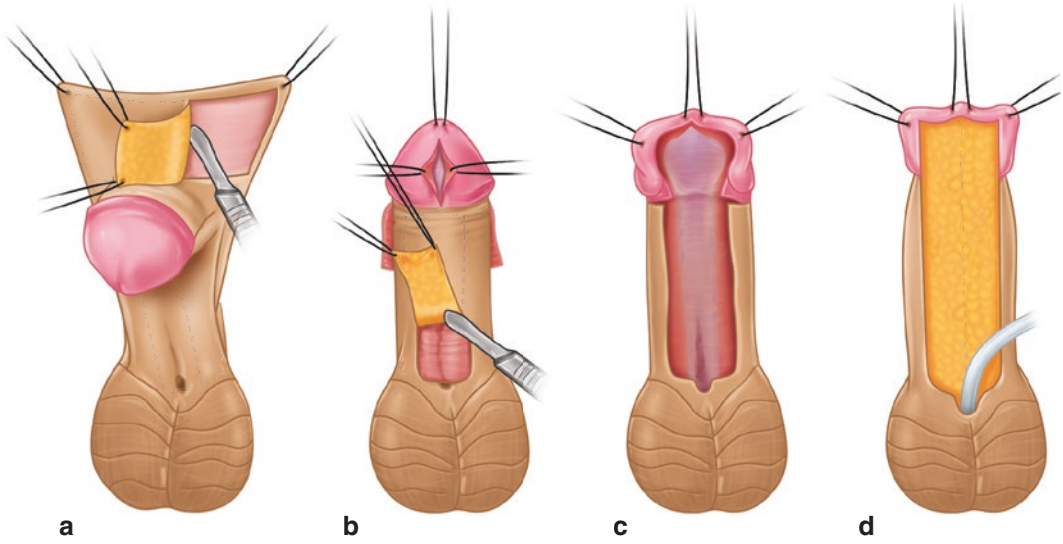


Fig. 14.13 Braka first-stage technique. (**a**) Incisions around urethral plate and removal of foreskin graft; (**b**) urethral plate is excised, removal of urethral plate; (**c**) glans incision; (**d**) graft affixing (Illustrations by Angelica Pistoia)

Pearls and Pitfalls

Patient selection and suggested surgical technique:

- Patients with apical hypospadias: Sliding and advancement technique.
- Patients with distal hypospadias: Urethroplasty according to Mathieu or Snodgrass technique.
- Proximal hypospadias: Standoli preputial island flap.
- Redo hypospadias, penoscrotal, scrotal, and perineal hypospadias: Standoli single or double preputial island flap.

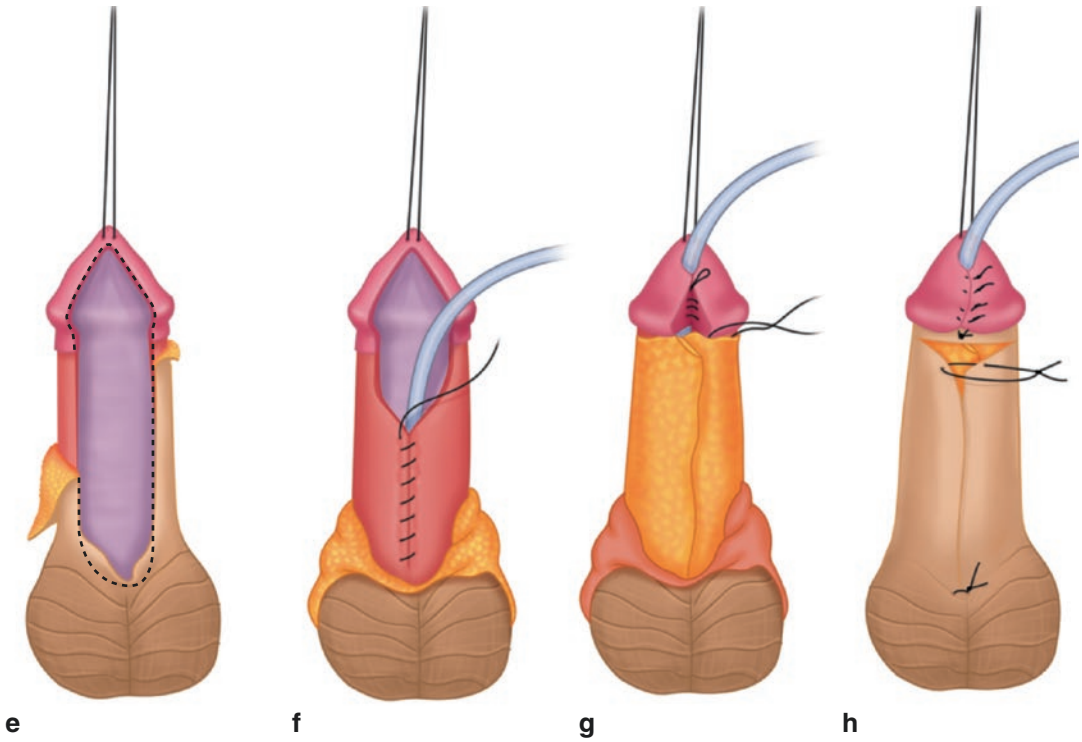


Fig. 14.14 Braka second-stage technique. (**e**) penis is degloved; (**f**) neourethral plate is tubularised around catheter; (**g**) dartos fascia flap is placed over the suture; (**h**) glansplasty and skin closure (Illustrations by Angelica Pistoia)

14.13 Outcomes

The literature about long-term results of hypospadias treatment is scarce [35]; however, different questionnaires with no standardization [36] have been proposed to evaluate the results after the treatment reporting about the cosmetic and functional outcome. Some of those are the Penile Perception Score (PPPS) [37], the Hypospadias Objective Scoring System (HOSE) [38], the Pediatric Quality of Life Inventory (PedsQl) [39], and the Hypospadias Objective Penile Evaluation Score (HOPE) [40].

Tips and Tricks

Currently, no standardized questionnaires are available for the evaluation of psychosexual function after hypospadias repair; however, the functional achievement is mostly evaluated by uroflowmetry and postvoid residual measurements.

In general, the questionnaires show that sexual function in men with corrected hypospadias is satisfactory in more than 80% [35]. Aesthetic appearance is gratified in more than 70% [35], even though children who undergo ventral penile curvature repair may experience a recurrence after puberty [41]; for this reason, it is suggested to have long-term follow-up.

Overall, the worst answers came from the sample with proximal and complex hypospadias.

Take-Home Message

- Genitaia malformations are an important field of interest for pediatric plastic surgery.
- The etiology is multifactorial, but genetic and chromosomal disorder, with hormonal dysfunctions, assume a preponderant role in the development of these anomalies.

- Hypospadias is a common malformation characterized by three different features: ectopic urethral meatus, ventral foreskin deficiency, and penile curvature. The overall complexity results from the severity of the above features. Assessment of the concomitant other anomalies is mandatory.
- Hypospadias has a wide variety of forms that require different surgical approaches. However, there is not a long-term follow-up evaluation of genital reconstructions, and no technique can be considered as the gold standard [42].

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Part III

Plastic Surgery for Trauma

Wounds

15

Giovanni Papa, Stefano Bottosso, Vittorio Ramella, and Zoran Marij Arnež

Background

In 2014, acute injuries resulted in 17.2 million hospital visits, resulting in hospitalizations or outpatients visits [1]. In most cases (57.8%), it is about outpatients' visits. Wound infections, especially surgical site infection (SSI), are the main problem; they are the second in order of frequency, which leads to a cost of 3.5–10 billions of dollars per year and 75% mortality [2].

It is important to distinguish an acute wound from a subacute and a chronic one. A subacute wound is a wound that has not received any treatment after 72 h or after 7 days if there was wound bed preparation (WBP) right after the trauma [3]. A chronic wound is a wound that is not healed 4–6 weeks after the trauma.

15.1 Introduction

A wound is any breach in the integrity of soft tissues in any site of the body [4]. It is defined by size, depth and anatomical structures involved, margins, and etiology.

The acute wounds can be simple or complex, depending on their dimensions, anatomical structures involved, and eventual bacterial load [5]. Therefore, a careful evaluation of the patient and the wound itself to offer the best treatment possible is mandatory.

The fundamentals of proper treatment are adequate surgical debridement and the best suitable reconstructive option in order to reach primary wound healing.

15.2 Mechanism, Etiology, and Classification

Various mechanisms can violate skin and subcutaneous integrity. These mechanisms include trauma, environmental exposure (such as burns that can have several causes like fire, chemical agents, ice, electrical shock), and surgical ones. Wounds from exposure to environmental agents will be discussed extensively in further chapters of this book. This chapter will treat traumatic wounds. Surgical wounds will be treated in Pearls and Pitfalls box.

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Traumatic wounds can be classified into the following:

Abrasion: superficial wounds caused by scraping, involving epidermis and dermis.

Laceration (Fig. 15.1): soft tissue lesion caused by penetrating trauma. The trauma can damage deep layers such as tendons, nerves, vessels, and bones. It can be associated with crushing and cavitation.

Crush injury (Fig. 15.2): wounds created by a blunt trauma. Often involves a greater area of tissue damage that cannot be always easily assessed. Avulsion and degloving are part of this category. An underlying hematoma is often present. It is important to consider early evacuation associated with compression if there is skin distress caused by the expansion of the hematoma.

Injection and extravasation injury: injection injuries are caused by inoculation of foreign materials (like paint, oil, dirty water), usually involving high pressure spray guns. They appear like a punctate wound, but the foreign material is often diffused in the deeper soft tissue. Extravasation injuries occur when solutions or medicines are delivered into the interstitial space due to occlusion or dislocation of arterial or venous catheters.

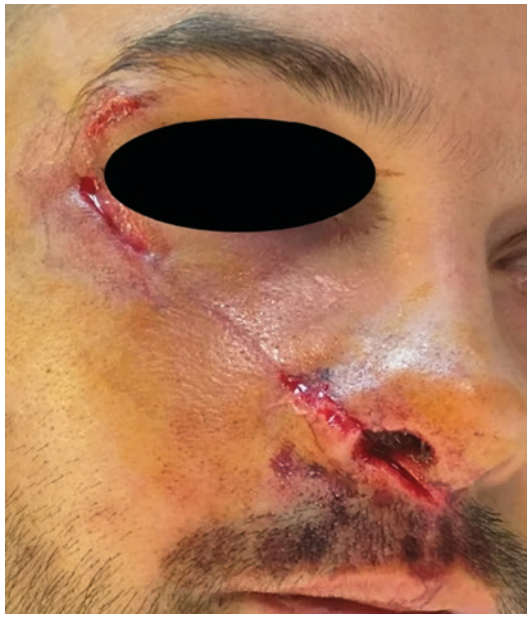

Fig. 15.1 Laceration caused by penetrating trauma

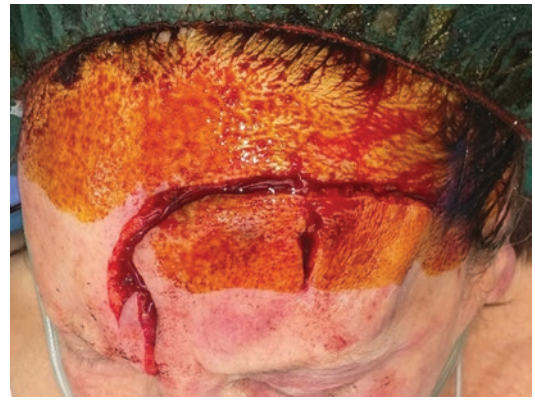

Fig. 15.2 Forehead wound with skin flap

They often can be treated conservatively, but in the case of high volume or chemotherapeutic drugs can cause skin ulceration and soft tissue necrosis.

Pearls and Pitfalls

The surgical wound management is essential to prevent, within the clinic risk, one of the most frequent healthcare-associated infections (HAIs), namely the surgical site infections (SSIs). Correct treatment of surgical wounds requires distinguishing simple wounds from those at risk. In the most used risk assessment scales (asepsis, WAR, etc.), they are often missing local risk factors due to the operator, such as tension, incorrect lines of incision, wrong planes of detachments, residual cavities, and useless stitches. The correct surgical treatment, linked to knowledge of the anatomical and vascularity of all body districts' skin and subcutaneous tissue, remains the basis of every plastic surgeon's education.

After having adopted all the prevention measures in accordance with the scientific evidence and having evaluated all risk factors [2], it is important to distinguish wounds at risk of dehiscence from those at risk of infection, as the treatment may differ.

- Simple wounds must be medicated in a sterile way with the least traumatic dressing possible that act as a barrier to external contamination, can remain in place as long as possible, and allow easy monitoring of the wound and the trophism of the surrounding tissues and an early discharge, through virtuous paths of territorial management (Fig. 15.3).
- *Wounds at risk of dehiscence* should be medicated with dressings that, in addition to possessing the previous characteristics, decrease the tension on the margins, such as negative-pressure wound therapy (NPWT) devices. In those cases, the possibility of decreasing tension from the inside with sutures approaching the margins, with the closing of the cavities and with fibrin glue, should also be considered.
- *Wounds at risk of infection* due to particular characteristics of the suture (such as the perineal site or the firearm traumatic modality) must be treated with dressings that also act on contamination and its prevention. The transition from critical colonization must be carefully followed with noninvasive devices for quantifying the degree of contamination. Only in the presence of clinical signs of infection, the wound should be treated with targeted antibiotic therapy (in collaboration with the infectious disease specialist who knows the endemic situation of the germs) after quantitative microbiological biopsy of residual tissues after debridement.

Proper prevention and training of the operators involved in the path of monitoring and correct treatment with even expensive dressings reduces enormously the healthcare costs that would lead to treating a SSI (prolonged hospitalization, further surgical operation, antibiotic therapies, often expensive in the case of resistant germs, and delay in returning to work).

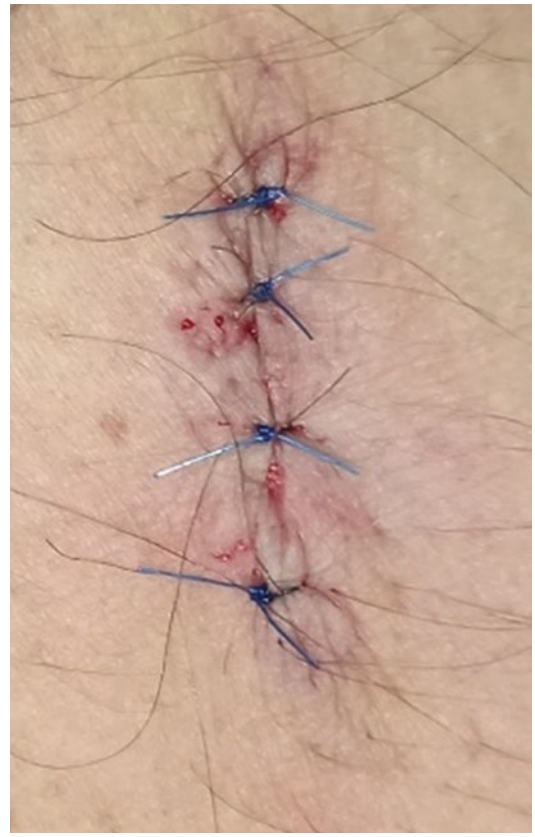

Fig. 15.3 Closed surgical wound with interrupted stitches

Bite, sting, and puncture wounds: particular type of injuries, discussed later.

15.2.1 Bite, Sting, and Puncture Wounds

15.2.1.1 Mammalian Bites

A particular cause of traumatic injury is animal or human bite. These are wounds that require special attention due to the potential morbidity linked to the infection. They are often underestimated in acute form due to their apparent benignity. Still, they may later present a serious infection of the tissue planes (Fig. 15.4).

Bite wounds can be classified according to the severity: grade I, superficial skin lesion, torn skin, scratched skin, bite canal, crushing injury; grade II, wound extending from the skin to the fascia, muscle, or cartilage; and grade III, wound with tissue necrosis or tissue loss.

It is important to remember that the deeper anatomical layers can slide underneath during trauma and then return to their original position, leading to an underestimation of the true depth of the wound at a first evaluation. Bites that may appear harmless on the surface may instead involve deep tissue and have important clinical relevance.

In general, 10–20% of bite wounds become infected, including 30–50% of cat bites, 5–25% of dog bites, and 20–25% of human bites [6]. Also, 30–60% of infections in bites are mixed infections with aerobic and anaerobic germs, coming from the oral flora of the animal that has bitten or, more rarely, from the skin flora of the victim or from the environment [7]. Along with *Staphylococcus* ssp. (including MRSA) and *Streptococcus* ssp. (including *pyogenes*), the commonly isolated pathogens reportedly include *Pasteurella* spp. (, *Pasteurella canis*, *Pasteurella dagmatis*), *Capnocytophaga canimorsus*, anaerobes (*Fusoacterium* spp., *Prevotella* spp., *Bacteroides* spp., *Porphyromonas* spp.), and others [6] (Table 15.1). Clinical signs of infection are redness, swelling, purulent secretion, pain, fever, and malaise. Infections usually involve soft tissues, generating cellulitis or a phlegmon with abscess formation and lymphadenopathy. In bites of the hands are common tenosynovitis and joint empyema. In some cases, the local infection can evolve into a systemic infection.

Surgical treatment of bite wounds consists in debridement of necrotic tissue, wound irrigation, and wound closure. Surgical debridement is superior to irrigation for the removal of devitalized tissue. There is a clinical consensus that wounds in the face should be closed primarily [8]. For bite wounds on the limbs, it is generally accepted that can be closed 12 h after trauma or longer. Primary closure is contraindicated for puncture wounds, bite wounds on the hands, and human bites (except on the face).

Meta-analyses do not recommend prophylaxis with antibiotics in the Cochrane Database [9]. Nevertheless, most physicians prescribe 3–5 days of antibiotic treatment in deep bite wounds and in wounds in critical areas of the body (hands, feet, areas near joints, face, genitals) or in patients at high risk of infection. Targeted antibiotic treatment is given for manifest bacterial infections [7].

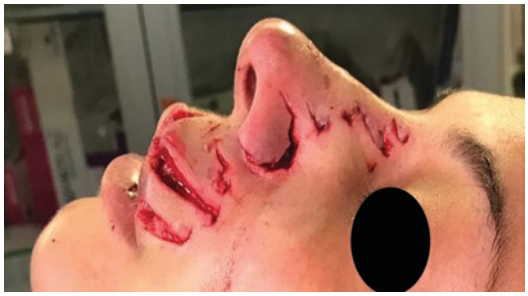

Fig. 15.4 Dog bite in a young woman nose and upper lip

Key Point

Bite wounds are at high risk of infection and are often underestimated. A meticulous surgical debridement is important. Prophylactic antibiotics are indicated if there is a high risk of infection. Wounds in the face should be closed primarily.

Table 15.1 Type of bacteria in bites

Type of bacteria	Dog bites	Cat bites	Human bites
Aerobic	Pasteurella spp. Pasteurella multocida Streptococcus spp. Staphylococcus spp. (incl. MRSA) Neisseria spp Capnocytophaga canimorsus	Pasteurella spp. Streptococcus spp. Staphylococcus spp. (incl. MRSA) Moraxella spp. Bartonella henselae	Streptococcus spp. Staphylococcus spp. (incl. MRSA) Eikenella corrodens
Anaerobic	Fusobacterium spp. Bacteroides spp. Porphyromonas spp. Prevotella spp.	Fusobacterium spp. Bacteroides spp. Porphyromonas spp. Veillonella	Bacteroides spp.

15.2.1.2 Snakebites

It is a rare condition in the developed countries. The most frequent venomous snakes indigenous to the United States are cotralids and elapids. No evidence-based recommendations exist.

In the case of snakebite, the first thing to do is immobilization, identification of the snake, and assessment of envenomation. If there is envenomation or mild–moderate envenomation, only observation and supportive therapy are indicated. In the case of major envenomation, it is appropriate to perform fluid resuscitation, laboratory evaluation, and correction of coagulopathy and administer polyvalent antivenin. In this case, the evaluation of the compartment syndrome and the possible execution of fasciotomies are essential.

15.2.1.3 Spider Bites

All spiders present a venom apparatus to kill other insects or spiders, although most are not dangerous to humans. One of the most common species dangerous to humans is the recluse spider (*Loxosceles rufescens*). It is a brown spider, with three pairs of eyes and a violin-shaped body. The bite causes a minimal pain, and often its location is difficult to identify. A hemorrhagic blister develops with progression to a dark black necrotic area that may extend over several centimeters. Only supportive treatment is indicated for systemic symptoms.

15.2.1.4 Bee and Wasp Stings

Bee and wasp stings are very common throughout the world. In the majority of the cases, the recovery is uneventful. The major problem in the case of stings is immediate hypersensitivity reaction. Sting tends to anchor to the victim's skin and the bee leaves it behind. The exuded venom sac should be scraped with a knife. The application of an ice pack to the local area tends to alleviate the associated pain.

Tips and Tricks

Skin tears are acute wounds caused by mechanical forces in patients at the extremes of ages, usually associated with cutaneous dystrophy (Fig. 15.5). The majority of these wounds occur in healthcare settings. Severity may vary by depth, but they never extend through the subcutaneous layer.

The treatment of skin tears involves an accurate cleaning of the wound bed and flap repositioning (with a damp gauze or with a wet finger). Due to skin fragility, stitches should be avoided, and nonadherent dressings are indicated in order to keep the skin in position, balance the wound exudate, and allow an atraumatic removal [10].

15.3 Clinical Evaluation

The evaluation of the patient with a traumatic wound starts with a general assessment of the patient itself that includes, according to the Advances Trauma Life Support algorithm, primary and secondary surveys.

Before focusing on the wounds, it is important to exclude other life-threatening causes.

External bleeding is managed by direct compression on the involved area. When possible, it is advisable to reposition any skin flap before compression in order to avoid ischemic damage. Tourniquet application can be necessary in the case of more severe bleeding. It is essential to remove any rings, jewels, or objects that can cause circumferential compression of the involved area and subsequent distal ischemia.

15.3.1 History

Patient's age and eventual comorbidity must be considered; its general health state and its functional status before trauma are important in order to assess whether the patient can be an outpatient one or it is necessary to have an anesthesiologist monitoring and further examinations.

Diabetes, chronic renal failure, heart disease, vascular pathology, smoking, vasculitis, malnu-

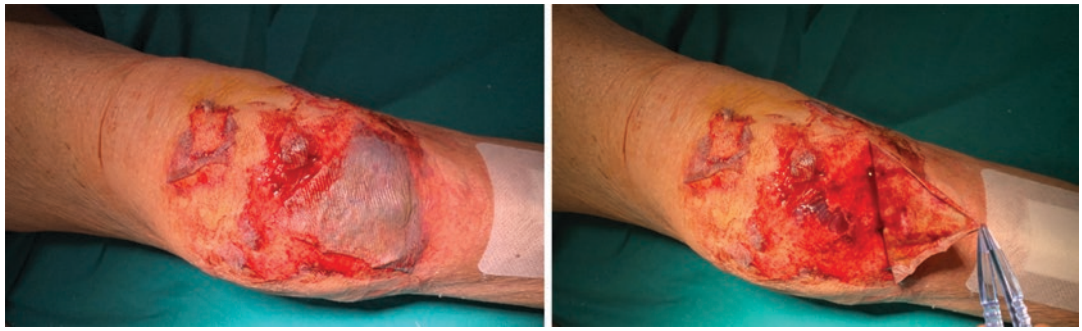

Fig. 15.5 Skin tear in an old woman's knee

trition, steroid therapy, previous radiotherapy, and hemophilia are all conditions associated with poor and delayed healing. They must be taken into consideration [11].

Any allergies to anesthetics and antibiotics should be inquired about. Even topical allergies to latex or disinfectants must be ruled out before treating the wounds.

Every patient needs the tetanus serum administration if the vaccination state cannot be assessed or if they have not been administered tetanus vaccine, according to Centers for Disease Control and Prevention recommendations [12].

15.3.2 Wound Evaluation

During the wound assessment, it is important to ask the patient how happened the trauma, the time and place, and any diagnostic or therapeutic procedures eventually performed before the current wound evaluation.

Then, wound components like extension, depth, and anatomical structures involved are considered, according to the anatomic location (skin, subcutaneous tissue, muscles, tendons, nerves, vessels, and bones) (Fig. 15.6).

Once the involvement of the anatomical structures is clarified, it is mandatory to evaluate the following:

- Signs of ischemia: examining the skin margins and the surrounding tissue looking for swollen, traumatized or bruised skin, thin flaps, or degloving.

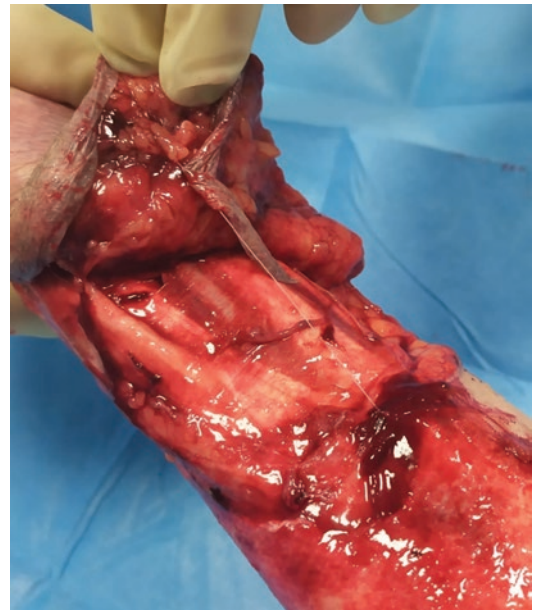

Fig. 15.6 The traumatic wound of the forearm with a skin flap and underlying structures' exposition

- Risk factor of infection: an examination of the wound bed looking for potential foreign body, heavy contamination, exudate, and any tunnel of fistulas.

After this local physical examination, wounds can be divided into simple and complex. The wound ends up complex if one of the following factor is present:

– Presence of loss of substance or size requiring reconstructive surgery (skin grafts, local o free flaps, etc.).

– Noble anatomical structures are involved (depends on depth and localization of the wound).
– There are signs of ischemia or patients factors that increase the risk of ischemia of the traumatized area.
– It is at high risk of infection or a patient's factor that increases the risk of infection.

15.3.3 Laboratory Studies

For simple wounds, a blood count is often sufficient in order to assess the level of hemoglobin and white blood cells' level. In the case of more severe injuries involving a crushing component of the muscles, an evaluation of creatinine and blood ions is also necessary.

In diabetic patients, the evaluation of glycated hemoglobin is important, which is an indicator of the trend in blood sugar over the last 3 months. Since diabetes is a risk factor for wound infection, close control of blood sugar levels is necessary in the perioperative period. In major traumas, insulin therapy is therefore advisable at the expense of oral antidiabetic therapy [13].

In chronic wounds, which do not tend to heal, careful evaluation of albumin and serum proteins and inflammation indices such as CRP and ESR is required.

15.3.4 Imaging

Radiological imaging is not necessary in the case of simple wounds. Otherwise, when major traumas occur, performing an X-ray could be useful for evaluating any fractures, presence of foreign bodies, and, in cases of chronic wounds, signs of osteomyelitis in the affected area.

In the case of penetrating trauma to the trunk, a CT scan is often required to assess the extent of the wound and the presence of any sinus or tunnel passages.

For the evaluation of chronic wounds with suspected osteomyelitis, an MRI may be necessary, as it has a greater specificity and sensitivity than X-ray for diagnosing osteomyelitis signs.

In the management of limb trauma, angiography or angio-CT are often indicated for the assessment of the vascular status, both for diagnosis and preoperative planning of reconstructive procedure, along with Doppler or color Doppler ultrasonography.

15.3.5 Diagnostic Tests

Microbiological and histological evaluations could represent further useful tools in the assessment and management of wounds. In fact, in subacute/chronic wounds, it is critical to exclude a strong contamination/infection and to have an antibiogram to choose a targeted antibiotic therapy, whereas histological biopsy in chronic wounds could exclude vasculitis, Marjolin's ulcer, or pyogenic granuloma.

Among other useful tools for the evaluations of lower limbs' wounds, the assessment of transcutaneous oxygen tension ($TcpO_2$) may be useful to exclude an impaired vascularization, or worse, an ischemic condition that impedes normal wound healing.

15.4 Treatment

The goal of wound closure is to achieve a functional and esthetically pleasant scar. The basic wound management consists of three components: wound debridement and preparation, wound closure, and wound dressing.

15.4.1 Wound Debridement and Preparation

Before debridement, it is important to cleanse the wound and the perilesional skin. The aim is to remove dirt, foreign material, or nonadherent metabolic debris and to create optimal local conditions for the tissue repair process [14]. Cleansing with surfactant antiseptic can also reduce the bacterial load. In the case of cleansing with the only purpose of eliminating foreign bodies and debris, the physiological solution is suf-

ficient. Since traumatic wounds are contaminated by definition, it is important to use detergents with surfactant action. They act by breaking the hydrophobic or electrostatic forces that guide the initial stages of adhesion of bacteria to the surface [15].

Wound debridement is the most important procedure of wound treatment. Inadequate debridement before closure brings to postoperative infectious complications. Operative wound debridement must be systematic and thorough, working simultaneously with wound exploration. It is important to determine tissue viability through examination of the color, temperature, and presence of bleeding. Debridement consists in the removal of devitalized, infected, or necrotic tissue from the wound [16]. At the end of the debridement, each cavity must have been explored and the surrounding anatomy known. At the heart of the debridement is the surgeon's knowledge of the anatomy [5]. Small islands or pedicles of tissue are frequently devascularized and should be removed. Inorganic material left in the dermis or superficial subcutaneous tissue can result in tattooing and should be removed whenever possible [12].

Key Point
Wound debridement is the most important procedure of wound treatment. Inadequate debridement before closure brings to postoperative infectious complications. It consists in the removal of devitalized, infected, or necrotic tissue from the wound to allow the remaining tissues' primary healing.

Skin is relatively resilient but is vulnerable to torsion and avulsion injuries, which lead to degloving and disruption of the septocutaneous and musculocutaneous perforating vessels [17]. In the case of extensive flap lacerations, all nonviable skin must be excised. Care must be taken to the viability of the subcutaneous fat. The area of fat necrosis is often more extensive than that of the overlying skin. Devitalized muscle may be difficult to assess, and it is useful to look for the four "Cs": color, contraction, consistency, and capacity of bleed [18].

Debridement to bleeding tissue serves as the endpoint for most tissues. Still, specialized tissue, such as cartilage, tendon, and irradiated wounds, often requires experienced judgment and careful consideration. Multiple operative wound debridements may be necessary to archive wound stability depending on the necrotic and infection bioburden. However, multiple serial debridement has been shown to be associated with worse outcomes [19].

The standard of surgical debridement is sharp debridement. It is classically performed with the scalpel blade or scissors. The tissue is removed in sections until bleeding tissue is reached. Often, curettes can be used to perform a scraping action on the tissues like granulation tissue, bone, or small cavity. Another useful tool for surgical debridement is hydrocision [20, 21]. This tool allows to simultaneously cut, remove, and rinse tissue with a water jet through a high-pressure opening, resulting in an ideal for soft tissue debridement. Studies done on wound biofilms in a polymicrobial porcin model have shown an almost 1000-fold reduction in bacterial colonies using Versajet® (Smith-Nephew, Hull, UK) and significant reductions in inflammatory neutrophil markers [22]. Other studies demonstrate that Versajet may be equally if not more effective than conventional surgical debridement by causing less damage to viable tissue and appear to be cost-effective by minimizing surgical duration and length of hospital admission [23].

Another useful instrument for debridement is the ultrasound system. Low-frequency, low-dose ultrasound has been found to break down dead tissue. These methods are painless and reduce bacterial burden [24] but will require several treatments [25].

In selected cases, a conservative sharp wound debridement can be performed. It consists in the removal of loose and devascularized tissues above the level of viable tissue. In this type of debridement, only clearly devitalized tissues are removed, retaining surrounding tissues that are traumatized but have healing potential. In this case, a second look is mandatory to evaluate the

tissues left in place [26]. It is important, after surgery, to indicate the type of debridement performed.

In wounds that remain open, due to the patient's general situation, to the impossibility of performing surgical interventions or the wound's local characteristics, it may be necessary to continuously manage the wound bed by maintenance debridement to remove the biofilm constantly [27].

Key Point
The surgeon should know the type of debridement performed: in the case of a radical one, he/she can close the wound immediately; in the case of a conservative one, he/she should perform a second look, after some time, in order to evaluate the trend of the tissues.

During surgical debridement, a bacterial quantification of wound could be necessary, depending on wound's contamination and timing of the injury. Acute traumatic wounds can be considered contaminated wounds or dirty. Antibiotic prophylaxis may be beneficial in those wounds because of the high risk of infection. The decision to use antibiotic prophylaxis depends on an accurate evaluation of the patient's comorbidities and risk of infections. It should be associated with postoperative dressing strategies, antiseptic wound dressing, and antiseptic agents. Superficial swab specimens collected at the time of injury are inappropriate and without clinical value for therapy. It can be useful for knowing the host microbiome. In the case of signs and symptoms of infection, the etiological diagnosis is crucial. After initial debridement and cleansing of superficial lesions, collecting a deep tissue is the most appropriate method for identifying the etiological pathogen [28].

The Centers for Disease Control and Prevention recommended against the use of topical antibiotic agents for prevention of SSIs (except silver sulfadiazine [29]). In contrast, topical antiseptic dressings may diminish topical microbe load and decrease the risk for potential infection [30].

Between staged debridements, various types of dressings are available. Negative pressure therapy and antimicrobial dressings play a major role as a bridge to reconstruction, creating healing environments and improving efficacy and comfort for the patient. Negative-pressure wound therapy (NPWT) has revolutionized wound care since it was popularized by Morykwas et al. and Argenta and Morykwas in 1997 [31, 32]. These articles demonstrated an increased rate of granulation tissue formation, decreased edema, and increased localized blood flow in the area treated. After surgical debridement, the use of NPWT allows delaying the reconstruction to 7 days after injury, keeping the wound in its acute phase, as it maintains the wound bed isolated and clean. It manages wound fluid exudate, minimizing dressing changes and exposure to bacteria, inflammatory cytokines, and matrix metalloproteinases [33]. Nevertheless, NPWT is not a substitute for appropriate medical and surgical care, nor is it a debridement modality by itself. Contraindications to its use are exposed vessels, malignancy, necrotic tissue, untreated osteomyelitis, or non-enteric and unexplored fistulas [34]. The use of negative-pressure wound therapy with instillation is appropriate for patients with substantial comorbidities that impair wound healing or response to the infection of those who have a complex wound, like wound complicated with invasive infection or extensive biofilm, diabetic foot wound infections, and severe or contaminated traumatic wounds [35]. Studies demonstrate that instillation of normal saline can achieve comparable outcomes to other types of solution [35].

Key Point
NPWT, after debridement, plays a major role as a bridge to reconstruction, increasing formation of granulation tissue, decreasing edema, and increasing localized blood flow.

Until new evidence, wound irrigation provides adequate wound preparation. Irrigation of the laceration reduces the likelihood of infection. The irrigation's objective is to physically remove bacteria and foreign material present in the wound that can serve as a nidus for bacterial contamination. There is little evidence to support the use of one lavage fluid over another. A large randomized controlled trial found no significant difference in reoperation rates between castile soap and normal saline for wound irrigation in open fractures. In contrast, it found an increased overall infection rate in the castile soap group [36]. While the type of fluid is not important, the irrigation technique may impact wound healing. Some studies report that, despite the removal of some contaminants and debris by conventional low-pressure irrigation with gravity flow and bulb syringe methods, only high-pressure pulsatile jet irrigation lowered the numbers of *E. coli* significantly [37]. However, conflicting studies show that high-pressure pulsatile lavage penetrates and disrupts soft tissue to a deeper level than low-pressure lavage, causing considerable gross and microscopic tissue disruption [38]. The FLOW trial demonstrates no statistically significant difference in reoperation rates between high-pressure pulsatile lavage and low-pressure pulsatile lavage, establishing very low pressure as an acceptable, low-cost alternative in the irrigation of open fractures [39].

15.4.2 Wound Closure

A useful tool to plan the wound closure is the reconstructive ladder. It is a guideline to reconstruction, and each case should be looked at on an individual basis, considering the patient's characteristics and the wound's anatomy in order to choose the best option for closure (Table 15.2).

15.4.2.1 Secondary Intention

After adequate debridement, a wound can close spontaneously. It is the first and most straightforward technique. It can be used in superficial wounds or according to the patient's general clinical condition, with an adequate dressing and optimal wound bed preparation. The disadvantages include the extended time period to healing, dressing changes, and often a suboptimal scar.

Table 15.2 Advantages and disadvantages of the different technique of wound closure

Technique	Advantages	Disadvantages
Secondary intention	• Simple • Avoidance of a closed wound infection	• Extended time of period to healing • Dressing changes • Suboptimal scar
Primary closure	• Simple • Best healing potential	• Potential wound infection • Potential need of advanced surgical technique
Skin graft	• Simple and quick • No need creation of flap	• Necessity of meticulous wound bed preparation • Poor esthetic outcome • Less durable result
Local flaps	• Their own blood supply • Similar texture • Durability	• More complex operation • Small zone of injury needed
Free tissue transfer	• Freedom in reconstruction for complex and specialized area	• More complex operation • Morbidity of the donor site

15.4.2.2 Primary Closure

Primary closure by direct suture is the most reliable technique with the lowest rate of dehiscence. Sutures can efficiently repair even more complex laceration. The choice of technique repair must not be arbitrary but needs to be based on wound characteristics and kind of patient:

- Simple interrupted sutures are excellent for wound edge approximation. Every suture is placed and tied individually. There is an excellent control over the level of wound eversion, and interrupted sutures give a good result in curved and nonlinear wounds. If infection occurs, only a few sutures need to be removed in order to drain subcutaneous collection.
- Intradermal suture can be used in the event that the wound is made linear by debridement as if it were a cut wound.
- The mattress sutures are efficient in reducing skin margin tensions and helpful in creating some sort of eversion, but they can cause

impaired skin perfusion. This technique increases the interphase or contact between the raw surface areas of two opposing wound sides.

- The figure-of-eight suture can simultaneously close two levels of depth, reduce rounded defects, and fix the nail to its bed after damage.
- The running sutures are easy and fast to do. They can offer a very good hemostasis, especially in scalp wounds. This technique is commonly used when the wound is actively bleeding and saving time is critical. The disadvantage is that suture breaks can cause wound gaps to occur. If the suture material breaks in a running suture, the whole wound will break down. For this reason, it is important to secure the knots on the two sides and consider adding a couple of interrupted sutures in addition.

In most traumatic wounds, subcutaneous or subcuticular sutures are mandatory to close dead spaces and approximate wound edges. They are performed with absorbable sutures and with buried knots. Subcutaneous sutures should be placed, preferably taking a bite of fascia to add strength and not cause unnecessary liponecrosis. Subcuticular sutures should be anchored to the deep portion of the dermis.

The wire size is expressed using the USP (United States Pharmacopeia) system. It centers around the "0" suture. Suture sizes increase from size 0 to size 1, 2, and upward and decrease in size from 0 to size 2–0, 3–0, and downward. The use of different wire sizes depends on wound dimension and tension. The smallest diameter of the suture that will accomplish the purpose should be chosen to minimize the tissue trauma with each passage of the needle and the amount of foreign material left inside. It is essential not to place large sutures near the most superficial layers of the dermis.

Whether a suture has a single or multiple strand composition is an important consideration. The use of multifilament is not recommended in contaminated or infected wounds because it can increase the infection rate as the microorganisms can nestle between the fibers. The advantage of the multifilament suture is the better knot strength. Monofilament sutures pose lower resistance on tissue passage and tend to snug down more readily. When used on the subcutaneous or intradermal level, multifilament sutures tend to be extruded in the form of a suture sinus or small localized abscess, compared with a monofilament, which behaves in a cleaner, less reactive manner.

Sutures can be absorbable or nonabsorbable. The absorbable ones are useful for deep layers' sutures or in the pediatric population that can be less compliant during stitch removal. In these cases, it is important to consider the reabsorption time of the filament that must be sufficient to keep the wound closed even during movement and under tension. Nonabsorbable sutures are instead appreciated for their nonresponsiveness to surrounding tissue and for maintaining their tensile strength during time.

Tips and Tricks

It is important to minimize scar tissue formation, ensuring that wound edges are not inverted during closure. The inversion will delay and/or compromise the healing process and leave an unsightly scar. It is appropriate to suture wounds with everted, or slightly lifted outward, edges.

Tension is the other factor that does not favor good healing. In order to obtain tension-free approximation of the margins, it is necessary to detach the surrounding tissues. The detachment must occur in the correct anatomical plane that maintains skin vascularization to achieve the best wound edge approximation, avoiding dead spaces. This is mandatory in the case of loss of skin substance caused by trauma or by subsequent surgical debridement.

The disadvantages of sutures are local anesthesia administration, time-consuming patient positioning, and an inflammatory tissue reaction. If left in place for a long time, it can cause permanent marks on the scar's sides.

Recently, tissue adhesives have been widely used due to their easy application. They are especially used in wounds without tension with cosmetic results comparable to sutures. They are not generally indicated in complex laceration that cannot be approximated manually. In these cases, they can be used only if adequate deep sutures are already positioned and the margins are well approached. It is not indicated to use this technique in tension areas or subjected to the repeated movement (as articular areas or hand).

Staples are a quick closing technique and help repair wounds of the scalp. They are associated with less foreign body-like reactions and infection. Staples do not provide optimal margin approximations like sutures. Still, they are considered a good alternative in an emergency when we do not have enough time, mostly in hidden areas. Removing staples is more complex than sutures, and the maneuver is more painful.

Adhesive tapes can be applied quickly and easily, without any discomfort for the patient. They are also associated with minimal tissue reactivity. They can be left in place for a long period of time. They have little tensile strength, and so they are not able to approach margins correctly in tension areas. Moreover, it can cause blister formation due to the presence of shearing forces on the epidermis. Tapes are very useful, especially after sutures removal, to reduce wound tension. They cannot be used in haired areas, and also the taped area should not be wet as it would lead to dislocation of the tapes.

15.4.2.3 Skin Grafting and Local Flaps

When a soft tissue defect is too large to be closed primarily or when the primary closure results in unwanted tension and tissue distortion, local skin flap or skin graft may be used.

In a skin graft, an underlying bed to supply the nutrients and ultimate blood supply is required. Meticulous wound bed preparation, hemostasis, and appropriate dressing to protect the graft are mandatory. Skin grafting is a simple and quick technique for wound closure without the creation of flaps. The disadvantages are the necessity of meticulous wound bed preparation, poor esthetic outcome, and less durable result compared with flaps.

Local tissue rearrangement consists in the creation of small geometric random flaps or larger flaps based on axial circulation. The advantages of local flaps are their own blood supply, texture similar to the surrounding tissues, and durability. Disadvantages include the need for a more complex operation and a small zone of injury.

15.4.2.4 Free Tissue Transfer

Free flap transfer is the most complex technique for acute wound closure. This method has all of the advantages of the local flap with the benefit of transferring the tissue anywhere on the body. The advantages are its freedom to reconstruct complex and specialized areas where local flaps are not available. Free flap success rates are well over 95% at microsurgical centers. Disadvantages are the need for a more complex operation and the morbidity of the donor site.

Pearls and Pitfalls

As the simplest solution is not always the best, the "reconstruction ladder" was modified in "reconstructive elevator." the most surgical demanding technique can be the first option if indicated. The reconstructive elevator encompasses the creativity needed to treat the wound in the best possible way [40] according to the local and general clinical situation of the patient (personalized treatment on the patient).

15.4.3 Wound Dressing

The function of a wound dressing is to provide a good environment for healing (Fig. 15.7).

In the case of acute wound treated by primary intention, a simple dressing is commonly used to cover the wound. The purpose of the dressing is to protect the suture from external

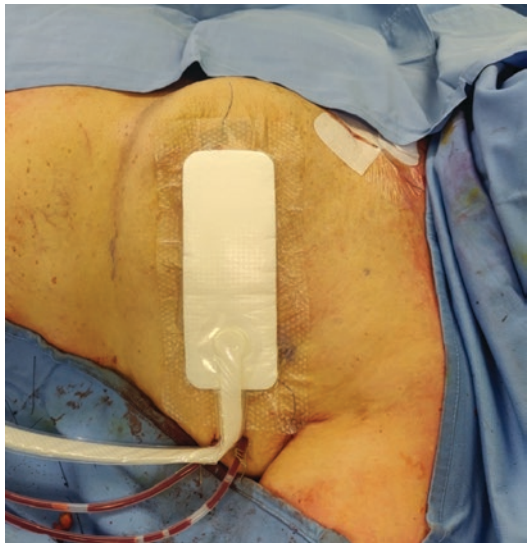

Fig. 15.7 NPWT on a surgical site

contamination and absorb any exudate. Adhesive film dressing with absorbent pad and different types of adhesive edges can act as a barrier to bacteria and water. It can be left in place for several days. They are useful in the case of simple wounds in areas not at risk of maceration of the suture.

In the case of second intention healing, the dressing should manage exudate and heal from the base upward. Many types of dressings can be used depending on the local clinical wound situation:

Nonadherent dressings, including paraffin gauze up to the most technologically advanced dressings with the addition of therapeutic substances, are useful for protecting skin integrity. They are easy to apply and do not cause pain on removal.

Hydrogels are indicated in dry necrotic or sloughy wounds and provide a moist wound environment and encourage debridement.

Foam dressing is used in the case of large volumes of exudate.

Hydrocolloid dressings are a thin polyurethane foam sheet bonded onto a semipermeable film. They are indicated in exudate wounds, with infection, to promote debridement.

Alginate dressings adsorb exudate and present hemostatic properties (calcium alginate). They form gelatinous mass, easy to remove without pain. A secondary dressing is needed to keep alginate in place.

Hydrofiber dressing is used to provide a moist environment for wound healing without macerating the skin edges (the exudate does not extend over the wound edges) [41].

Antimicrobial dressings, including silver sulfadiazine, silver dressings, dressings with PHMB, and dressings with honey, can be used in wounds at high risk of infection.

New materials stimulate healing through various mechanisms depending on the active ingredient, such as autolysis (hydrogel, collagenase, etc.).

Take-Home Message

- Knowing the mechanisms of trauma and describing the wound locally is fundamental for a correct diagnosis.
- Classifying the wound as simple or complex leads to a different treatment.
- Skin tears, hematomas, and bites are special situations that can be encountered in the emergency room, and it is important to know how to manage them correctly.
- Prevention and proper dressing, even with negative pressure wound therapy (NPWT), of the surgical wound can prevent surgical site infection (SSI).
- Wound debridement is the most important procedure of wound treatment. Inadequate debridement before closure brings to postoperative infectious complications.
- After proper debridement, it is possible to choose the best reconstructive tech-

nique from all options: secondary intention healing, direct closure, use of skin grafts, local flaps, or free flaps.
- The suturing technique depends on the clinical situation and the mechanism of the trauma.
- To get the best results, we need to know the basic techniques to deal with the correct eversion of the margins and the correct detachment of the soft tissues.

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Upper Limb Trauma

16

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Background

Trauma involving the upper limb represents a major problem due to the high functional requests in our society, then needing comprehension and correct treatment by qualified and specialized personnel. Looking just at hand traumas in working environment, every year in Europe, 8,8 million of such injuries are to be treated. These lesions are the first reason for absence from work. Furthermore, the social costs for the sequelae and relative invalidity are enormous. Then, special attention should be paid from the beginning to early recognition and management of lesions sometimes involving single tissues but often requiring combined orthopaedics and plastic know-how.

16.1 Generalities

16.1.1 Introduction

To deal with hand and upper limb trauma means having clearly in mind the indications and contraindications for emergency or delayed treatment of lesions in which a wrong decision may lead to irreversible functional outcomes. Once the decision is taken, all the steps for the treatment of these often complex injuries should be respected in order to obtain the best possible return to normal anatomy and function. An open-minded approach is necessary, thinking to the best solution for every single involved structure and then combining plastic and orthopaedic concepts.

Key Points

Achieving a good function more than restored anatomy of the upper limb is the most important goal in trauma surgery.

Clear indications and contraindications are the best way to achieve a good result.

Meticulous attention to technical details in bone fixation, flexor and extensor tendon suture, nerve repair and soft tissues reconstruction is helpful to achieve a good function of the traumatized segment.

Early recognition and management of complications improve the final outcome.

Early recovery of motion by means of rehabilitation maintains joint pliability and prevents tendons adhesion, giving the best outcomes. Sensory re-education improves the recovery of sensibility.

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16.1.2 Essential Surgical Anatomy

Upper limb traumas often frighten inexperienced surgeon for the complexity of forearm and hand anatomy.

In the upper limb, the surgical approach should be often as wide as needed in order to have the best view of the complex anatomy and of all the possible lesions.

Any wound must be prolonged proximally and distally, following the basic plastic principles of skin incisions.

For a detailed anatomy of the hand, wrist, forearm and arm, we send the reader to anatomic atlas [1]. In this paragraph, we just outline some anatomical details that can help the surgeon in choosing the better approach.

At the level of the hand and wrist, extensor tendons are much thinner and more superficial than the flexor tendons, so they are more exposed to rupture in case of a wound. Moreover, unlike flexor tendons that tend to retract proximally, extensor tendons remain in place when injured, especially at finger level.

We can identify five and eight zones of possible flexor and extensor tendon injuries, respectively (Figs. 16.1 and 16.2). For each zone, a slightly different surgical technique must be used, and the injury prognosis varies considerably.

When approaching flexor tendons, we must keep in mind that they are surrounded and kept in place by several pulleys (Fig. 16.3).

The digital sheet is opened only through pulleys A1, A3 and A5, leaving in place pulleys A2 and A4. If these pulleys are violated, a bow stringing effect is produced, reducing the active arc of motion of the finger and its strength. The FPL is the most radial tendon in the carpal tunnel, right next to the median nerve.

Dorsally, at wrist level, all the tendons pass under the extensor retinaculum, through six separate channels.

In the hand, except for selected cases, bones and joints are generally approached dorsally. Lateral or palmar incisions are limited and generally used for the digits.

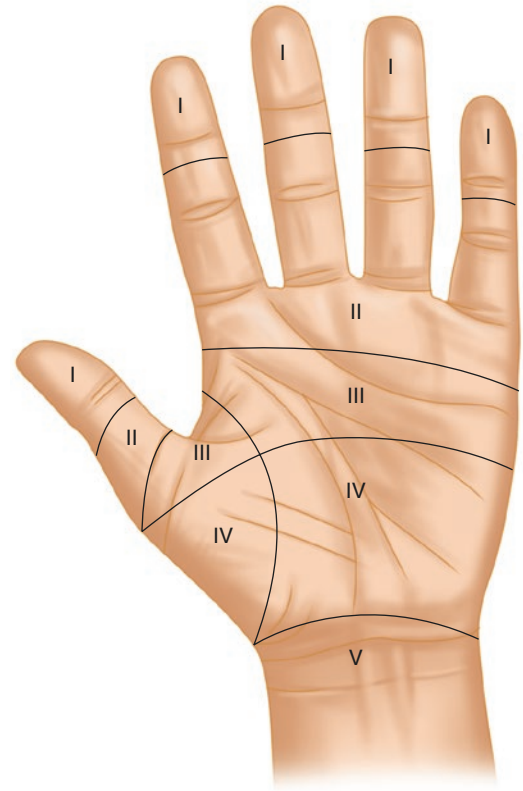

Fig. 16.1 The five palmar zones in which the hand is divided for possible flexor tendons injuries. The critical one is zone 2 or "no man's land"

Conversely, distal radius fractures are approached palmarly in most of the cases, through the Henry or modified Henry approach, passing under the FCR tendon or between it and the radial artery. More proximally, the radius can be approached either volarly or dorso-laterally; close to the elbow attention must be given in avoiding any injury of the posterior interosseous nerve, which passes under the supinator muscle close to the radius. Ulna should be treated by a posterior direct approach.

When surgically treating the elbow medially or posteriorly, care must be taken in isolating and protecting the ulnar nerve. In the lateral approach, surgeons should pay attention when extending the incision over 10 cm proximal to the epicondyle, in order not to injure the radial nerve.

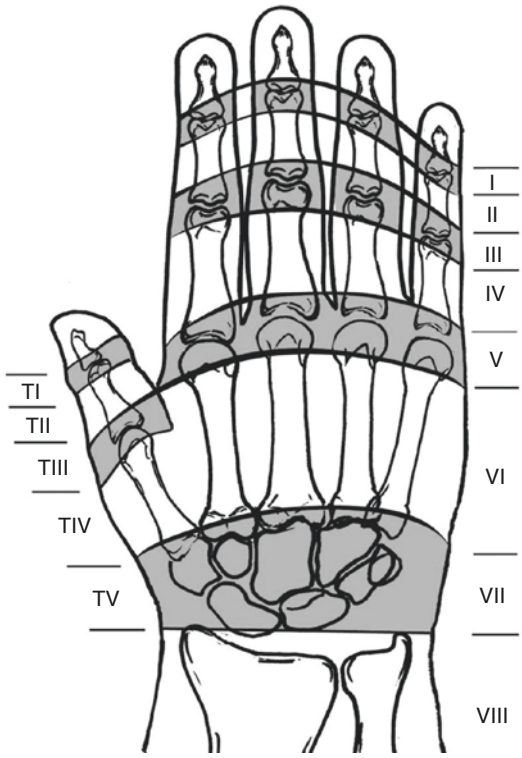

Fig. 16.2 The eight dorsal zones which divides the hand for possible extensor tendons injuries

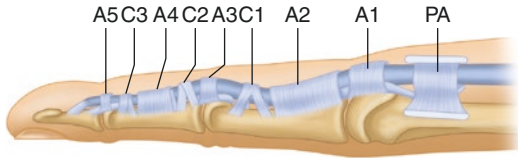

Fig. 16.3 Anatomy of the digital sheet with position and numbering of the pulleys

16.1.3 Aetiology, Classification and Principles of Treatment

The factors to be considered in the aetiology of a trauma at upper limb level are mechanism (direct or indirect; crush, stretch and cut injury; flexion, extension or rotational force and its direction; energy of the trauma (low or high); and open or closed lesions. Trauma to an upper limb may go from a minor injury following an accidental fall to high-energy traumas which may produce extensive tissue lesions. In the upper limb, it is not the extent of the apparent trauma which may influence our treatment and the prognosis but the number and type of involved tissues. A small skin lesion produced by a knife may hide a flexor tendon and/or a nerve injury, then needing an immediate correct diagnosis and consequent appropriate treatment. Apart from the classifications used for lesions of the single tissues, which will be presented in the devoted paragraphs, many predictive indexes have been proposed in order to facilitate surgeons in a difficult decision-making process for the treatment of multiple tissue injuries. Nowadays, the Mangled Extremity Severity Score (MESS) for the upper limb is the most common score used on emergency, predicting amputation for those patients who present a high score. However, many studies and our experience suggest that MESS alone is not sufficient to decide between amputation or limb salvage because many injuries lie in a "grey zone" in which the results of treatment are sometimes unpredictable and sometimes superior to those expected. These borderline conditions should be analysed case by case [2].

The treatment of the lesions caused by an upper limb trauma follows the general updated rules published in the literature and that we'll present later. Here we just recall that more and more in the last years has been understood the importance of timing of treatment and the coexistence of orthopaedics and plastic surgery concepts leading to the rise of a kind of new specialty that is "orthoplastic surgery" [3].

16.2 Upper Limb Trauma

16.2.1 Bone

The general principles of bone and joint trauma management in the upper limb remain the same as in the other regions of the body. Simple, stable fractures are generally treated conservatively, except special needs (athletes, etc.). Criteria for surgical treatment are displaced fractures, irreducible or unstable or open lesions especially needing combined soft tissues repair. Generally, X-ray study of the fracture is sufficient for plan-

ning treatment. However, in lesions at joint level, the articular surface alterations should be studied by means of CT scan for a good understanding and a correct treatment plan. Articular fractures need open reduction and synthesis to restore the best joint anatomy and following function. More and more in articular trauma we should consider not only the bony elements but also the ligament structures, often surgically reconstructing them to avoid secondary instabilities. No EBM exists on the superiority of one special device to treat upper limb fractures. The use of plates, nails, K-wires or external fixators, if correctly managed, leads to similar results. The choice is generally made on the type of fracture (transverse, oblique, spiral, comminuted) and the patient's needs (age, profession, etc.). Anyway, we need stable synthesis allowing early mobilization, possibly not interfering with soft tissues. Then, Ex Fix is mainly used in open, contaminated lesions or for a "damage control" before the final treatment (in politrauma, etc.) [4]. Simple K-wires are less and less used, changed by more stable modern synthesis devices.

The wrist and hand are specialized structures in the upper limb with special needs. The good functional recovery at this level needs good anatomy restoration and early motion, even more than in other sites. Particularly at the metacarpal and finger level, attention should be given to secondary deformities, especially rotational problems. A closed or open approach should prevent malrotation, checking the plane of the fingernails with MP flexion, otherwise leading to finger overlapping and relevant dysfunction.

At the wrist level, the most common lesions are distal radius and scaphoid fractures. Distal radius extra-articular or partially displaced articular factures in the aged patient are generally reduced and managed conservatively. On the contrary, articular involvement, especially in young patients, needs surgical repair particularly if there is shortening >2 mm and an articular step >1–2 mm. The predictors of fracture instability, then needing surgery, are multifragmentary fractures, dorsal comminution, relevant displacement and ulnar and/or radio-ulnar joint involvement [5]. Actually, plating is the preferred method of treatment, but also Ex Fix is often a good solution.

Scaphoid fractures are really common which can lead to severe secondary problems if not recognized. Then, careful clinical and radiographical evaluation should be done in all wrist sprains. Treatment again may be conservative or surgical (with screws) depending on fracture site (proximal ones are the worst), displacement and patient's needs (conservative treatment needs at least 45–60 days of immobilization).

For most fractures of metacarpals and phalanges, closed manipulation, proper splinting and protected motion will produce good functional results. Criteria for surgery are degree of displacement (> than 15–30° of angulation), rotational deformities, unstable or open fractures, multiple fractures and articular displaced fractures. Even at this level, the surgical technique will use K-wires, simple screws or plates according to the fracture type but with the aim of maximal stability for an early mobilization in order to avoid tendon stuck and stiffness, frequent complications at this level.

16.2.2 Tendons

In recent years, a significant amount of studies in the field of tendon injury in the hand has contributed to advances in both surgical techniques and postoperative motion protocols. The introduction of early motion has improved tendon healing, reduced complications and enhanced final outcomes [6]. Whatever the type, or level, of flexor or extensor injury, the ultimate goal is to perform a strong suture and a gliding tendon, protect the repair, modify peritendinous adhesions, increase tendon excursion and preserve joint motion.

Flexor tendons of the hand are divided into five zones (Fig.16.1).

Bunnell, in 1918, coined the term "no man's land" to describe zone 2 in the hand, because at that time it was felt that no man should attempt repair within this zone. While this belief fell, tendon repair in this zone remains challenging for

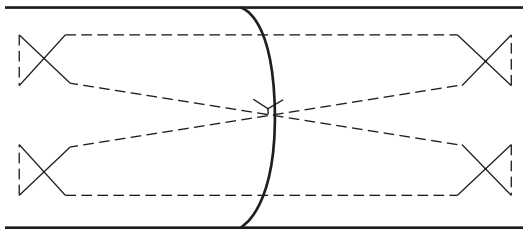

Fig. 16.4 Adelaide type of suture for flexor tendon repair

any hand surgeon. This zone has a fibro-osseous digital canal where both flexor tendons interweave in a complex manner (Fig.16.3).

The multiple pulleys increase its complexity because minimal swelling of the epitenon can impair free motion of the tendon. Usually, flexor tendon repair is performed in an emergency setup. However, if the surgeon does not possess enough expertise to treat such lesions, it's better to delay the repair (best within 48 h, though the end-to-end repair is often possible 5 weeks after injury).

Current key practices for zone 2 flexor tendon repairs include:

- Using wide-awake local anaesthesia without tourniquet, allowing active motion of the tendon during surgery [6].
- Making strong core sutures, typically 4- or 6-strand repairs. We prefer Adelaide suture with interlocking peripheral suture (Fig.16.4).
- Judicious venting of the critical A2 and A4 pulley to promote tendon gliding.
- Early active motion in mid-range.

In zone one, if the distal tendon stump is shorter than 1 cm. a pull-out suture has been the common treatment for many years (Fig.16.5), but now most of the Authors prefer direct repair using several strong core sutures, up to eight or ten strands or reinsertion with anchors.

The flexor tendons in zones 3, 4 and 5 are repaired similarly as zone 2. The repairs are easier because of lack of sheath over the tendon.

The injuries in zone 4 are rare and can be associated with median nerve and arteries lacerations, while wounds in zone 5 are called "full house"

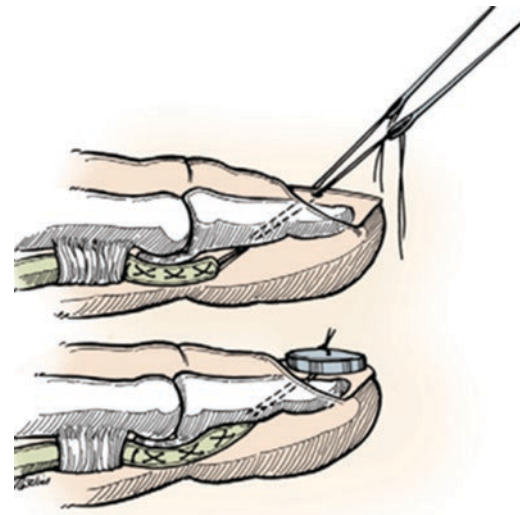

Fig. 16.5 The flexor tendon lesion in zone 1 is reconstructed anchoring the tendon to the bone with a dorsal pull-out of the suture

because they often involve multiple tendons and neurovascular injuries. It's mandatory to repair at the same time all the involved structures.

Pearls and Pitfalls

- Wide-awake anaesthesia allows a good check of the quality of the repair.
- Strong 4-strand sutures are needed for early mobilization.
- Pulley venting reduces tendon stuck caused by bulky sutures.
- Lack of repair of at least one pulley (mainly A2/A4) will result in bowstringing and poor function.
- Delay in mobilization for a weak repair will cause adhesions and a poor function.

The extensor tendons are placed in a superficial position on the dorsal aspect of the hand and are highly susceptible to injury. Kleinert and Verdan divided the extensor mechanism of the hand in eight zones (Fig. 16.2).

The extensors do not have good excursion of flexor tendons, so adequate repair is important

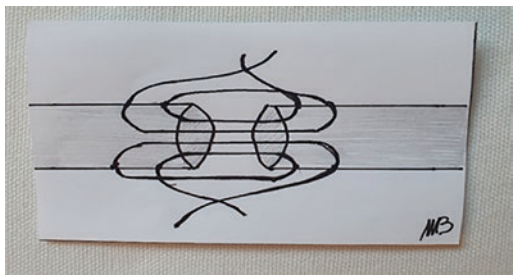

Fig. 16.6 The extensor tendon in zone 1 may be repaired with figure-of-eight suture

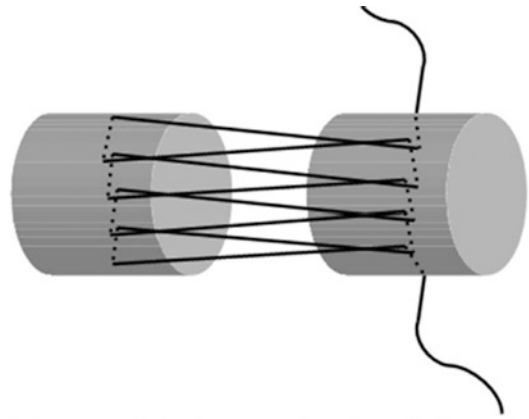

Fig. 16.7 In zone 4, it's possible to perform a core suture as at this level the extensor tendon is no more flat as in the distal zones

because even 1 mm tendon gaps, especially in 1–5 zones, may cause 20° of extension loss. Shortening of the extensor tendon may cause decreased finger flexion.

There are three treatment strategies for extensor tendon injuries: conservative with splinting, primary repair and tendon graft (in case of tendon gap) [7, 8].

Zone 1: correct management is mandatory because chronic zone 1 tendon injuries may lead to swan-neck deformity. Closed injuries with or without fracture (type 1) can be managed with 7 weeks of DIP joint extension splinting followed by gentle active flexion range of motion and night splinting for 2 months. Injuries with loss of tendon continuity and with skin laceration (type 2) can be repaired with figure-of-eight suture (Fig. 16.6) or dermatotenodesis and DIP joint extension splinting. Injuries with loss of skin and tendon substance (type 3) generally require immediate soft tissue coverage and primary grafting versus secondary free tendon graft. Injuries with >50% fracture of articular surface and palmar subluxation of distal phalanx (type 4C) require K-wire fixation and splinting.

Zone 2: we recommend conservative management with splinting for 2 weeks followed by active range of motion therapy for tendon lacerations less than 50% and primary repair if tendon lacerations are greater than 50%. We prefer figure-of-eight suture because in this zone tendons are still flat.

Zone 3: the classic presentation of extensor tendon injury in this zone is a Boutonniere deformity with loss of extension at the PIP joint and hyperextension at the DIP joint, but it may only occur 10 to 14 days after the initial injury. The Elson test is then to be performed to understand if a central slip injury is present.

For closed injuries, we prefer splinting with PIP joint in extension and DIP, MP and wrist free for 4 weeks; for open ones, we recommend primary repair of the central slip.

Zone 4: In the case of patients without extension deficits, we splint the PIP joint in extension for 3 weeks. If there is an extension deficit, surgical exploration and tendon repair are mandatory. In zone 4, we prefer a core suture-like running interlocking horizontal mattress (Fig. 16.7).

Zone 5: tendons with greater than 50% laceration should be repaired primarily with the same technique as zone 4. An injury in this zone can also produce a sagittal band rupture.

Sagittal bands must be repaired to prevent ECD subluxation and MCP extension loss.

Closed injuries are uncommon and can be treated with splinting.

Zone 6: tendon injuries in this zone may be masked by an adjacent juncture tendinum that

may maintain extension of the digit through adjacent intact extensor tendons; any amount of extension deficit is an indication for surgical exploration and repair (same as zone 4).

Zone 7: in this zone, tendon adhesion is common because of the overlying capsule and retinaculum. After tendon repair (same as zone 4), it is important to maintain at least a portion of the extensor retinaculum to prevent bowstringing of the tendons.

Zone 8: as the injury is proximal, muscle bellies may be lacerated. They should be repaired with multiple slow-absorbing figure-of-eight sutures.

Now interest in using early motion protocols also for extensor tendon is increasing, with a greater number of good-to-excellent results.

16.2.3 Nerves

A peripheral nerve lesion is a disabling problem especially in the upper limb where motor function is more sophisticated than in the lower limb and sensibility recovery makes the difference as motion without sensory perception produces a blind and inefficient hand. Nerve lesions may be open, caused by a penetrating injury, or closed and generally due to crush or stretching mechanisms as it is generally for the brachial plexus. A clinical evaluation, muscle by muscle and sensory territories, allows to understand the level of the nerve lesion. However, an early understanding of nerve discontinuity needing surgical repair is generally difficult in closed lesions. EMG, to be done not earlier than 30 days after the lesion, is helpful. Echography may give us a support when showing nerve discontinuity, but generally it's the repeated clinical exam looking for lack of recovery that gives us the indication to surgery. In brachial plexus lesions, MRI may show a root avulsion then facilitating the indication to an early repair. If we look for spontaneous recovery, the waiting time should not be too long: if no sign of recovery of the closest muscles appears by 3 to 4 months from the injury, nerve exploration and repair are suggested [9]. In such case, generally, the surgeon works in a scarred bed and, after isolation of the nerve lesion, generally faces two situations: an in-continuity lesion without function needing neuroma resection and reconstruction and an established nerve gap to be bridged in order to offer the possibility of nerve regeneration and function restoration. The reconstruction will be based on the use of nerve autografts or even by means of conduits (biologic or synthetic) in case of short gaps (2 to 5 cm) [10] (Fig. 16.8).

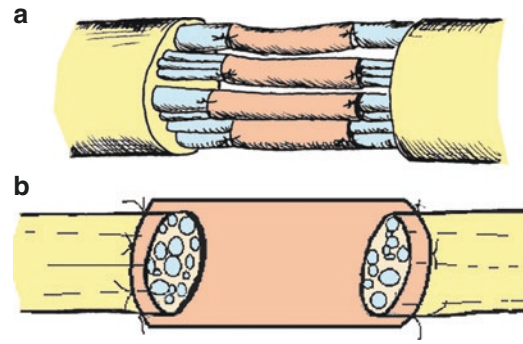

Fig. 16.8 (**a**) The nerve gap is generally repaired by means of autografts withdrawn from the sural nerve. (**b**) A biologic or synthetic conduit may bridge the nerve gap allowing spontaneous orientation of the regenerating axons inside it

The advantages offered by the transposition of the stump of a functioning nerve to the distal stump of a damaged nerve near the muscle effector (nerve transfer) have opened up new options. The use of nerve transfers is increasing over the years not only for brachial plexus repair with root avulsions, when there is not a proximal nerve stump, but also for distal nerve injuries, in which low functional results may be expected because of the distance to be filled by the regenerating axons between the injury site and the target muscle [11].

In acute open lesions, a clean cut of the nerve allows a direct suture with microsurgical technique. The suture should be always performed without tension. In proximal mixed nerves, an epi-perineurial repair facing group of fascicles is the preferred method (Fig. 16.9a), while in more distal well-defined nerves, perineurial repairs are preferable (Fig. 16.9b).

In case of blunt/crushed stumps, nerve ends should be trimmed up to healthy tissue. In this

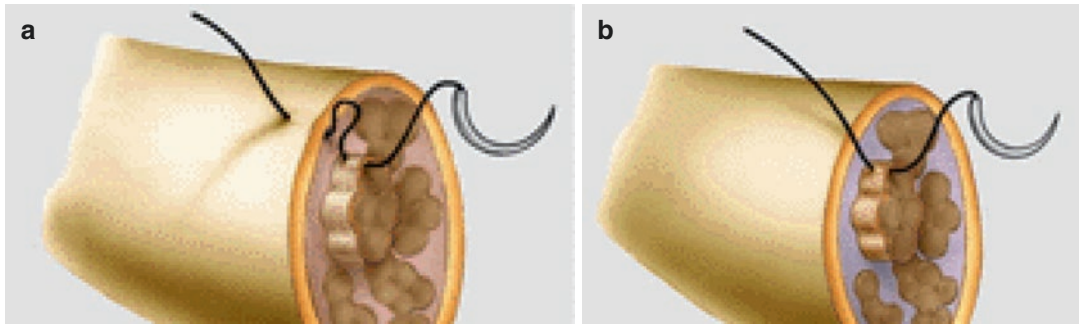

Fig. 16.9 (**a**) In proximal nerve lesions, an epi-perineurial suture is sufficient to face not yet well-defined groups of fascicles respecting a topographical distribution. (**b**) Distally, a perineurial suture is preferred to better match well-defined motor or sensory nerve components

case or if there is already a clear substance loss, the two stumps must be bridged. If the nerve may be repaired with good surrounding tissues, the reconstruction will be based on immediate nerve autografting or even by means of a conduit.

If the coverage is impossible or there is some risk of infection or the need of further debridement, the repair should be delayed. When the surgeon finds a very large nerve defect or bad surrounding tissues in a proximal lesion, a good alternative may be represented by a distal nerve transfer. Some Authors directly choose a distal nerve transfer to reduce reinnervation time bringing a functional nerve stump near the muscle effector, furthermore selectively directing the regenerating fibres to well-defined distal branches for an improved and faster functional restoration [12].

The success of the repair depends on the chosen technique but also on the factors influencing nerve regeneration: age of patients and associated diseases; level and site of the lesion (at a distal level, pure motor or sensory nerves with already well-defined destination are compromised, while proximal injuries generally involve mixed nerves which furthermore need more time to reach the distal targets); lesion margins (neat or crushed); surrounding tissues; defect length; and biomolecular factors action (neurotrophic, neurotropic and neurite promoting factors) [10].

However, also, rehabilitation plays an important role, and in the upper limb, sensory re-education programmes are as important as the ones aimed to the recovery of the motor function.

16.2.4 Skin

The aim of treatment in severe injuries with soft tissue defects is to restore coverage of the deep structures to avoid infections and to allow function restoration as soon as possible.

The upper limb-rich vascularization and the presence of a good network of anastomoses between the main vascular axes represent the key point for skin reconstruction decision-making and is the basis for successful flap surgery. These characteristics mean that free flaps are rarely needed to cover simple skin defects and explain the great number and variability of local flaps.

Decision-making to determine whether the defects can be reconstructed by local flaps, distant pedicle flaps or free flaps is based on several factors:

- Location of the defects.
- Involved tissues (skin, skin + tendons/muscle, skin + bone, bone).
- Characteristics of the lesion (size, tissues, depth).
- Patient's profile.

The algorithms are based on the fact that a poorly vascularized tissue needs blood supply from other sites in order to heal, especially in case of a local contamination or infection. In addition, bone exposure with loss of periosteum requires good coverage to protect and ensure adequate blood supply for bone healing. For these

reasons, sometimes, small defects require more complex flaps than large well-vascularized soft tissue lesions.

Extensive literature is available concerning the variety of local and regional flaps that may be used for coverage of upper limb soft tissue defects. The continous endeavour toward optimization of reconstructive techniques, both in terms of minimization of donor site defects or morbidity and in terms of refinements of the reconstructed site and function brought to the gradual substitution of simple random flaps or axial flaps based on constant vessels (i.e. LateralArmFlap, Dorsal Interosseous Flap, etc) or even sacrificing one main artery (i.e. radial or ulnar forearm flap) with flaps based on perforator vessels as described by Koshima on 1989 [13].

The hand represents a special issue. Until the 1990s, soft tissue reconstruction in the hand was limited to a small variety of flaps. After the anatomical studies describing the interconnections between the palmar arterial system and its perforating vessels into the vascular network of the dorsum of the hand, many new flaps even based on small perforating vessels have been developed.

In contrast to traditional distant pedicle flaps, intrinsic flaps (raised within the territory of the hand and based on intrinsic vessels) allow defect closure and early active mobilization. Intrinsic flaps, as every flap, are generally classified according to recipient and donor location (homo- or heterodigital flap, dorsal metacarpal, etc.) and their vascularization: random pattern flap, axial pattern flap with proximal or distal inflow (anterograde-retrograde flap) or local perforator flaps.

Soft tissue reconstruction of the hand could be divided up into three main areas: fingertips, digits and hand.

The fingertip is an area where local flaps are commonly used for reconstruction of traumatic skin loss.

One of the most performed flaps for small apical oblique or transverse defects is the volar VY advancement flap (Tranquilli-Leali flap), but occasionally a laterally based V–Y advancement (Kutler flap) may be used.

Thumb apical defects are often treated with a volar advanced flap (Moberg): radial and ulnar midaxial incision defines a flap that is elevated in the plane above the flexor tendon sheath.

Reconstructions of larger dorsal and volar apical problems by cross finger flaps, utilizing subcutaneous tissue and skin of the adjacent finger with donor and recipient site remaining attached for at least 2–3 weeks before being divided and insetted, are less and less performed and changed by homodigital and heterodigital flaps. These are usually axial flaps that are elevated in an anterograde or retrograde fashion, based on the digital arteries or its branches.

These latter are also used for more proximal digital reconstructions, where another source of flaps is the dorsum of the hand using the dorsal metacarpal network (anterograde or reverse dorsal metacarpal flaps).

The number of digital flaps described in literature is so large that we send the reader to specialized book chapters.

The regional tissue used for coverage of the hand are distally based fascial or fasciocutaneous flaps that rely on flow from the radial or ulnar artery.

The reverse radial and ulnar forearm flap, for instance, are based on the blood supply coming from the communication with the other main artery through the intact palmar arch.

The posterior interosseous artery flap is another example of regional flap used to cover palmar or dorsal hand wounds and is based on the watershed communications of the anterior interosseous artery on the volar wrist with the posterior interosseous artery in the fifth dorsal compartment of the dorsal wrist.

Nevertheless, there are some areas where the use of free flaps can be made irreplaceable for the limited availability of local flaps or the complexity of the lesion in terms of dimensions and involved structures. If the most commonly used free flaps in the upper limb were generally the parascapular, latissimus dorsi, serratus anterior, gracilis and flaps from the foot, representing the conventional workhorses of reconstruction, in the last few years, the flaps based on perforator vessels represent one of the major recent technical advancements decreasing donor site morbidity.

In the hand, it's important to distinguish the reconstruction of the dorsum or of the palm.

The back of the hand is covered with hairy, thin and very mobile skin allowing tendon gliding and finger and wrist movements. The characteristics of the ideal flap should be thinness, elasticity and a good gliding surface.

Among the free flaps, the anterolateral thigh flap (ALT) and the superficial circumflex iliac artery perforator flap (SCIP) are very good options: they are foldable, offer a good gliding surface for tendons (adipofascial flaps) and have ideal donor sites. Both flaps are almost always too thick to offer a valid functional and aesthetic result, but many authors described how much they can be thinned after harvesting. The dorsalis pedis offers an optimal reconstruction from an aesthetic and functional point of view (thin and foldable skin, tendons can be included) but has a relevant donor site morbidity.

The palm of the hand is an extremely specialized structure as the skin is glabrous, thick, very horned but at the same time elastic to allow protection and good grip. The ideal flap should be formed by glabrous, resistant skin, well adherent to the underlying planes and sensitive. The free medial plantar foot flap, based on branches of the medial plantar artery, faithfully reproduces all these characteristics when simple thick skin grafts or local flaps are not sufficient.

When local flaps are not possible, the thumb and the long fingers have the ideal pick-up site for the reconstruction from the toes as the anatomy and sensibility matches as no other donor site may do. The indications for reconstruction of the thumb are different depending on the level of injury. Injuries involving the fingertip can be repaired with a free toe pulp flap, while more proximal lesions, also involving the nail, may be reconstructed with the Morrison flap (wrap-around and variances).

16.2.5 Mangled Upper Limb and Amputations

Nowadays, clear-cut injuries are dropping off and are being substituted with high-energy traumas which may produce extensive tissue lesions that increase complications and lead to poor functional results. In mangled upper limbs, the key point for decision-making is a careful assessment of the involved structures. Based on this evaluation, the surgeon will decide on amputation (extremely crushed segments with extensive tissue loss) or reconstruction. In the latter case, a plan is to be done deciding for an early total care (debridement, bone definitive synthesis and contemporary soft tissues repair) or a damage control (good debridement and temporary stabilization, generally with external fixation) followed by an early or delayed reconstruction. The decision-making process may utilize indexes as the MESS system which help in deciding if amputate or not but have limitations in understanding the possible functional recovery of the traumatized limb [2]. In mangled upper limbs, the simultaneous treatment of the fractures and the associated soft-tissue injuries is spreading so much to create a new "orthoplastic approach" for extremity trauma [3]. Microsurgical flaps, especially in a composite setting, may solve in one-stage severe combined tissue loss, needing contemporary orthopaedic and plastic competence. The reconstruction of combined bone and soft tissues defects, even with traditional techniques, is more than a simple decision on the system to be adopted: it is mainly a question of timing and then of strategy. If the lesion is clean or sufficiently debrided, we may consider an "all-in-one" reconstruction by means of bone grafts, osteosynthesis and coverage flaps (fix and flap). If the general conditions of the patient are critical and/or the lesion is highly contaminated, a reconstruction in two or more stages is suggested. An early reconstruction 3 to 5–6 days later is generally suggested if allowed by patient's general conditions. The main goal is reconstruction of the coverage with a flap. The underlying structures (tendons, bone, etc.) may be repaired at the same time, even with a composite free flap, or secondarily with the same techniques already described in the previous paragraphs.

If trauma caused sub-amputation with devascularization or a complete amputation at upper limb level, a revascularization/replantation of the

segment is to be considered. Replantation of an amputation, the dream of all surgeons in the past, is no longer a technical problem. However, what we really want from a replant is not just survival but mainly function. The important role of emergency organization in this type of surgery is to be emphasized as the preservation of the amputated parts. Then, indications for replantation will follow careful and objective patient selection, with a careful examination of the general conditions and of the amputated part. The main general criteria for the decision are patient's age and general conditions, ischemia time and level, type and extent of tissue damage [14].

People over the age of 60 generally have greater number of complications and worst results. Associated multiple lesions (head trauma, etc.) and poor general conditions are generally considered a contraindication as life-threatening injuries are the priority. Replantation can be considered after achieving stable general conditions. Smoke habit is no more an absolute contraindication.

Revascularization time must not exceed 6 h of warm and 12 h of cold ischemia if segments contain large muscular masses and 12 h of warm and 24 h of cold ischemia for digits. This rule not only guarantees limb survival but also avoids severe postoperative complications such as cardiac or renal failure. The correct preservation of the amputated part has a key role in a successful replantation.

As for the level of lesion, we do believe that even in very proximal amputations, we may get an often elementary but useful limb [14] (Fig. 16.10).

Double-level lesions are generally contraindications, even though in some cases, a replanta-

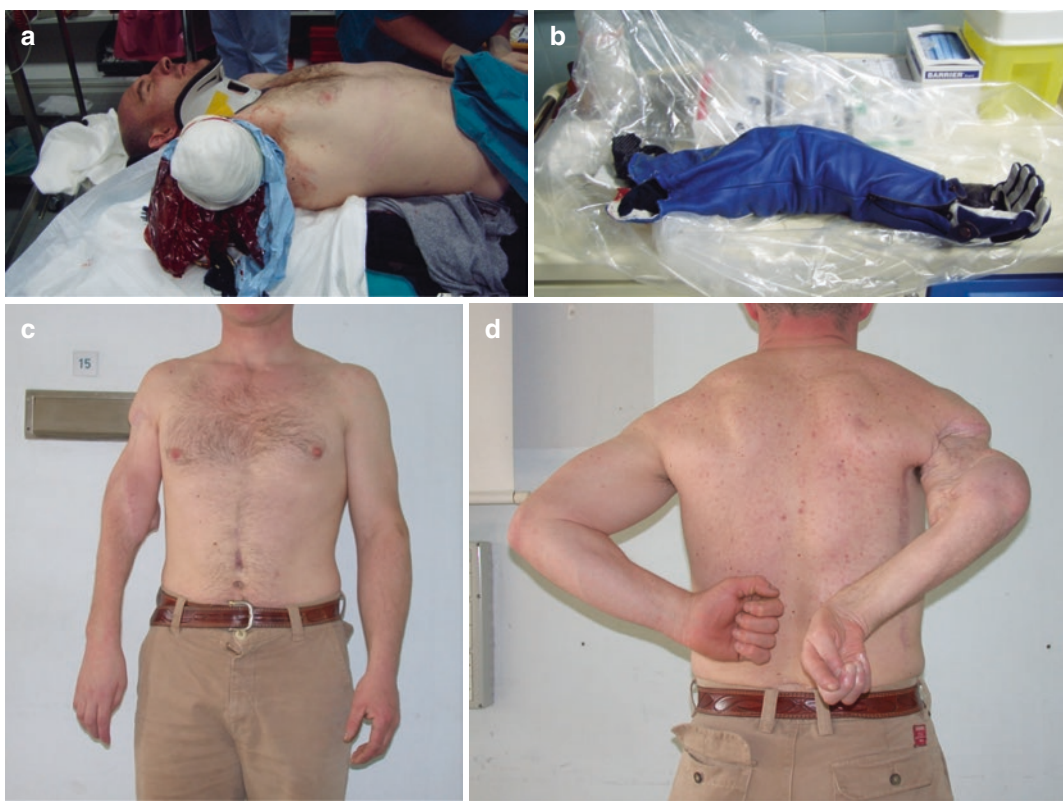

Fig. 16.10 (**a** and **b**) Amputation by avulsion at arm level in a motorcycle accident. (**c** and **d**) Clinical result 2 years after the replantation and a second intervention of latissimus dorsi transfer for biceps reconstruction. Reinnervation even of the hand allowed the patient to use it in grasping and to get back to normal daily life

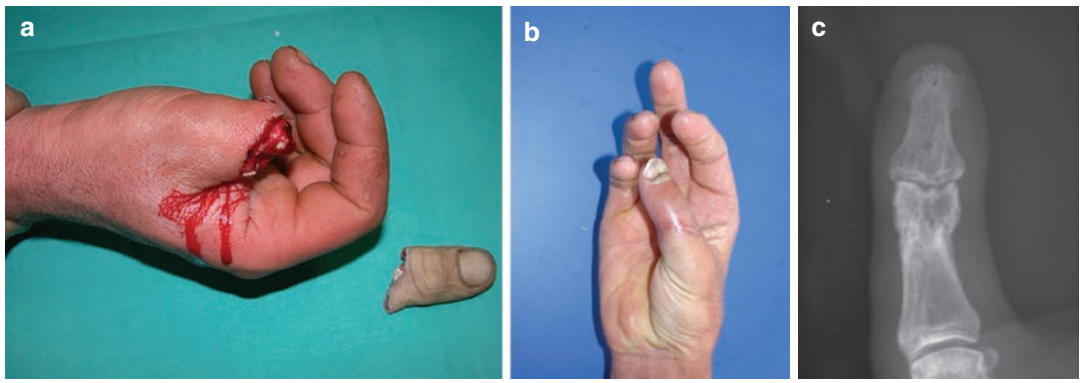

Fig. 16.11 (**a**) Thumb amputations at P1 level by circular saw. (**b** and **c**) Clinical and radiographical result at 6 months

tion can be attempted. Amputations around the hand, wrist and middle forearm are good indications and must be replanted unless life-threatening conditions or severe crush/avulsion and contamination exist. Thumb amputation should be repaired regardless of the level, age, health and local conditions [15] (Fig. 16.11), as also multiple fingers, single-finger distal to flexor superficialis tendon and in every kind of digital amputation in children.

A poor indication still remains for single-digit proximal to flexor superficialis, specifically in manual workers, because of the important stiffness that can result in very poor functional outcomes. This general rule presents some exceptions, such as strong aesthetic (young females) or cultural requests. Poor functional results are to be expected in case of avulsion or blunt injuries, but sometimes an accurate radical debridement may change the lesion into a neat and repairable one. Ring avulsion injuries are no more a contraindication, except for complete degloving injuries proximal to flexor superficialis with proximal interphalangeal joint damage [16].

Finally, the decision-making process of limb salvage can't be completely defined by general rules, but in case of replantation, the microsurgeon must define a general operative plan: how many fingers can be saved, which joint can be preserved or fused, the entity of bone shortening, reducing the need for grafts of nerves and vessels and the need for skin reconstruction.

Tip and Tricks

Good margin debridement not only avoids subsequent necrosis, fibrosis and/or infections but also guarantees clean and vital structures. Excision of muscles in the amputated segment, especially if damaged, leads to an "elementarization" of the function but reduces the risks of general complications. We normally follow this sequence for the repair: Bone fixation (shortened), flexor tendon(s), extensor tendon(s), nerves, artery(ies) and veins (at least two veins for each artery) and loose skin.

The replanted part is then monitored by checking skin colour, capillary refill, tissue turgor and skin temperature. Arterial and venous occlusions are two fatal complications for the replant, and their early recognition is essential for an early revision of the anastomosis. Blood pressure should be kept in a normal range, avoiding hypotension. Fluid maintenance is mandatory, and the patient should be well hydrated, an advantage in terms of fluid rheology that reduces the risk of thrombosis. Many authors suggest a postoperative pharmacological protocol which comprises 4000 units of heparin SC per day and 100 mg of aspirin per day. Patients are strongly encouraged to stop smoking and assuming caffeine for at least 30 days after surgery.

Early recovery of motion is the main goal in rehabilitation depending on the stability of osteosynthesis and on the quality of microvascular and neural sutures, but sensory re-education programmes have shown to be as much important [17].

Take-Home Messages

- Good knowledge of the upper limb complex anatomy is relevant in surgical reconstruction of traumas at this level.
- A complete evaluation of the lesion and of the traumatized patient (from general health to functional requests) is fundamental in giving a correct indication to reconstruction or even amputation.
- The treatment should be given to experienced surgeons possibly knowing both plastic and orthopaedic concepts in order to give the correct priorities and to choose the best technical solution.
- Early recognition and management of lesions sometimes involving single tissues but often extensively damaging the upper limb are crucial in getting the goal not only of a morphological reconstruction but mainly of a restored functional segment.

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Lower Limb Trauma

17

Mario Cherubino, Tommaso Baroni, and Luigi Valdatta

Background

The ability to move in space was a conquest of the animal kingdom of the vegetable and this in the evolutionary scale and it was possible since the development of the limbs. In humans, lower limb surgery requires a precise knowledge of anatomical structures and physiology in order to be performed successfully. Car accidents, motorbike accidents, and sports-related trauma represent majority of the etiology of lower limb trauma. In Italy, open fractures of the legs are estimated to be 3000 every year. This is to prevent unnecessary amputation, but a fast and correct recovery needs to be traded in a specialized center with competences of orthoplastic.

17.1 Introduction

Lower extremities are unique anatomical appendages that allow for bearing weight, locomotion and adaptation to gravity. Lower limb restoration requires knowledge of all plastic surgery reconstructive armamentarium, which encompasses negative pressure therapy, skin grafts, dermal matrices, locoregional flaps, microvascular free flaps, and bone, arterial, and nerve repair skills (Fig. 17.1).

Key Points

Debridement procedures are the most challenging part. Knowledge of what should be debrided and what should be spared requires that the most experienced in the unit surgeon should be the one that performs it. A complete evaluation of the damage and the correct classification of the open fracture could be done only after the debridement.

17.2 History

Originally, lower limb traumas were managed through amputation, according to the first systematic technique described by the French barber-surgeon Ambroise Paré in the sixteenth century. However, Hippocrates (460–370 BC) already described the first cases of lower limb amputation after ischemic gangrene centuries before that time. Parallel to that, the concept of debridement (removal of nonviable tissue) was independently described by Sushruta around 3000 BC in India and Pierre-Joseph Desault during the French Revolution. The first lower limb

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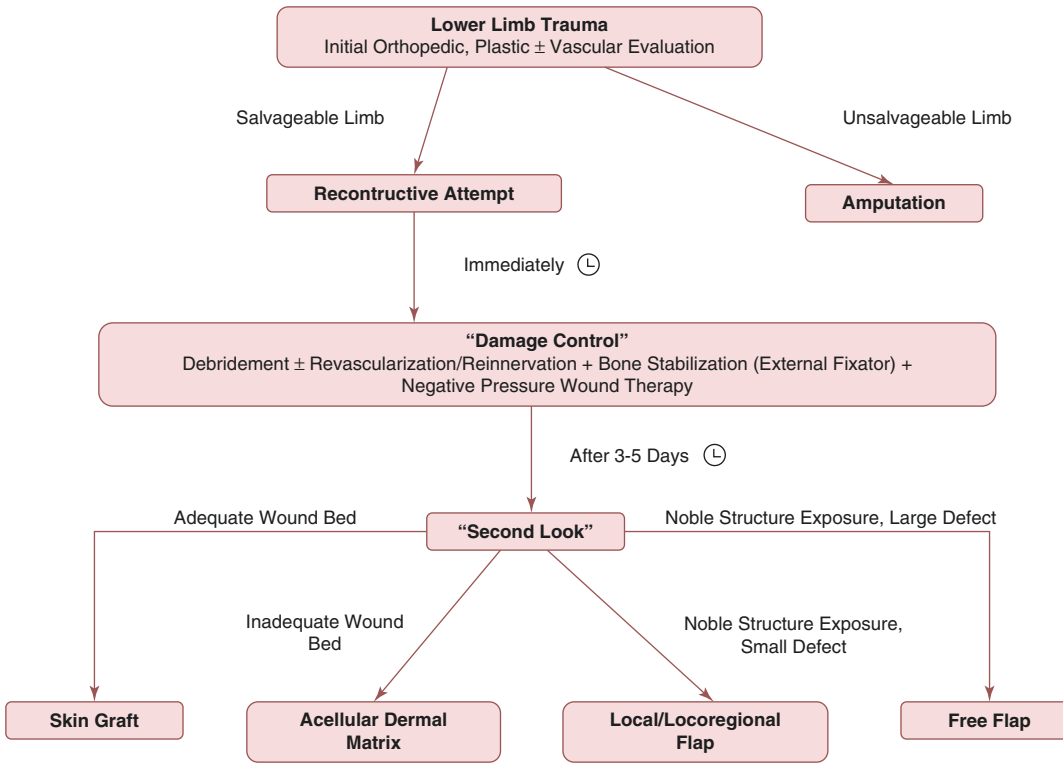

Fig. 17.1 Treatment algorithm of the lower limb trauma (Illustrations by Tommaso Baroni)

amputation under ether anesthesia was performed by Liston in 1846. In that occasion, in addition, one of his students, Joseph Lister, applied antiseptic principles based on Pasteur's findings for the first time in a clinical setting.

Regarding bone management, fracture fixation foundations were introduced by Ollier ("closed plaster" technique) in the Franco-Prussian War and Orr during World War I. The first external fixation device was patented in 1942 by Hoffmann, even though as early as 1840, Malgaigne started to work on the same principles. Danis and Müller developed internal fixation in the 1950s. Distraction osteogenesis was initially described by Alessandro Codivilla in 1840 and the first bone lengthening device subsequently designed by Gavriil Abramovič Ilizarov during the 1960s–1970s.

Soft tissue management owes much to Frank Hastings Hamilton, following the first cross-leg flap performed in 1854. He also pioneered skin grafting in the field of soft tissue reconstruction. Daniel and Taylor reported the first free flap reconstruction of a tibial defect in 1973.

During the First World War amputation, mortality decreased from 40 to 60% to 12.4% as a result of antisepsis. No techniques were developed in World War II, but mortality of wound complications further declined. During the Korean conflict, the concept of artery repair as opposed to artery ligation allowed an overall decrease of amputation rate by 49%.

In the modern era, several attempts were made in order to classify tibial fractures and to create new scoring systems with the purpose of definitively assessing limb salvage versus amputation criteria. Different schools of thought formed as regards reconstruction timing after trauma. Byrd and Godina supported the idea that early reconstruction was related to a decrease in infection and postoperative complication rate. Conversely, Yaremchuk emphasized the importance of wound stabilization with serial debridement prior to reconstruction. At the current state of the art,

despite huge advances in the field of lower limb reconstruction, no reliable scoring systems have yet been developed, and the existing classifications show all their limitations in the accurate patient stratification and trauma management.

17.3 Surgical Anatomy

The lower limb is distinguished in three regions: thigh, leg, and foot.

Key Points
The thigh has an abundance of muscular and soft tissue envelope to cover the femoral bone, so open fracture that cannot be reconstructed and easily covered with soft tissue is rare. Most fractures are treated directly by trauma surgeons without any assistant from plastic surgeons. On the opposite, the leg is more challenging and requires an arthoplasty approach to achieve good results in terms of limb savage.

The leg is the portion of the lower extremity between the knee and the ankle and transmits all body weight directly to the foot. It's the most challenging part to reconstruct, and knowledge of the anatomy is mandatory (Table 17.1).

17.3.1 Bones

The leg consists of two bones, the tibia medially and the fibula laterally. The tibia provides the majority of the weight-bearing capacity of the leg, whereas the fibula is predominantly a structure for muscle and fascial attachments, as well as an important structural component of the ankle joint. The two bones are connected in their mid-portion with the interosseous membrane. The mid-shaft tibia has three surfaces. The medial surface is subcutaneous and thus more prone to exposure after injury, while the lateral and posterior surfaces are protected by the anterior and posterior compartment muscles. The fibula is a smaller bone. It is not weight-bearing and is less troubling in case of injury, made exception for fractures involving the proximal and distal portions, since their significance in knee and ankle joint stability, respectively. Consequently, the middle portion of the fibula can be sacrificed for reconstructive purposes.

17.3.2 Fascial Compartments and Lower Leg Muscles

The lower leg can be divided into four fascial compartments by the interosseous membrane, the anterior intermuscular septum, the transverse intermuscular septum, and the posterior intermuscular septum. Each compartment contains muscles, connective tissue, nerves, and blood vessels (Fig. 17.2).

The *anterior compartment* comprises four muscles: the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus, and the peroneus tertius. All four muscles dorsiflex the foot, are innervated by the deep peroneal nerve, and are supplied by muscular branches of the anterior tibial artery.

The *lateral compartment* comprises the peroneus longus and the peroneus brevis muscles. Both muscles plantarflex and evert the foot and are innervated by the superficial peroneal nerve. The vascular supply is provided by the anterior tibial artery (peroneus longus) and the peroneal artery (peroneus longus and brevis).

The *superficial posterior compartment* includes the gastrocnemius, soleus, plantaris, and popliteus muscles. All four muscles plantarfex the foot, except the popliteus muscle that flexes the knee and rotates the tibia. Also, the gastrocnemius is a knee flexor. They are all innervated by the tibial nerve and vascularized by the popliteal, sural, posterior tibial, and peroneal arteries.

The *deep posterior compartment* is comprised of three muscles: the flexor hallucis longus, the flexor digitorum longus, and the tibialis posterior muscles. All three muscles plantarflex the foot. The tibialis posterior muscle also inverts the foot, while the flexor hallucis longus and the flexor digitorum longus muscles flex

Table 17.1 Summary of anatomy of the leg

Compartments and muscles	Muscle function	Nerve	Artery
Anterior compartment			
Anterior tibialis	Dorsiflex, invert foot	Deep peroneal nerve	Anterior tibial artery
Extensor hallucis longus	Extend great toe, dorsiflex foot	Deep peroneal nerve	Anterior tibial artery
Extensor digitorum longus	Extend II-V toes, dorsiflex foot	Deep peroneal nerve	Anterior tibial artery
Peroneus tertius	Dorsiflex, evert foot	Deep peroneal nerve	Anterior tibial artery
Lateral compartment			
Peroneus longus	Plantarflex, evert foot	Superficial peroneal nerve	Anterior tibial artery and peroneal artery
Peroneus brevis	Plantarflex, evert foot	Superficial peroneal nerve	Peroneal artery
Superficial posterior compartment			
Gastrocnemius	Plantarflex foot, flex knee	Tibial nerve	Popliteal artery, sural branches
Soleus	Plantarflex foot	Tibial nerve	Posterior tibial, peroneal, and sural arteries
Plantaris	Plantarflex foot	Tibial nerve	Sural artery
Deep posterior compartment			
Posterior tibialis	Plantarflex, invert foot	Tibial nerve	Peroneal artery
Flexor hallucis longus	Flex great toe, flex foot	Tibial nerve	Peroneal artery
Flexor digitorum longus	Flex II–V toes, flex foot	Tibial nerve	Posterior tibial artery
Popliteus	Flex knee, rotate tibia	Tibial nerve	Popliteal, genicular branches

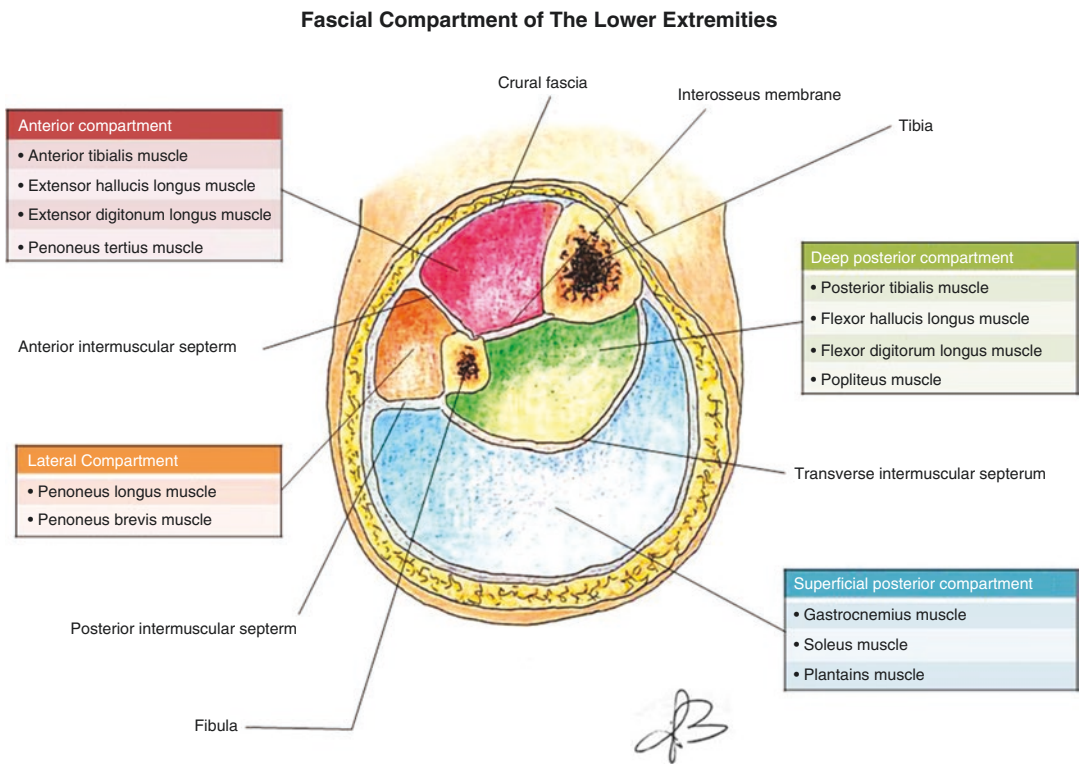

Fig. 17.2 Leg compartments and muscles inside (Illustrations by Tommaso Baroni)

the great toe and the lateral four toes, respectively. The deep posterior compartment muscles are innervated by the tibial nerve and vascularized by the peroneal artery (flexor hallucis longus and tibialis posterior muscles) and the posterior tibial artery (flexor digitorum profundus muscle).

When the interstitial fluid pressure within an osteofascial compartment significantly and rapidly increases, a subsequent bloody supply impairment with myoneural necrosis can occur. This condition is known as *acute compartment syndrome*, and it is primarily caused by tibial fractures or crush injuries. The clinical signs of compartment syndrome are pain out of proportion, pain with passive stretch of the involved muscle, and paresthesia in the distribution of any sensory nerves within the compartment. Loss of pulse is a late sign. An early diagnosis can be achieved by frequent or continuous measurement of intramuscular pressure. The threshold for fasciotomy is quite controversial, and several authors have proposed different diastolic differential pressures, such as an absolute >30 mmHg pressure or a >40 mmHg value for 6 h. In case of suspected compartment syndrome, a four-compartment fasciotomy should be performed (Figs. 17.3 and 17.4).

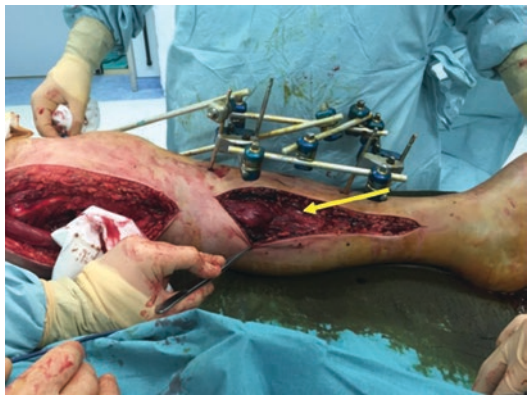

Fig. 17.3 Clinical aspect of the muscular fascia. Patient affected by a closed fracture with injuries of the blood vessels that drive a compartment syndrome. The yellow arrow shows the muscle fascia

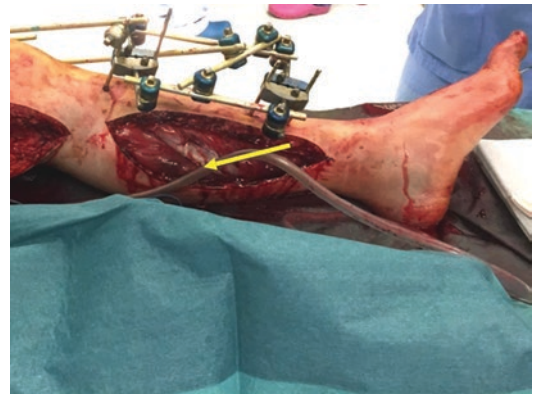

Fig. 17.4 Same leg after complete fasciotomy; the posterior muscles are extruded once released from the fascia

17.3.3 Arteries

Above the soleus arcade, the *popliteal artery* gives off the *anterior tibial artery* and the *tibioperoneal trunk*. The anterior tibial artery pierces the interosseous membrane descending through the anterior compartment and running down into the foot where it becomes the *dorsalis pedis artery*. The tibioperoneal trunk bifurcates into the *posterior tibial* and *fibular arteries*. The posterior tibial artery continues inferiorly along the deep posterior compartment entering to the sole of the foot where it splits into the *lateral* and *medial plantar arteries*. These arteries contribute to the supply of the toes via the *deep plantar arch*. The fibular (peroneal) artery descends posteromedially to the fibula within the posterior compartment and gives rise to perforating branches supplying the muscles of the lateral compartment. If all the main three vessels or two of them are injured, reconstruction of at least one vessel is mandatory, with ligation of the others. This principle must be applied to the single clinical case considering other critical factors such as the type and gravity of trauma, the possible patient's vascular comorbidities, and the type of vessel involved in the injury (Fig. 17.5).

Pearls and Pitfalls

Trifurcation of the arteries in the leg: The anterior tibial artery is always the first to rise and become the vessels of the anterior compartment. The peroneal artery is the second, and it's always lateral. The posterior tibial artery is usually the main vessel of the leg and can easily find posterior to the medial malleolar prominence.

17.3.4 Nerves

At the popliteal fossa, the *sciatic nerve* (L4–S3) divides into two main branches: the *tibial nerve* and the *peroneal nerve*. The tibial nerve innervates the skin of the posterolateral leg, lateral foot, and sole of the foot (*medial calcaneal*, *medial plantar*, and *lateral plantar nerves*), as well as the posterior compartment muscles and the intrinsic foot muscles. A tibial nerve injury results in loss of plantar flexion, loss of flexion of toes, and weakened inversion.

The common peroneal nerve innervates the skin of the lateral leg and the dorsum of the foot. Furthermore, it supplies the muscles of the lateral (*superficial fibular nerve*) and anterior (*deep fibular nerve*) compartments of the leg. Damage to this nerve leads to loss of ability to dorsiflex and evert the foot and extend the digits.

The *sural nerve* is a cutaneous nerve originating from the fusion of the tibial nerve (*medial sural cutaneous nerve*) and the peroneal nerve (*lateral sural cutaneous nerve*). These two branches are connected by the *sural communicating branch*. It descends on the posterolateral aspect of the leg down to the posterior region of the lateral malleolus. It innervates the skin of the posterolateral distal third of the leg, lateral aspect of the foot (*lateral dorsal cutaneous nerve*), heel, and ankle (*lateral calcaneal branches*). Given its

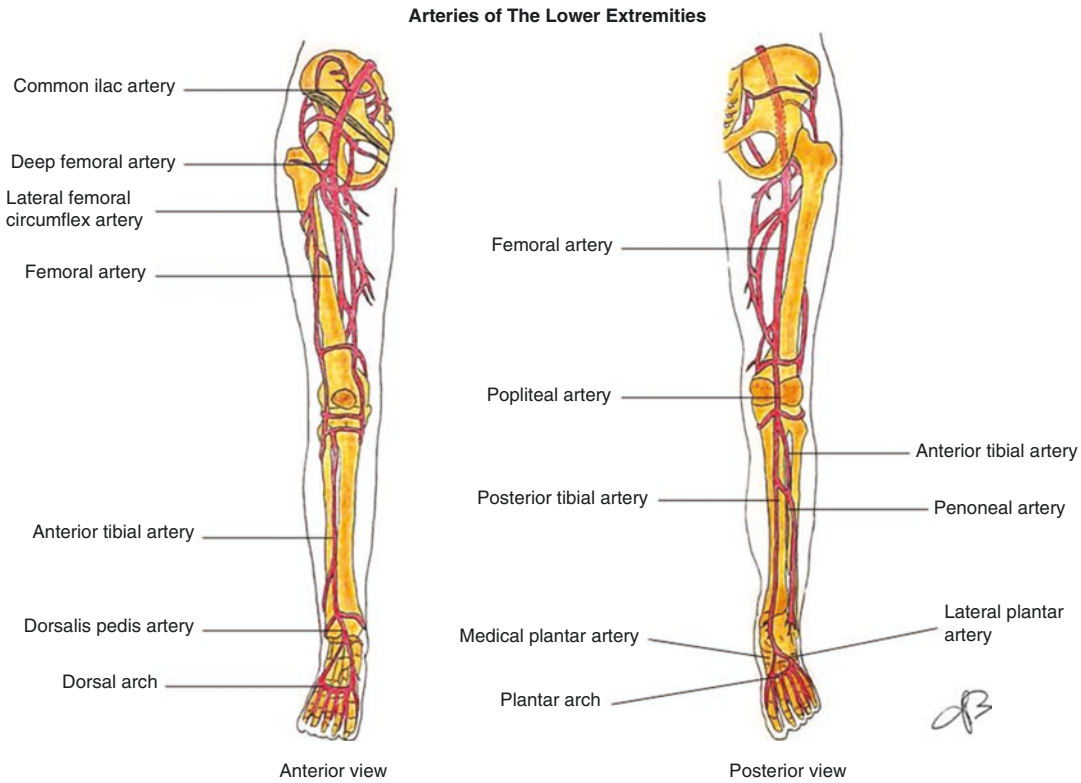

Fig. 17.5 Circulatory pathways lower limb (Illustrations by Tommaso Baroni)

purely sensory function and the subsequent minor deficit due to its removal, it is often used as a donor site for nerve grafting.

The *saphenous nerve* is the largest cutaneous branch of the femoral nerve. It has no motor function, and it innervates the anteromedial aspect of the leg and the medial foot through the *medial crural cutaneous branches*. Along its course, the nerve communicates with the common fibular nerve.

Sensibility on the plantar aspect of the foot is necessary for normal ambulation, since the full force of the body is transmitted to the feet. Normal sensibility is required for tactile sensation, perception of the position, and protection of pressure-bearing portions of the foot. This implies that loss of the tibial nerve is a relative contraindication for lower extremity salvage. Nerve injuries to the lower extremity should be repaired at the time of injury, by direct nerve repair or nerve grafting, even though results of nerve reconstruction in the lower extremities are poor (Fig. 17.6).

Key Points

Furthermore, it is important to keep in mind that a significant muscle loss of the leg is not an absolute contraindication to reconstruction and salvage, since adequate deambulation can be maintained even in case of ankle fusion. With a no longer functioning ankle, in fact, the functional needs of the leg muscles are greatly unnecessary (Fig. 17.7, illustrations by Tommaso Baroni).

17.4 Aetiology

The nature and severity of lower extremity injuries differ between the military and civilian settings.

Civilian extremity injuries most often are caused by falls, industrial or work-related accidents, and motor vehicle crashes. The long bone that is most commonly involved in open fracture is the tibia, and high-energy motor vehicle collisions are responsible for almost 60% of these injuries. Associated vascular injuries occur in <1% of all civilian fractures, and the risk of vascular damage increases with increasing injury severity. Minor leg injuries can be due to contact and high-speed sports.

Approximately 50% of *military injuries* involve the *extremities*. Most extremity armed wounds have a penetrating component, typically resulting from explosions (81%) or gunshot wounds (17%). Only 2% of extremity injuries during combat are due to isolated blunt trauma. Many of these injuries involve multiple functional components and noble anatomical structures (such as bone, muscles, nerves and arteries), resulting in a high rate of mangled extremities. The overall incidence of military extremity injuries is lower than in previous recorded conflicts (50%), while the overall rate of vascular injury in modern combat is increased.

Other minor causes of lower extremity complex wounds are the acute compartment syndrome, infections and osteomyelitis, vascular insufficiency, diabetes mellitus, and tumors that require extensive resections.

17.5 Classification

The most widely used classification for open fractures is that of Gustilo and Anderson (Table 17.2).

Grade IIIA injuries are usually treated with debridements, local wound care, skin grafts, or simple local flaps. Complex plastic surgery procedures are reserved for grade IIIB and IIIC injuries. Although this is the most commonly applied classification system in the orthoplastic setting, it remains fairly inadequate to describe the injury or to evaluate the prognosis of an open tibial fracture for which the plastic surgeon is involved. Furthermore, other supplemental information needs to be included, such as the mechanism and energy of the injury, if a degloving of the soft tissue is present, and the presence of any other concomitant injuries or comorbidities. The Byrd-Spicer classification

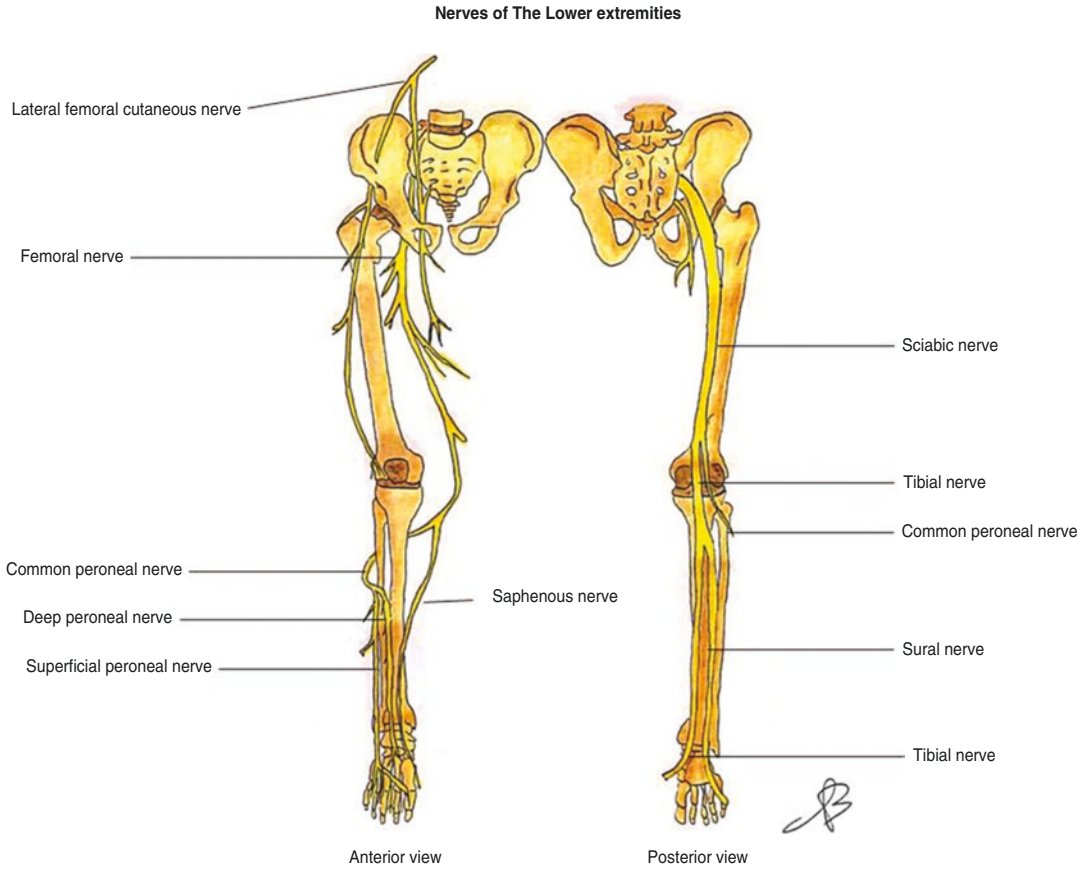

Fig. 17.6 Lower limb innervation (Illustrations by Tommaso Baroni)

of lower extremity trauma is less commonly used because of a large degree of interobserver variability, but it includes additional information such as the energy and presence of devitalized tissue (Table 17.3).

Pearls and Pitfalls

The Gustilo-Anderson classification is the most used because it is quite easy to remember; however, it has some drawbacks like not considering the eventual ischemia of the limb. It must also be done after the debridement and not before, considering the reality of the extension of the soft tissue injuries and considering the high or low energy of the trauma.

17.6 Orthoplastic Concept and Lower Limb Trauma Score

The orthoplastic concept for treatment of lower limb trauma is based on the collaboration of the orthopedic (traumatologist) and plastic surgeons. All the surgeons must have knowledge of the required steps, timing, and needs of every figure involved to achieve the best recovery for the patient.

Different lower limb trauma score indexes have been proposed in order to overcome the aforementioned classification limitations. The *Predictive Salvage Index* was devised in 1987 and recognized the importance of vascular injury as a prognostic indicator, in order to avoid unnecessary amputations. It consists of seven components including artery, deep vein, nerve, bone,

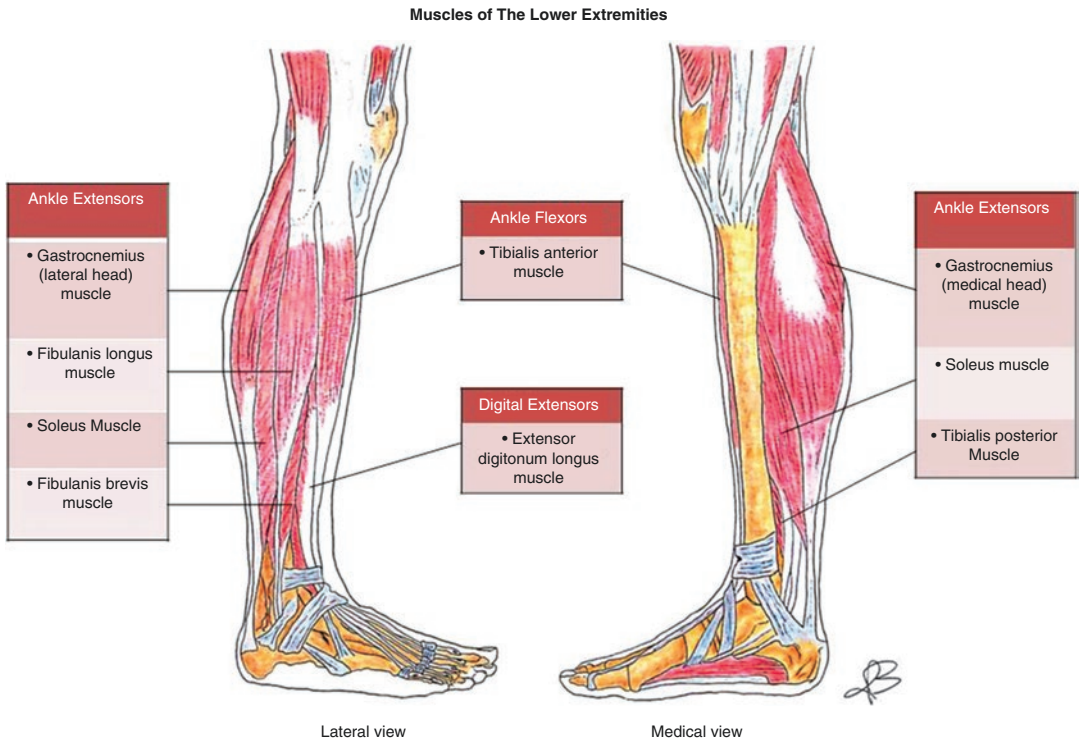

Fig. 17.7 Muscle of the lower etremities

Table 17.3 Byrd and Spicer classification of lower extremity trauma

Byrd and Spicer classification of lower extremity trauma	
Type	Description
Type I	Low-energy forces causing a spiral or oblique fracture pattern with skin lacerations <2 cm and a relatively clean wound
Type II	Moderate-energy forces causing a comminuted or displaced fracture pattern with skin laceration >2 cm and moderate adjacent skin and muscle contusion but *without* devitalized muscle
Type III	High-energy forces causing a significantly displaced fracture pattern with severe comminution, segmental fracture, or bone defect with extensive associated skin loss and devitalized muscle
Type IV	Fracture pattern as in type III but with extreme-energy forces as in high velocity gunshot or shotgun wounds, a history of crush or degloving, or associated vascular injury requiring repair

Table 17.2 Gustilo and Anderson classification of open fracture

Gustilo and Anderson classification of open fracture	
Type	Description
Type I	Clean wound <1 cm in diameter with simple fracture pattern and no skin crushing
Type II	A laceration >1 cm and < 10 cm without significant soft tissue crushing. The wound bed may appear moderately contaminated
Type III	An open segmental fracture or a single fracture with extensive soft tissue injury >10 cm. Type III injuries are subdivided into three types
Type IIIA	Adequate soft tissue coverage of the fracture despite high-energy trauma or extensive laceration or skin flaps
Type IIIB	Inadequate soft tissue coverage with periosteal stripping and bone exposure
Type IIIC	Any open fracture that is associated with vascular injury that requires repair

skin and muscle injury as well as warm ischemia time. The *Mangled Extremity Severity Score* differently considers four variables: patient age, presence and duration of shock, ischemia time, and the energy of injury. Other index scores such as the *Hanover Fracture Scale* and the *Limb Salvage* Index have been proposed. These scores can be useful tools in the decision-making pro-

cess when used cautiously but should not be used as the principal means for reaching difficult decisions. The *Ganga Hospital Open Injury Severity scoring* was proposed by S Rajasekaran et al. for predicting salvage versus amputation in open type III B injuries and providing management guidelines depending on the total score. The authors felt the need for this score due to the varied presentation of type III B injuries, lack of proper management guidelines, and lack of a comprehensive scale to determine salvage versus amputation in severely injured limbs. However, the practical use of the assessment scale is still unclear in emergency situations.

An interesting review was published by *Keller* et al. in 1983. He found that comminution, displacement, bone loss, distraction, soft tissue injury, infection, and polytrauma in tibial shaft fractures were related to a higher risk of systemic complications, while fracture location or configuration and concomitant fibular fracture had no prognostic significance.

When dealing with lower limb reconstruction, important goals have to be considered. A complete debridement of all devitalized tissue is necessary, in order to obtain a healthy wound bed. It is equally important to restore stability, structure, vascularity, and function, to obliterate possible dead spaces, to provide durable coverage of vital structures, and to ensure an acceptable aesthetic result.

17.7 Treatment

The beginning of lower limb trauma treatment should start in the emergency room at the patient income. The antibiotics should be administered within 3 h from the injury, even in the site of the trauma. The initial assessment should start immediately after the stabilization of the general patient's condition. Evaluation of the vascularization of the limb, the possibility of a compartment syndrome, or a massive muscle destruction should be performed by the orthopedic and plastic surgeons together. As initial assessment, an X-ray exam of the traumatic leg must be performed to evaluate the bone fractures in standard projections. After initial evaluation, if a CT scan is possible and indicated (massive destruction and/or unclear bone fracture), the patient needs then to be treated in the OR.

Debridement is the keystone of the treatment of a lower limb trauma. It should be performed by the most experienced surgeon of the unit and must be adequate and precise. All the necrotic tissues and all the compromised muscles need to be removed. Only the longitudinal tissue (nerve and main vessels) can be spared.

Key Points

The irrigation of the wound needs to be massive and in a low pressure to assure the reaching of a clean wound. Six to seven liters of low-flow saline solution is the minimal amount to clean from all some contaminated fragments and residues.

Only after the debridement can the final assessment of the wound be done. Only at this point, the open fracture can be classified using the Gustillo-Anderson classification. If there is no fracture, the Arnez-Kahn-Tyler classification can be used to determine the evolution of the soft tissue involved (Table 17.4).

Table 17.4 Types of degloving injured and their management

Types of degloving injury and their management	
Types of degloving injuries	Management
Limited degloving with abrasion/avulsion	Minimal tissue excision Free tissue transfer for primary healing if bones, tendons, and joints exposed
Non-circumferential degloving injuries	Assessment of vascularity of degloved flaps Tissue excision Flap reconstruction or grafts
Circumferential single plane degloving	Re-suturing never! Excision of flap Assess muscular viability Wound reconstruction and coverage
Circumferential multiplane degloving	Suffers greater degree of tissue disruption Staged reconstruction

Bone fixation is the next step, performed by the trauma/orthopedic surgeon, and can be temporary or definitive. It depends on the contamination of the bone, the lack of bone tissue, the state of the bone itself, and the possibility to reconstruct right afterward. In most of the time, an external fixation is preferred in case of open fracture.

The next step is represented by soft tissue reconstruction. If it is possible and if there is a clear and definite wound, soft tissue closure should be performed immediately. The choice of the technique depends on the characteristics of the wound. If primary closure can be easily achieved, it is the best choice and should be performed if no sign of infection is present. However, in the lower third of the leg, a primary closure is not generally possible, due to the lack of soft tissue, in particular in case of a high-energy trauma. If there is a loss of tissue substance and a more complex reconstructive procedure is needed.

The correct reconstructive procedure is chosen, again, considering the characteristics of the wound. A clear, superficial wound, without any bone exposure, can be treated with a skin graft (split thickness or full thickness); however, deep or complex wounds require a more stable and demanding reconstruction.

The dermal substitute is a reality in clinical practice for the treatment of lower limb. They have different characteristics; however, they represent a valid choice in case of a deep not complex wound. If the bone or the tendon exposure is limited, a simple dermal substitute guarantees an easy and fast procedure to reconstruct the defect. In case of wide superficial defects, where the skin is lost due the trauma (degloving injury) but the muscular fascia is preserved, the dermal substitute guarantees a softer and more pliable finale cover compared to a direct splint thickness graft.

If a flap is required, it can be a local or a free flap based on the experience of the surgeons and the dimension and the etiology of the trauma. Low energy, with a small dimension defect, can be treated with a local flap, (including options such as propeller or other local perforator flap which requires microsurgical skills, avoiding the anastomosis) or a free flap.

Tips and Tricks

The correct hemostasis is necessary before starting the negative pressure therapy. Sometimes, it is better to postpone the beginning of the negative pressure therapy by a few hours (up to 24 hours) to stop the bleeding in the damaged field. The damage control concept allows to repeat the debridement that should be performed as soon as possible from the trauma, but also must be repeated after a few days to allow the maximal expert of the unit to be present at the surgery.

17.8 Clinical Cases (Figs. 17.8, 17.9, 17.10, and 17.11)

Take-Home Messages

In the lower limb trauma, the lower leg open fractures management is a challenge both for the orthopedic and plastic surgeons. Nowadays, the orthoplastic approach, with a close collaboration and synergy of competences between the orthopedic and plastic surgeons, represents the gold standard for treatment. This requires planning and acting with synergy, starting from the access of the patient in the emergency room. The debridement represents the keystone, and damage control is the following step. An adequate reconstruction of the soft tissue can be performed after a few days, and the correct techniques can be chosen based on the characteristics of the wound.

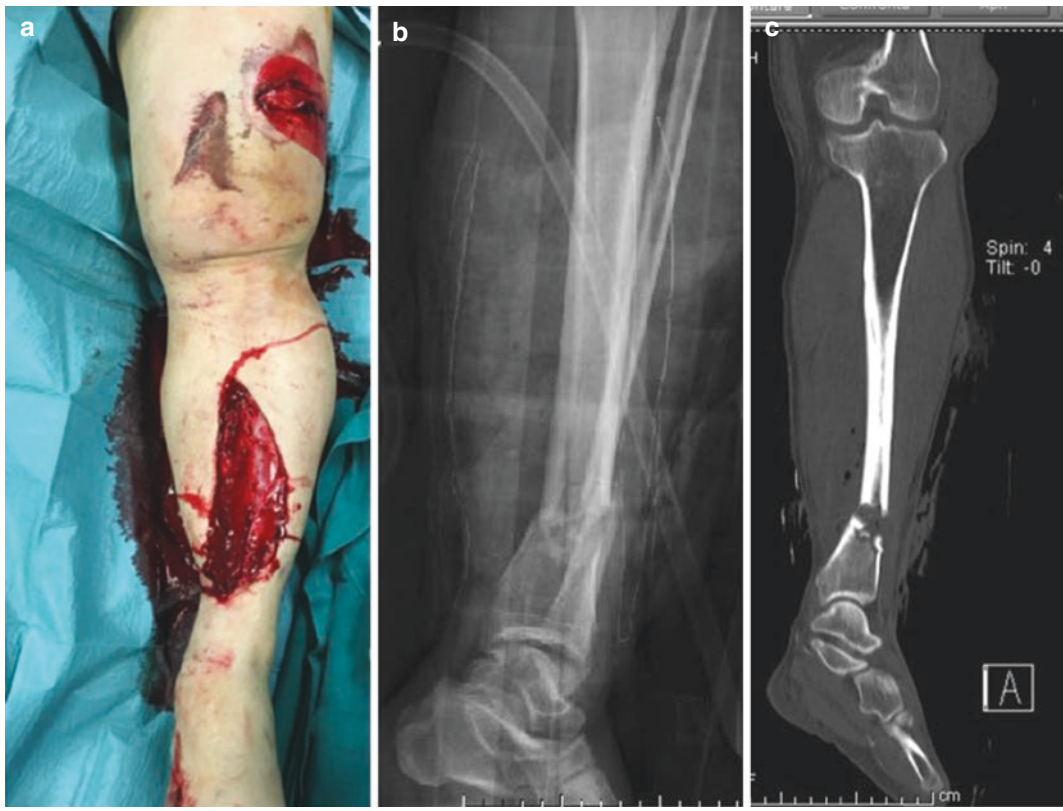

Fig. 17.8 A 57-year-old patient is in the hospital after a motorbike accident. (**a**) Initial evaluation shows wounds of inferior left limb. (**b**) X-rays reveal tibial and peroneal fractures. (**c**) Confirmed by CT scan

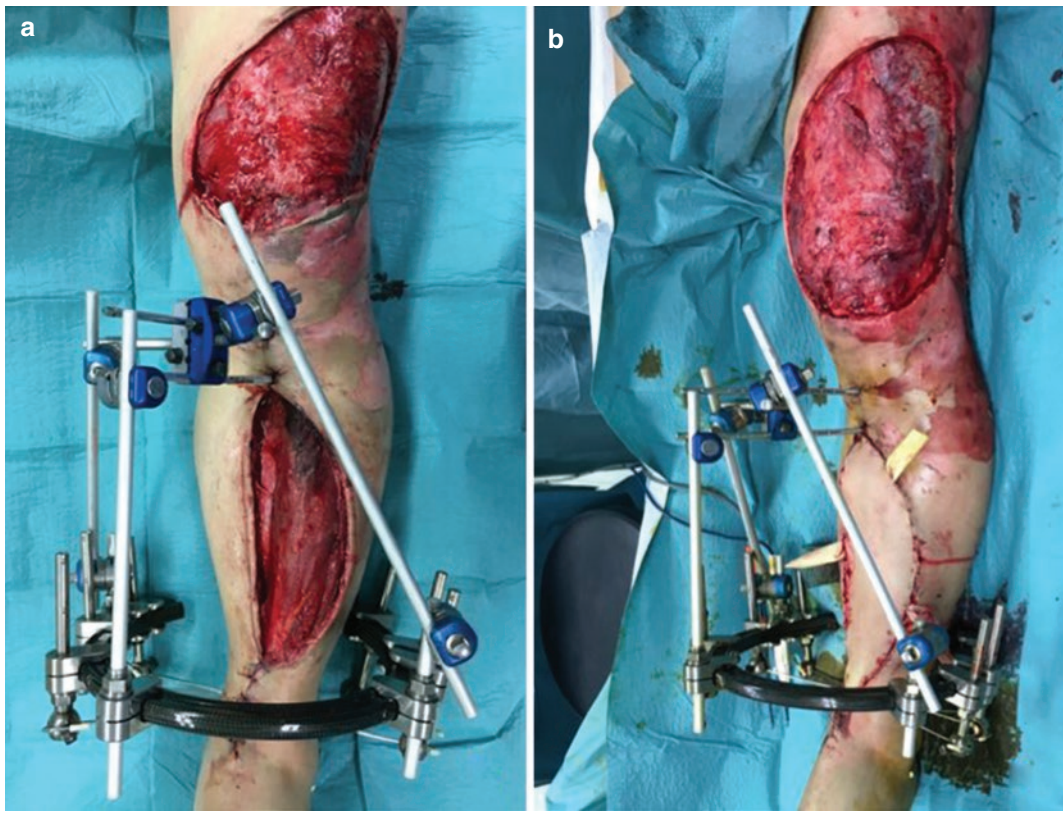

Fig. 17.9 (**a**) In the operating room, the patient was treated with initial debridement and damage control with an external fixator for the bone alignment and negative pressure device for control of the wounds. After 5 days, (**b**) an anterolateral thigh free flap from the contralateral thigh was harvested and used to reconstruct the leg defect to guarantee a stable and viable cover of the fracture

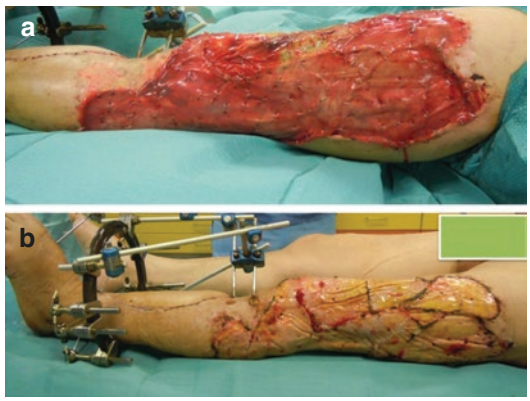

Fig. 17.10 The skin of the thigh was reconstructed with a dermal substitute, whereas there was no exposure of the deep structures. (**a**) Aspect of the dermal substitute immediate. (**b**) After three weeks, the color of the dermal substitute change due to the take of the neodermal

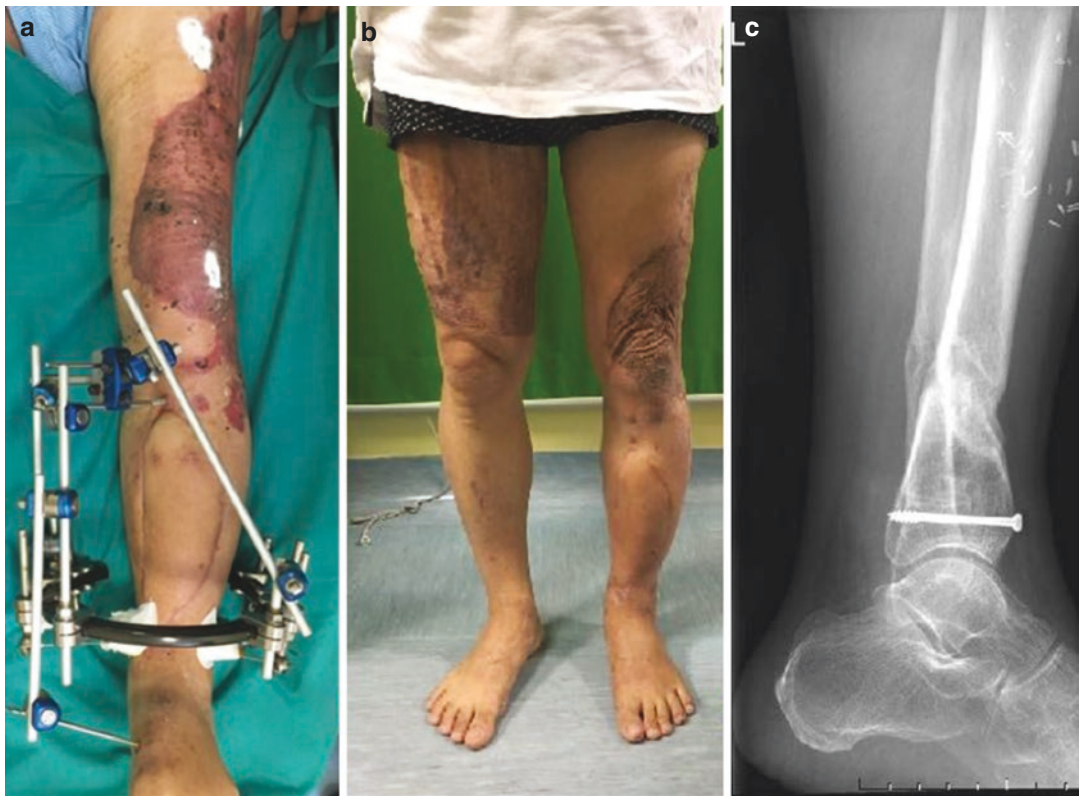

Fig.17.11 (**a**) Early and final aspect of the inferior limb. The external fixator was used to let the bone heal. (**b**) The inferior leg after 6 months shows a complete recovery. The contralateral thigh shows scars due the donor site. (**c**) X-ray shows complete bone healing

Further Reading

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Burns: Classification and Treatment

18

Elia Rossella, Maggio Giulio, and Maruccia Michele

Background
According to the World Health Organization, burns are a global public health problem, accounting for an estimated 180,000 deaths annually. They represent the fourth most common type of trauma worldwide, after traffic injuries, falls, and interpersonal violence [1].

18.1 Introduction

A burn is defined as an injury to the skin or other organic tissue primarily caused by heat or due to radiation, radioactivity, electricity, friction, or contact with chemicals.

The majority of burns accidents occur in low- and middle-income countries, and almost two thirds occur in the WHO African and Southeast Asia regions. In these areas, burns are also among the leading causes of disability-adjusted life years (DALYs) lost. On the other side, in many high-income countries, burn death rates have been decreasing. In economically developed nations, 1–2% of the population experience a burn injury annually, and 10% of those require medical attention. Roughly, 10% of those needing medical attention require burn center management. For instance, The Burn Incidence Fact Sheet of the American Burn Association (ABA) states that each year in the United States, about 450,000 people receive medical attention for burn injuries. The ABA reports that 40,000 patients were hospitalized with burns in 2016, and 30,000 of those patients were admitted to 128 burn centers in the United States [2].

18.2 Etiology and Risk Factors

Exposure to flame is the most common cause among people older than 5 years of age. Scald burns are more common in children under the age of 5 years. Most burns (75%) occur at home, and 13% occur at work. Approximately 95% of burns are accidental, 2% are related to abuse, and 1% are self-inflicted. Almost all burns are preventable, and simple measures such as installation of smoke detectors have been highly effective [2, 3].

Risk factors for burns include:

- Gender: females have slightly higher rates of death from burns compared to males according to the most recent data. This is in contrast to the usual injury pattern, where rates of injury for the various injury mechanisms tend to be higher in males than females. The higher risk for females is associated with open fire

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cooking, or inherently unsafe cookstoves, which can ignite loose clothing.
- Age: children under 5 years old are particularly vulnerable to burns. They account for 75% of all pediatric burns. Among all children, scald burn accounts for about two-thirds of burn injuries.
- Socioeconomic factor: major burn trauma occurs mainly among the poor and the disabled in poor neighborhoods and in low-income countries.
- Other risk factors include, for adults, smoking, alcoholism, psychiatric disorders and neurological disease as epilepsy, occupations that increase exposure to fire, use of kerosene (paraffin) as a fuel source for non-electric domestic appliances, and inadequate safety measures for liquefied petroleum gas and electricity.

18.3 Skin Pathophysiology

The thermal injury first causes enzyme changes in the cells, then protein denaturation and membrane damage, and finally necrosis [4]. The extent of thermal burn injury scales with both the tissue temperature and duration of exposure. Chemical burns are divided into acid or alkali burns. Alkali burns tend to be more severe causing deeper penetration by liquefying the skin (liquefaction necrosis). Acid burns penetrate less because they cause coagulation injury (coagulation necrosis). Electrical burns can be deceiving with small entry and exit wounds; however, there may be extensive internal organ injury or associated traumatic injuries.

In the same burned area, areas of different depth are identifiable, mostly extending centrifugally from a deeper central area to less deep peripheral areas, as the heat propagates in the tissues based on their thermal conductive capacities, progressively losing energy. Typically, three zones can be detected: (i) coagulation, (ii) stasis, and (iii) hyperemia. The zone of coagulation is the central area and represents the most severely burned tissue. The zone of stasis is characterized by cellular swelling; initially, blood flow is present, but over the subsequent 24 h, hypoperfusion and ischemia prevail, and part of this area combines with the zone of coagulation. Surrounding the zone of stasis is the outer zone of hyperemia, which contains viable tissue. Vascular perfusion is increased in response to inflammatory status.

The damage directly induced by the thermal agent can deepen due to the occurrence of additional factors: progressive drying of superficial layers, extension of the thrombotic phenomena, stasis produced by the edema, and bacterial contamination. This is the reason why the exact diagnosis of depth is not obvious initially; the final depth becomes clear 48–72 h after the injury.

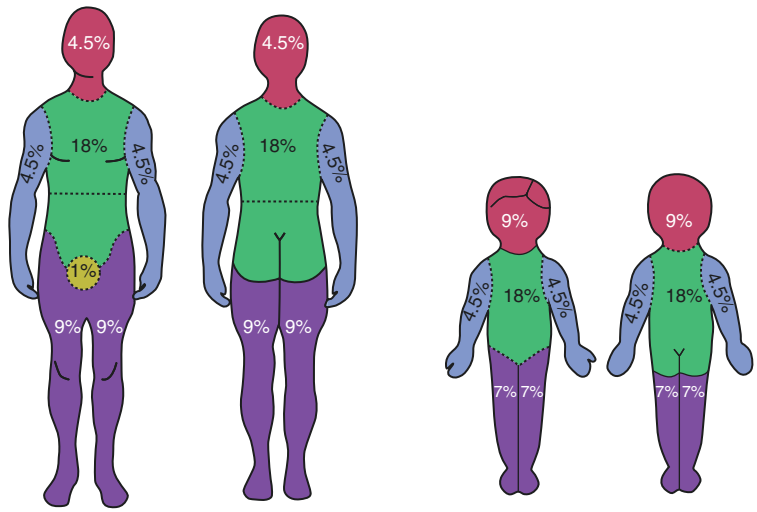
18.4 Clinical Evaluation

It is essential to be able to promptly identify the severity of a burn as it affects the correct therapeutic orientation. The burns' gravity is diagnosed based on the following parameters:

- *Burn Extension*

  The percentage of total body surface (TBSA) involved in a burn injury is useful to determine whether a patient should be admitted to a Burn Center and to guide the fluid resuscitation. Several methods are used to quantify the burn size. For adults, the Wallace *Rule of Nines* is a simple method to calculate the TBSA, namely, distinct anatomic regions represent approximately 9%—or a multiple thereof—of the TBSA. In infants or children, the "Rule" deviates because of the large surface area of the child's head and the smaller surface area of the lower extremities. *Lund and Browder Chart* is a more accurate method, especially in children as it accounts for unique pediatric body proportion (Fig. 18.1).
- *Burn Depth*

  Burns can be classified according to depth, namely, based on how deeply into the epidermis or dermis the injury might extend. Superficial burns involve only the epidermis and are warm, painful, red, soft, and blanch when touched. Usually, there is no blistering. A typical example is a sunburn. Partial thickness burns extend through the epidermis and into the dermis. The depth into the dermis can vary (superficial or deep dermis). These burns are typically very



Body Area	Age (y)				
	0y	1y	5y	10y	15y
Head (half)	9 ½	8 ½	6 ½	5 ½	4 ½
Trunk (half)	2 ¾	3 ¼	4	4 ¼	4 ½
Lower leg (half)	2 ½	2 ½	2 ¾	3	3 ¼

Fig. 18.1 Burn extension according to the Wallace Rule of Nine (upper). The table shows an estimation of the burn size (% of TBSA) according to the Lund and Browder method in the pediatric population

painful, red, blistered, moist, soft, and blanch when touched. Examples include burns from hot surfaces, hot liquids, or flame. Full-thickness burns extend through both the epidermis and dermis and into the subcutaneous fat or deeper. These burns have little or no pain; can be white, brown, or charred; and feel firm and leathery to palpation with no blanching. These occur from a flame, hot liquids, or superheated gasses (Fig. 18.2; Table 18.1).

Note that superficial burns without blister formation areas are not included in the TBSA burn calculation.

- *Critical Areas*

Face and neck are considered areas of risk. The burn can be associated with inhalation of gases and vapors with damage to the upper airways; the result could be pharyngo-laryngeal edema that requires prompt treatment. In these regions, the scarring results are also invalidating both on a functional and aesthetic level. Remember also to ask for an ophthalmologic consultation. Additional critical areas are hands, joint surfaces, the genitals, and perineal areas due to the increased infectious risk (a urethral catheter or, eventually, rectal should be placed) (Fig. 18.3).

- *Age (young children <5 years and elderly patients >75 years), preexisting comorbidities, and/or associated injuries* represent additional negative prognostic factors.

Tip and Tricks

Remember to check signs of inhalation injury if there is a history of flame burns or burns on the face or if there is a change in voice with hoarseness or harsh cough [5].

Remember to check the extremities in case of circumferential burns for the existence of distal vascular compromise. Total

or subtotal circumferential burn contracture may compromise the perfusion of all tissues (not only muscles vs compartment syndrome) at and distal to the site of compression. You may need to perform prophylactic incisions deep to the fascia (fasciotomies) at the time of admission to allow restoration of distal perfusion.

18.5 Severe Burn Injury (SBI)

A severe burn injury (SBI) occurs when burns involve >20% of the TBSA in an adult patient. Local burn injury rarely leads to systemic illness, whereas SBI leads to significant metabolic derangements that require immediate and intensive management. SBI results in a severe fluid loss and consequent derangement of cardiovascular dysfunction known as "burn hypovolemic

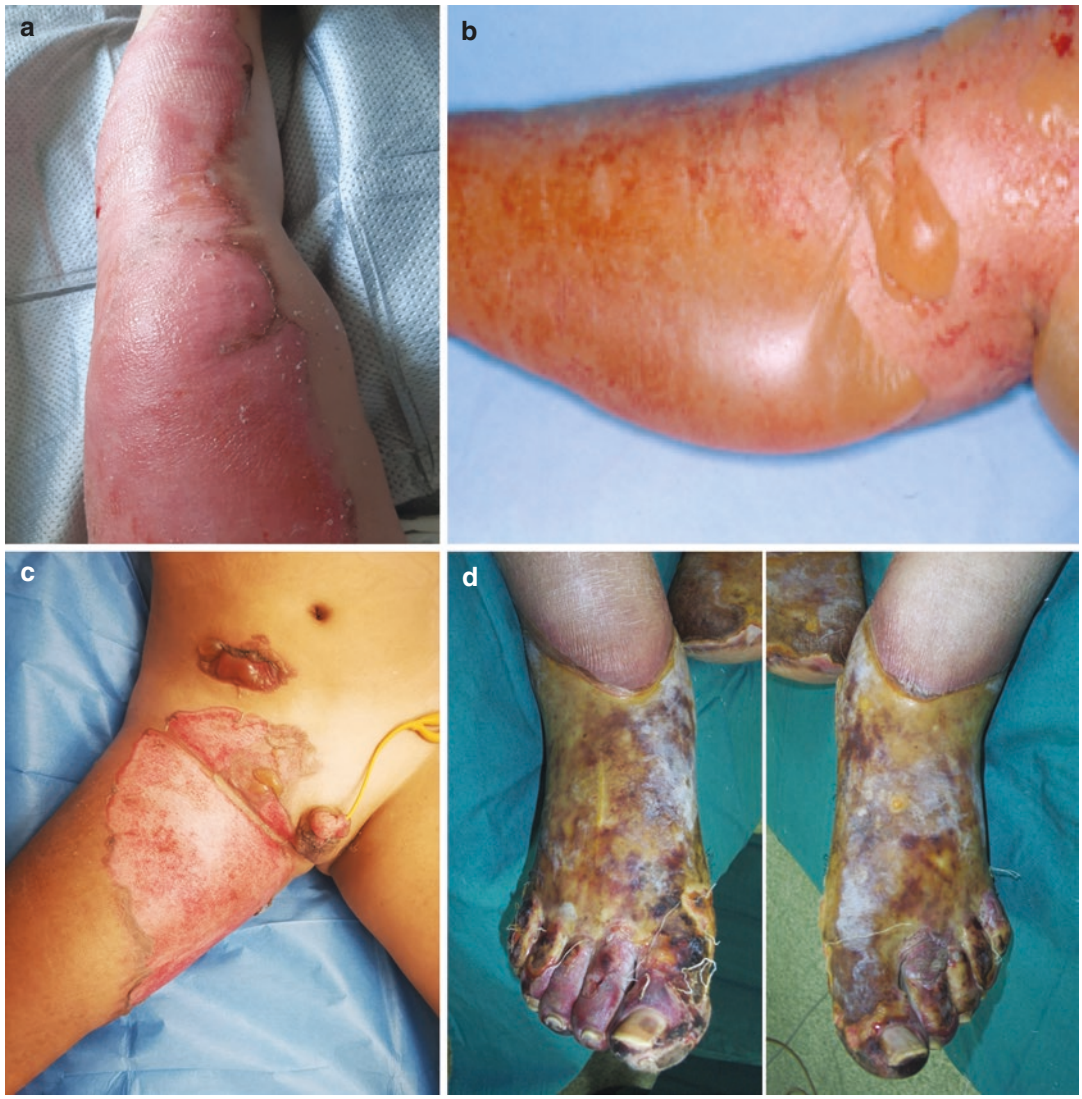


Fig. 18.2 Typical appearance of skin burns of different depth. **Panel a**: Superficial hyperemic burn. **Panel b**: Intermediate-partial thickness burn presenting with blisters. **Panel c**: Intermediate-deep burn presenting with mixed white, pearly appearance. Note the importance of a prompt insertion of a urinary catheter when genitalia is involved in the thermal injury. **Panel d**: Full-thickness burn of both feet with a typical charmed aspect

Table 18.1 Burn injury classification according to depth

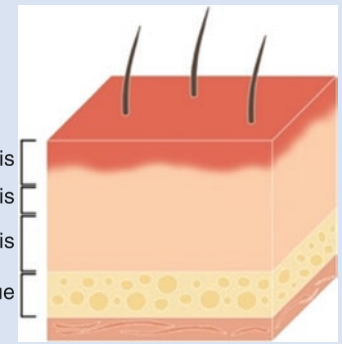
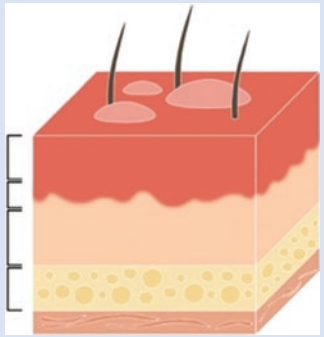
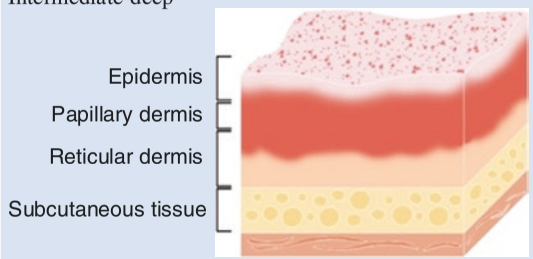
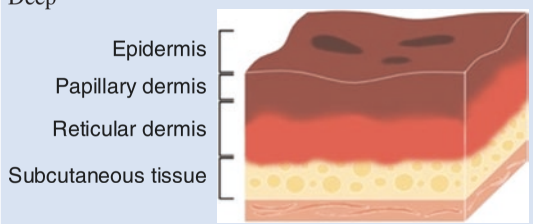
Depth of burn	Tissue involvement	Clinical signs	Sensation	Healing time	Sequelae
Superficial 	Epidermis	Erythema No blisters Blanches with pressure	Painful	7 days by re-epithelialization from viable keratinocytes within dermal glands and hair follicles	No scarring sequelae A pigmented area can remain if the area is not adequately protected from sun exposure
Intermediate-superficial 	Epidermis and papillary dermis	Pale pink to cherry red Blisters Blanches with pressure	Painful because of exposed superficial nerves	14 days by re-epithelialization from viable keratinocytes within dermal glands and hair follicles	Possible color match defect Low to moderate risk of hypertrophic scar

Table 18.1 (continued)

Depth of burn	Tissue involvement	Clinical signs	Sensation	Healing time	Sequelae
Intermediate-deep 	Epidermis and dermis down to reticular dermis	Mixed white, pearly; dark pink No blisters Fixed capillary staining	Little or no pain	Up to 21 days. Closure by epithelialization may not occur. Need for surgical intervention	Moderate to high risk of hypertrophic scars and scars contracture
Deep 	Whole skin and, eventually, deeper tissues	White, waxy, or charred. No blisters No capillary refill	Insensate because of destruction of nerve endings	No spontaneous healing Need for surgical intervention	Wound contraction Severe contracture deformities

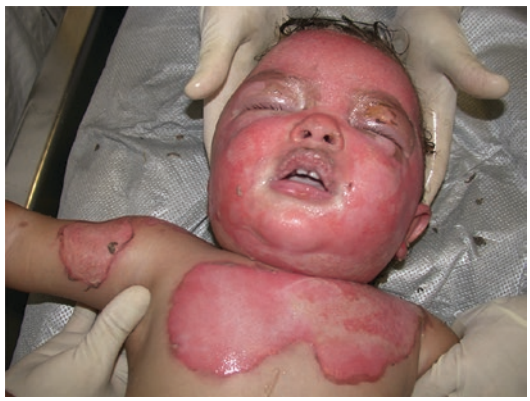


Fig. 18.3 Intermediate-deep burn, caused by flame, involving a critical area (face) in a pediatric patient. The patients should be referred to a Burn Center. Signs of inhalation should be sought, and an ophthalmologic consultation should be done

shock." The physiologic changes that occur with SBI can be divided into two distinct phases: the resuscitation phase and the hyperdynamic hypermetabolic phase.

18.5.1 Resuscitation Phase

A resuscitation phase, also known as the "hypodynamic" or "burn hypovolemic shock," occurs first and lasts for approximately 24 –72 h. Local tissue trauma, i.e., the burn, activates the release of an array of systemic mediators such as complement, arachidonic acid, and cytokines, particularly IL-1 and TNF. Cytokines and other metabolic products of activated leukocytes can act either beneficially to provide for enhanced host resistance or deleteriously to depress the function of remote organs.

This period is characterized by increased vascular permeability, fluid shifts resulting in intravascular volume depletion, and edema formation. Increases in microvascular permeability occur due to direct vascular thermal injury and through release of inflammatory mediators. The release of reactive oxygen species (ROS) from neutrophils contributes to increased vascular permeability, tissue edema, systemic inflammation, and multiorgan dysfunction. How does edema occur? In a normal tissue, a 20–25 mm Hg gradient between the plasma and interstitial oncotic pressure causes fluid to reabsorb back into the intravascular space. Indeed, hyaluronic acid, collagen, and proteoglycans provide the structural integrity of the interstitial space and exist in a coiled state providing a negative elastic force. In a burned tissue, as this extracellular matrix is disrupted, the forces limiting the influx of fluid are lost, and this gradient approaches zero or may even become negative, drawing fluid out of the vasculature and into the interstitium. Given the increased vascular permeability, plasma proteins shift into the interstitial space resulting in decreased capillary oncotic pressure, creating an osmotic gradient that pulls additional fluid into the interstitium [6].

Key Points

All the symptomatology is consequent to the reduction of the edema and reduction of the circulatory mass: reduction of the cardiac output with decrease of the central venous pressure, fall of the arterial pressure, dyspnea, polypnea, oligo-anuria, or weight gain (related to edema and fluid resuscitation).

The erythrocytes are retained in the circulatory stream, aggravating the condition of *ispissatio sanguinis*. Organ perfusion becomes insufficient, and the cells find themselves in a state of hypoxia, releasing toxic catabolites which aggravate general suffering.

Coagulopathy is frequently seen in patients with severe burns. Coagulopathy early after a burn resembles coagulopathy seen in patients with sepsis and in patients after major trauma: activation of coagulation could be a consequence of a systemic inflammatory response and endothelial damage following the burn. Specifically, a procoagulant shift characterized by increased levels of thrombin-antithrombin complex (TAT), activated FVII (FVIIa), activated FXII (FXIIa), and markers of thrombin activation such as fibrin degradation products and prothrombin fragment F1 + 2 inhibiting fibrinolysis characterized by increased levels of PAI-1 and decreased natural

coagulant activity shown by decreased levels of antithrombin, protein C, and protein S, are seen in patients after severe trauma, in patients with sepsis, and in patients with severe burns [7].

If the renal perfusion persists below the threshold values for too long, the renal parenchymal suffers from insufficiency (*shock kidney*). Acute kidney insufficiency (AKI) related to thermal injury is most likely to occur at two distinct time points: early during resuscitation or late secondary to sepsis. Early AKI has been shown to be associated with early multiple organ dysfunction and higher mortality risk.

Respiratory complications include *shock lung*, a complex syndrome characterized by progressive lowering of pO_2 and elevation of pCO_2. This condition is caused by alterations of the permeability of the alveolar-capillary membrane due to damage to the alveolar epithelium and the capillary endothelium, with consequent pulmonary edema which can be complicated with atelectasis and death from acute pulmonary heart.

Cellular hypoxia leads to an increase in intracranial pressure and cerebral edema formation. Other signs of central nervous system dysfunctions can include agitation, confusion, ataxia, abnormal posturing, transient loss of consciousness, seizures, and even shock.

At the gastrointestinal level, the most important damages are represented by hemorrhagic gastritis and *stress ulcer* (Curling ulcers) which can occur in more or less serious form up to diffuse hemorrhages throughout the digestive tract especially if a coagulopathy has been established. It is currently unknown if these syndromes are iatrogenic consequences of excessive or poorly managed fluid resuscitation (corticosteroid infusions and fasting) or unavoidable sequelae of the primary injury. Aspartate aminotransferase (AST) and alanine aminotransferase (ALT) levels are increased immediately after burn injuries and are the most sensitive indicators of hepatocyte injury. Liver damage has been shown to be associated with an increased hepatic edema formation. Liver weight significantly increases 2–7 days after burn.

Key Point

The major cause of death, if the burn patient survives the first 24 h, is multiple organ dysfunction syndrome (MODS) [8].

18.5.2 Hyperdynamic Hypermetabolic Phase

The hyperdynamic hypermetabolic phase begins approximately 3–5 days after the injury. This phase is characterized by hyperdynamic circulation and an increased metabolic rate that can persist up to 24 months post burn injury. This phase is characterized by a decrease in vascular permeability, increased heart rate, and decreased peripheral vascular resistance resulting in an increase of cardiac output. Approximately 24–48 h after burn injury, the microvascular integrity begins to heal, and peripheral blood flow is augmented by a decrease in systemic vascular resistance with preferential redistribution to the area of burn wounds. Cardiac output is more than 1.5 times that of a non-burned fit patient 3–4 days following the burn injury. Furthermore, metabolic rate is increased nearly three times more that of their basal metabolic rate.

Key Point

Sepsis in Burns

Sepsis is a major risk after any large burn because the primary barrier to microbial invasion, the skin, is lost. Sepsis can develop any time after resuscitation, and the risk persists as long as the wound remains open. Unfortunately, antibiotics are ineffective in preventing infection. Instead, their use leads to more resistant organisms. Sepsis is a different problem in patients with burns than in most other kind of patients because there is a persistent exposure to microbial products combined with the hypermetabolic response. All

patients with burns have persistently elevated temperature, tachycardia, and variable white-cell counts. By definition, all patients with large burns have the systemic inflammatory response syndrome (SIRS) throughout their inpatient stay, so SIRS alerts are of little value. In addition, the use of central lines, ventilators, and urinary catheters for prolonged periods increases the risk of iatrogenic infections. Herein is the definition of sepsis in burned patients, according to the American Burn Association Consensus Conference [8]:

I. Temperature >39° or <36.5 °C.
II. Progressive tachycardia.
    1. Adults >110 bpm.
    2. Children >2 SD above age-specific norms.
III. Progressive tachypnea.
    1. Adults >25 bpm not ventilated
    2. Minute ventilation 12 L/min ventilated.
    3. Children >2 SD above age-specific norms.
IV. Thrombocytopenia (will not apply until 3 days after initial resuscitation).
    1. Adults <100,000/mcl.
    2. Children <2 SD above age-specific norms.
V. Hyperglycemia (in the absence of pre-existing diabetes mellitus)
    1. Untreated plasma glucose <200 mg/dl.
    2. Insulin resistance.
VI. Inability to continue enteral feedings >24 h
    1. Abdominal distension.
    2. Enteral feeding intolerance.
    3. Uncontrollable diarrhea (2500 ml/d for adults or 400 ml/d in children).

*At least three of the previous parameters.

In addition, it is *required* that a documented infection is identified:

A. Culture positive infection
B. Pathologic tissue source identified.
C. Clinical response to antimicrobials.

18.6 Acute Burn Trauma Management

The initial assessment of a burn patient is identical to other trauma: recognize and treat life–/limb-threatening injuries first. Many patients with burns also present associated trauma. The primary survey consists of the following:

Airway maintenance with cervical spine protection.

Pearls and Pitfalls

Indicators of a possible requirement for intubation are:

- Burn size >40%TBSA.
- Burns to the head and mouth.
- Stridor, tachypnea, and dyspnea.
- Change in voice.
- Altered level of consciousness.

- **B**reathing and ventilation.

Problems with breathing take many forms in patients with burns. Flames consume oxygen, which results in low ambient levels of oxygen and can lead to severe hypoxemia. Another cause of hypoxemia is carbon monoxide (CO). CO is a combustion by-product from the burning of biomaterials such as petroleum products, coal, and gas. CO binds to deoxyhemoglobin at 200 times greater affinity than molecular oxygen. Measurements of arterial blood gases and pulse oximeter readings are of no value in case of smoke inhalation, since they do not reveal carbon monoxide levels. Measurement of carboxyhemoglobin is the only accurate test to identify carbon monoxide levels. Treatment consists of the administration of 100% oxygen. A CO intoxication can be suspected according to the burn agent and in presence of clinical signs of carboxyhemoglobinemia including nausea, headache up to drowsiness, lethargy, confusion, and respiratory depression.

In patients with circumferential chest and abdominal burns, it can be observed the development of compartment syndromes which require escharotomies, namely, incisions through the burn to relieve pressure and ensure ventilation,

but such syndromes occur after 12–18 h and are preferably treated in a burn center.

- **C**irculation and cardiac status with hemorrhage control.
- **D**isability, neurological deficit, and gross deformity assessment.
- **E**xposure and environmental control (completely undress the patient, examine for associated injuries, and maintain a warm environment).

A thorough assessment should then take into account: type of burn (e.g., flame, electrical, radiation, chemical), depth and %TBSA, coexisting medical conditions, and social circumstances. These evaluations are essential to understand whether a patient should be referred to a Burn Center or not.

Key Point

The American Burn Association recommends burn center referrals for patients with:

- Partial thickness burns greater than 10% of total body surface area.
- Full-thickness burns.
- Burns of the face, hands, feet, genitalia, or major joints.
- Chemical and electrical burns or lighting strike injuries.
- Significant inhalation injuries.
- Burns in patients with multiple medical disorders.
- Burns in patients with associated traumatic injuries.

At the hospital, a peripheral intravenous access should be established, preferably through unburned skin. This avoids the complications that may ensue with central lines, such as pneumothorax (subclavian a), inadvertent arterial injury (femoral a), and venous thrombosis. In elderly patients, patients with cardiorespiratory disease and patients who have delayed presentation, consider inserting a central venous pressure line. Baseline screening tests are often performed; under specific circumstances, additional specialized tests are appropriate: arterial blood gases with carboxyhemoglobin level (carbon monoxide) if inhalation injury is suspected and ECG with cardiac enzyme in case of electrical burns or preexisting cardiac problems.

A urinary catheter should be inserted to establish fluid balance monitoring. Antithrombotic and anti-acid treatments should be started. Morphine (or opioid equivalents) are indicated for control of pain associated with burns. Pain should be differentiated from anxiety. Benzodiazepines may also be used to relieve the anxiety associated with the burn injury. Unless contraindicated by spine immobilization, elevate the patient's head to 45 degrees. This will help minimize facial and airway edema and prevent aspiration. Similarly, elevating the affected extremities reduces edema.

18.7 Fluid Resuscitation

Crystalloid fluid is the cornerstone of resuscitation for burn patients. The amount of replacement fluid is predicted from the extent of burn and size of the patient, and fluid replacement should proceed at the same rate of the loss. Lactated Ringer's (LR) is the fluid of choice for burn resuscitation because it is widely available and closely resembles intravascular solute content. Hyperchloremic solutions such as normal saline should be avoided.

By consensus, the American Burn Association published a statement in 2008 establishing the upper and lower limits from which the 24-h post-burn fluid estimates could be calculated. These limits were derived from the two most commonly applied resuscitation formulas: the Parkland formula and the modified Brooke formula. For any traditional formula, it was estimated that one-half of the calculated total 24-h volume would be administered within the first 8 h post-burn, calculated from the time of injury. The traditional formulas further estimated that the remaining half of the calculated total 24-h resuscitation volume would be administered over the subsequent 16 h of the first post-burn day. After the initial rate of fluid resuscitation has been determined, fluids

should be adjusted on the basis of urine output (with a target urine output of 0.5 ml per kilogram of body weight per hour for adults). Administration of albumin and other colloids is usually avoided in the first 24 h post burn, but they may have a role in severe burns after the first 24 h. High-dose vitamin C (66 mg per kilogram per hour) has also been reported to reduce fluid needs, but there are questions about whether it works primarily as diuretic.

Key Point

Fluid Resuscitation Formulas

Parkland's Formula

4 ml/kg/% of TBSA burned, with a starting rate based on giving half the 24-h volume in the first 8 h.

Adjust rate up or down to target urine output of 50 ml/h (0.5 ml/kg/h).

Modified Brooke Formula

2 ml/kg/% of TBSA burned, with a starting rate based on giving half the 24-hr volume in the first 8 h.

18.8 Hypermetabolic Phase Management

The strategy for reducing metabolic stress is to remove the burned tissue and cover the exposed area with skin or some other form of barrier (see "Management of the Burn Wound"). Additionally, patients with a hypermetabolic response have an elevated core temperature; therefore, setting the patient's room temperature at around 18 °C will reduce the metabolic demand. Patients with major burns need nutritional support in order to keep up with the high metabolic demand. Placing an enteral feeding tube and starting nutrition as soon as possible, even during the initial resuscitation, are recommended. Increased intake of both total calories and protein is needed to restore the deficit. Calorie requirements can be calculated with the use of various formulas for resting energy expenditure (es. Curreri Formula: (25 × body weight) + (40 × TBSA) for adults).

A final strategy is to reduce catabolism and increase muscle mass by providing anabolic agents. Insulin, insulin-like growth factor 1, and growth hormone have all been shown to have a benefit but are rarely used. Minimizing pain and distress also reduces the metabolic demand.

18.9 Management of the Burn Wound

The priority in burn wound management is to create a physiological environment for healing and in order to reduce evaporation losses. Minor burns (superficial and intermediate superficial) can be approached using the "C" of burn care:

- *Cooling*: Small areas of burn can be cooled with tap water or saline solution to prevent progression of burning and to reduce pain.
- *Cleaning*: Mild soap and water or mild antibacterial wash. Debate continues over the best treatment for blisters. If left intact, the blister becomes a potential source of infection, increases healing time, and may hide deep partial-thickness burns underneath. Large blisters are debrided while small blisters and blisters involving the palms or soles are left intact.
- *Covering*: Topical antibiotic ointments or cream with absorbent dressing or specialized burn dressing materials are commonly used. Common topical ointment is 1% silver sulfadiazine. This cream can be applied directly to the burn wound or impregnated into gauze and then applied to the wound. Other topical ointments can be used, either alone or in combination, depending on the depth of the wound. Examples are bacitracin, double- or triple-antibiotic ointment,
  and petrolatum. A secondary dressing provides a layer to absorb drainage and will provide mechanical protection. All secondary dressings are loosely secured with size appropriate rolled gauze or surgical netting if available.
- *Comfort*: Over-the-counter pain medications or prescription pain medications when needed.

Splints can also provide support and comfort for extremities' burned areas.

Deep partial- or full-thickness burns need an operative wound closure. The main goals of surgical treatment are removal of damaged or devitalized tissue (debridement) and replacement with viable tissue. It has been established that early removal of the necrotic tissue decreases wound infection and mortality. The burned and dead tissue of partial-thickness and full-thickness burns create an opportunistic environment for gram-positive cellulitis to occur and leads to the sequelae of the wound burden, including slow healing time, physiologic impairment, contractures, and functional deficit. At the same time, open wounds lose heat and fluids, contributing to the patients' hyperdynamic hypermetabolic response. Surgeons have to overcome two problems: the physical insult of the debridement and, occasionally, large % TBSA, the limited source of replacement skin.

18.10 Debridement

The order of excision is dependent on the surgeon, but the goal is to safely excise and debride the largest surface areas first, such as the anterior or posterior trunk or large areas on the extremities. The size of the primary excision largely depends on the amount of available autograft or skin substitute, as it is essential to cover the excised and debrided areas. Generally, no more than 10–20% TBSA is excised at one time to prevent excessive blood loss and allow for complete coverage [9].

- Conventional surgical debridement of acute burn wounds has consisted of sharp tangential excision of nonviable tissue with handheld knives such as the Goulian or Weck knife. Tangential excision of burned tissue involves unroofing the burn eschar and debriding the dead tissue layer by layer until encountering healthy bleeding tissue. This approach is opposed to a fascial excision, which is an excision of all skin elements to the subcutaneous fat/fascia and can be considered in case of obvious full-thickness injuries. The disadvantages of the surgical debridement are that it often results in significant blood and heat loss. Indeed, it is vital to have multiple units of packed red blood cells and plasma type and cross-matched preoperatively. Moreover, steps can be taken to avoid excessive blood loss using tourniquets, compressive dressings, limb elevation, infiltration, topical application of epinephrine solutions, electrocautery, or topical hemostatic agents (recombinant thrombin or fibrinogen). The additional critical issue related to the surgical debridement is its poor selectivity that results in viable skin or healthy tissue being sacrificed along with the necrotic skin (Fig. 18.4).
- Hydrosurgical debridement (e.g., water jet and high-powered parallel water jet tools) is another useful tool in surgical debridement. It works by producing a high-pressure jet of water across an aperture in an angled handpiece. The Venturi effect creates a vacuum that removes surface debris which is sucked into the machine together with the irrigation fluid. The cutting and aspiration effects can be controlled by adjusting console power settings, handpiece orientation, and handpiece pressure. The vacuum that is created by the speed of the jet aims to lift only nonviable tissue, and thus maximal dermal preservation could be achieved. Only eschars that are deep, hard, dry, or leathery are not easily debrided and require multiple passes as well as higher pressure settings or may still need cold knife excision (Fig. 18.4).

Key Point
NexoBrid® (Mediwound Ltd.), a form of debriding gel dressing (DBD), has gained popularity in recent years. It is a form of bromelain-based enzymatic debridement agent that is derived from pineapple stems. Its effects on burn wounds particularly deep partial- and full-thickness wound have been evaluated in several studies [10, 11] Its benefits mainly are due to eschar removal without removing any viable or healthy tissue, leaving a clean dermal/subdermal tissue, preparing the wound for closure.

Technique: NexoBrid® is licensed for a total wound area of not more than 15 per cent TBSA. Some users have described treating burn areas of more than >15 percent safely. Before application of NexoBrid®, the wound must be cleansed, to remove any keratin layer or blisters. Adequate analgesia must be given to the patient before, during, and after application. A NexoBrid® mixture is applied over the wound, 1.5–3 mm thick. The wound is then covered with a sterile occlusive dressing, not leaving any air between the dressing and NexoBrid® gel. One must ensure complete containment of NexoBrid® gel in the wound area. The affected area is then covered with a secondary dressing and bandaged. After 4 h, the occlusive dressing and adhesive barrier can be scraped off. The dissolved eschar is then removed in a non-traumatic manner. The wound is wiped with a large sterile dry gauze, followed by a normal saline-soaked gauze until a pinkish surface with bleeding points or whitish tissue is seen. The debrided area must be covered immediately to prevent desiccation, formation of pseudoeschar, and infection (Fig. 18.5).

Due to the ability for NexoBrid® to preserve healthy dermis and reduce the need for surgical debridement and subsequent grafting, this method of burn treatment is known as minimally invasive modality. In conclusion, the main advantages of the MIM approach with bromelain-based enzymatic debridement are:

- Reduced time to complete healing.
- Reduced need for surgery.
- Reduced area of burn excised.
- Reduced need for autograft.
- Reduced time to wound closure.
- Improved scar quality.
- Reduction of costs.

18.11 Wound Coverage

Autologous split-thickness skin grafts (STSG) from unburned areas are the "gold standard" for definitive coverage of burn wounds. Meshing the skin grafts improves graft "take" and allows faster coverage of larger areas. In cases of extremely large burn areas, if enough donor sites are not available, temporary wound coverage still guarantees physiological closures (Fig. 18.6).

They can be either biologic wound dressing (fresh or frozen human cadaveric skin, xenograft, cellular or acellular tissue-engineered biomaterials, isogenic human keratinocytes in tissue cultures) or physiological wound dressing (synthetic materials such as polyethylene or silicone which prevent adherence to the wound and plastic films which reduce contamination and evaporation) (Fig. 18.7; Table 18.2).

The use of stem cells, easily found in the stromal vascular fraction of the adipose tissue, could potentially represent a valid alternative to the current standard of care aiming to induce tissue regeneration and re-epithelialization, with a decreased need of invasive surgery, better scar quality, and consequent improved patients' quality of life [12].

18.12 Burn Sequelae

Alteration in body image, mechanical disabilities, and pain are only some of the problems which can occur. The most common pathological consequence of burns is what it is called the "dystrophic phase." The wounds of burn patients often heal with pathological processes and often with excess (hypertrophic) scarring.

The major scar sequelae at the scalp level is represented by alopecia, a serious aesthetic problem especially in young patients and in women. The technique of skin expansion has improved the therapeutic approach even at the cost of many procedures, a long and socially demanding time dedicated to expansion and possible complications *in itinere*. The main aesthetic problems on

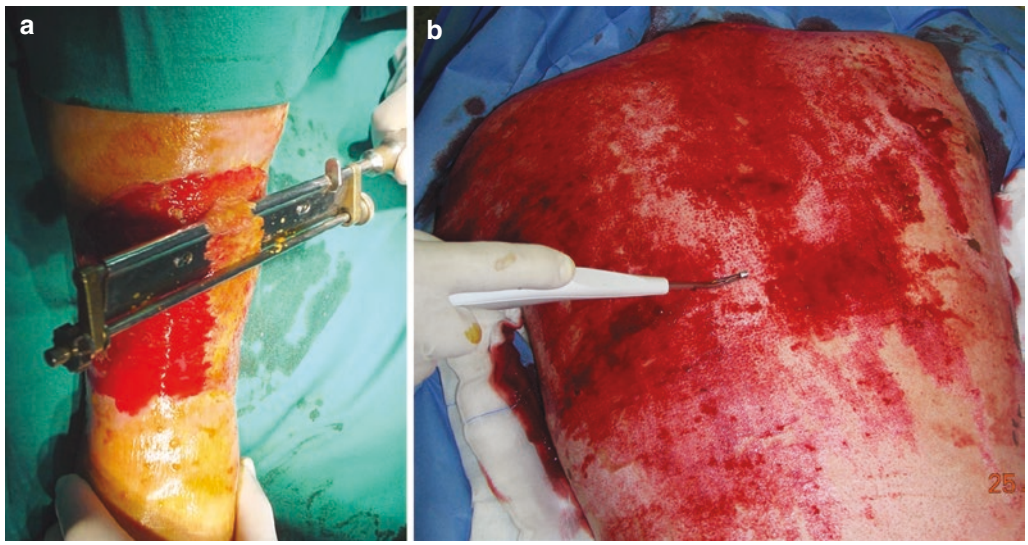


Fig. 18.4 **Panel a**: tangential debridement with dermatome. **Panel b**: hydrosurgical debridement

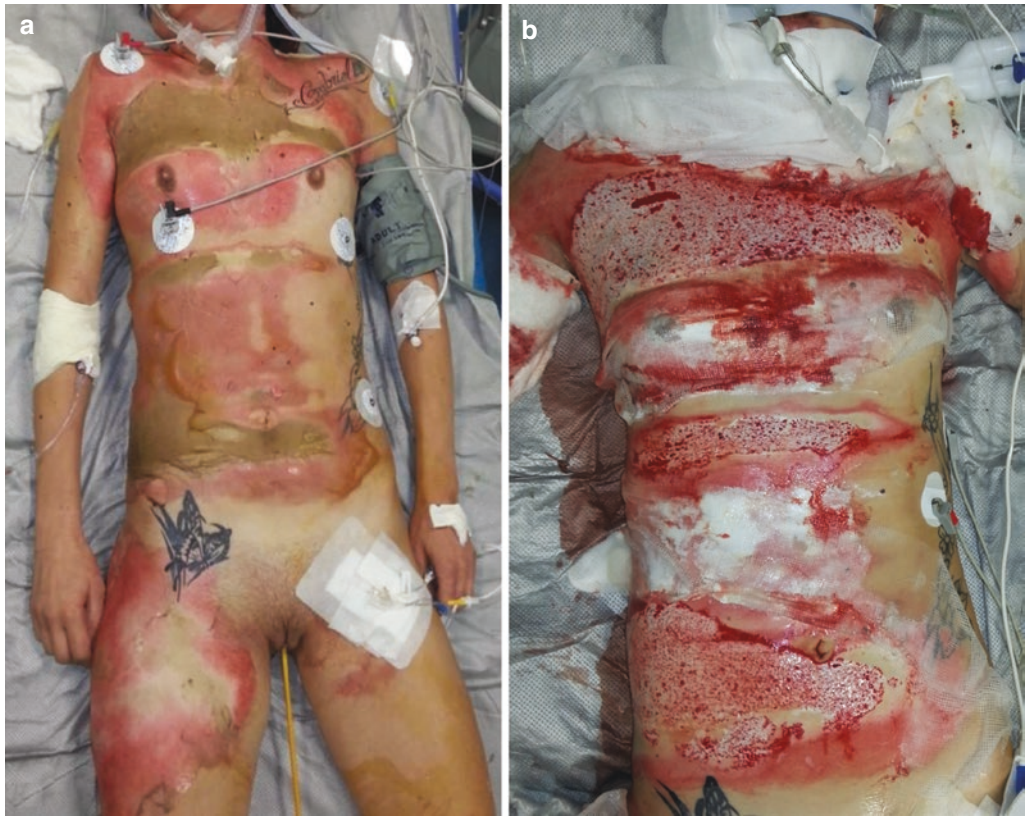


Fig. 18.5 **Panel a**: Severe burn injury affecting more than 20% of the TBSA with intermediate-deep and full-thickness burns. A bromelain-based enzymatic debridement of the 15% of TBSA was planned soon after the patient admission. **Panel b**: After 4 h, the dissolved eschar is removed in a non-traumatic manner. The wound is wiped with a large sterile dry gauze, followed by a normal saline-soaked gauze until a pinkish surface with bleeding points or whitish tissue is seen

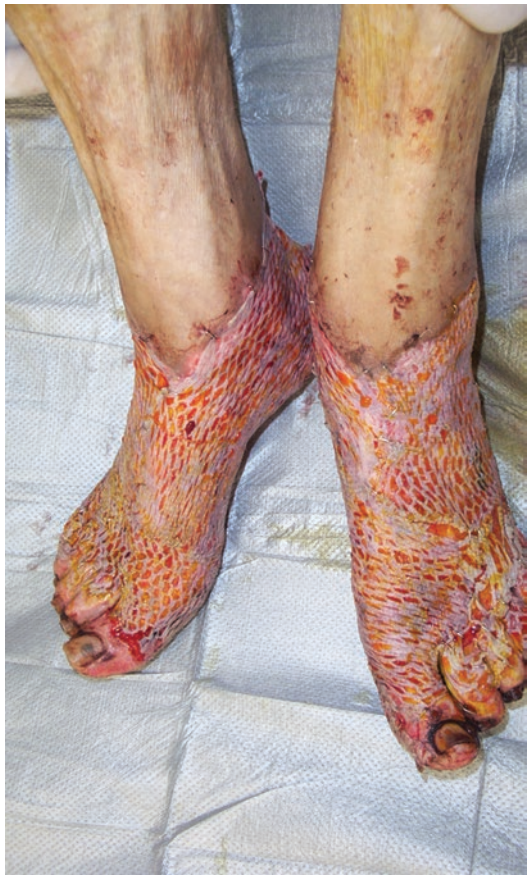


Fig. 18.6 Split-thickness meshed skin grafts were used for deep burn coverage after surgical debridement

the face are represented by the presence of hypertrophic and keloid scars and by the distortion of the facial mimic. At a functional level, this translates in retraction and distortion at the level of the eyelid and lips. In the cervical region, scar retraction can induce the formation of chin-sternal adhesions which may result in limitation of head excursions and normal chewing. Generally, the cervical retracted scars are dealt with by removing the scar tissue and coverage with full-thickness skin grafts, dermal matrix and split thickness skin graft, and locoregional flaps (acromioclavicular), possibly pre-expanded or free flaps. Burns of the mammary region can leave underdevelopment and dysmorphia. Retraction in the flexor regions of the limbs is repaired in the simplest cases with Z-plasty; in the most serious cases, it is necessary to resort to local or distant flaps.

Formulation of an optimal rehabilitation strategy is critical for prevention and as support for reconstructive surgery. It begins in the first few days after hospital admission. The joints must be mobilized, the muscle masses kept trophic and active, and the skin soft and elastic. The correct position of the different segments of the body must be checked. The prevention of hypertrophic and keloid transformation of skin scars is based on continuous compression, for at least 6 months, using special elastic clothing supplemented by silicone dressings. Furthermore, it is important to monitor and guide the correct growth of all the body segments during the developmental age and the adequate support from the social structures for reintegration [13].

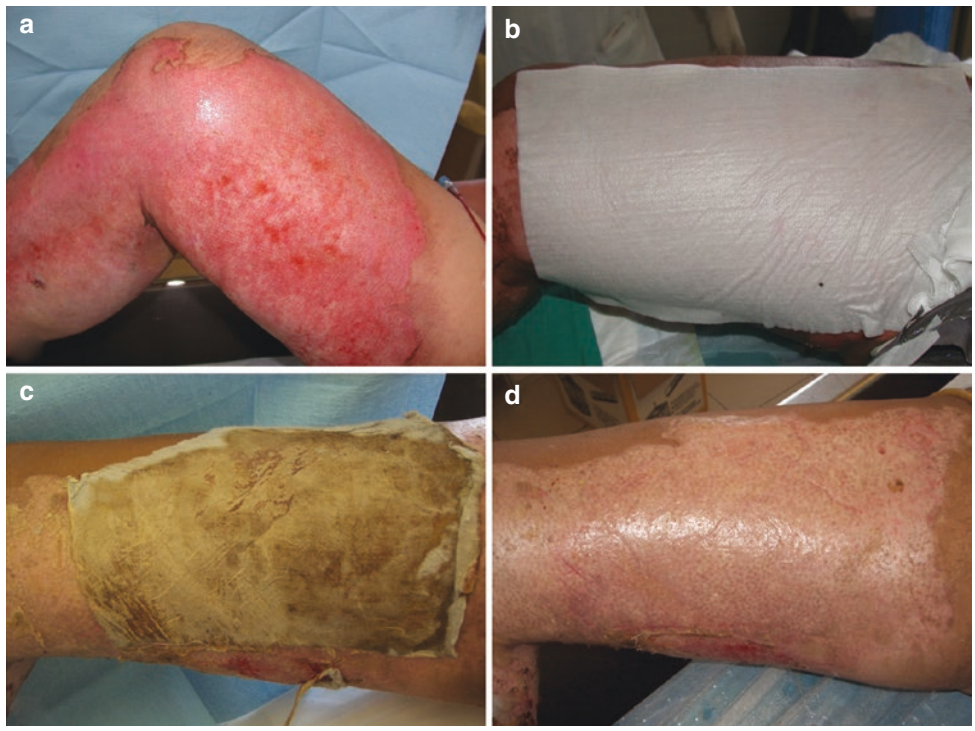


Fig. 18.7 **Panel a**: Intermediate-partial thickness burn. **Panel b**: Wound coverage with advanced medial dressing (alginate). **Panel c**: Appearance of the advanced medical dressing 10 days after application. Note the optimal control of exudation. **Panel d**: spontaneous healing 15 days post injury

Table 18.2 Burn wound coverage

Permanent wound dressing	**Advantages**	**Disadvantages**
Autograft Gold standard for burn wound coverage. Epidermis and partial thickness (STSG) vs full thickness (FTSG) dermis	– STSG: More reliable take; cover of large areas especially if meshed. Donor site heals spontaneously	STSG: Higher secondary contraction
	– FTSG: Typically used for face and hand coverage. Donor site closed primarily. Less secondary contraction (elastic fibers)	FTSG: Less reliable take
Cultured epithelial autograft	Sample of patient's skin is cultured in lab to produce epithelial cells, which are attached to petrolatum gauze or other scaffolds	Fragile wound coverage in absence of dermal layer
Temporary wound dressing	**Advantages**	**Disadvantages**
Dermal matrices (es. INTEGRA® (INTEGRA LifeSciences) bovine tendon collagen shark chondroitin-6-sulfate with silicone layer, or PELNAC® (Eurosurgical Ltd.)	– Readily available. It forms neodermis in 3 weeks and then can be covered with STSG in a second operation – Can be used also for the treatment of scar contractures	– Very expensive for coverage of large burns – Require skin graft for definite wound coverage – High risk of infection
Human allograft (cadaveric split-thickness skin graft)	– A bilayer skin providing epidermal and dermal properties – Dermis incorporates	– Epidermis will reject – Moderate expensive – Need for cryopreservation
Skin substitutes (i.e., BIOBRANE® (Smith & Nephew) nylon fabric coated with porcine dermal collagen and silicone membrane)	– Promote fibrovascular ingrowth – Promote physiological environment for healing of superficial wounds	– Poor adhesion on deep wounds – Risk of infection
Advanced dressing (i.e., alginate, carbossimetilcellulosa)	– Antiseptic property (Ag release) – Coverage for 10–15 days – Low costs	– No revascularization – No dermal formation

Take-Home Messages

- Burns prognostic criteria include burn extension (rule of nine), burn depth, age, involvement of critical area (face, hands, genitalia, perineum), inhalation injury, and comorbidities.
- Major burns (≥20% TBSA for adults, >10% TBSA for elderly and pediatric patients), involvement of critical area, suspicion of inhalation, and burns associated with preexisting medical disorders should be referred to a Burn Unit.
- Severe burns undergo two phases: the hypovolemic shock phase and the hypermetabolic hyperdynamic phase.
- The Parkland formula is used to calculate initial fluid resuscitation for the first 24 h after burn injury.
- Rapid debridement with enzymatic escharolysis and wound coverage are the main steps of early burn treatment.
- Meshed skin graft is the main standard for the coverage of burn areas in severe burned patients.

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Further Reading

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Extravasation

19

Sara Carella and Maria Giuseppina Onesti

Background

Extravasation injuries in adults and pediatric patients are relatively common injuries. They are most frequently seen in the context of cancer care or in the care of neonates and infants. Extravasation can result in significant physical and psychological morbidity. Today, the incidence of chemotherapy extravasation is between 0.01 and 7% [1, 2]. This wide gap exists as this iatrogenic damage is often unrecognized and/or unnoticed; furthermore, the absence of a centralized register determined the scant of data. In the neonatal intensive care, the reported incidence of infiltration is 78%, and the incidence of extravasation is 11% in newborns [3, 4]. Around 4% of injuries from extravasation may result in cosmetic or functional scars. Chemotherapy drugs which can extravasate and cause significant injuries are often classified into vesicants, non-vesicants, and irritants [5] (Table 19.1). Other causes of extravasation injuries would include intravenous (IV) fluid preparations, parenteral nutrition, and IV antibiotics, which are more often associated with injuries in neonatal and pediatric populations [3, 4, 6, 7]. Risk factors for extravasation can be related to agent used for infusion, infusion procedure, patient, and staff factors [3, 8, 9] (Table 19.2). Extravasations treatment is not standardized and remains variable and highly individualized [8, 10, 11]. We used a therapeutic protocol, standard, conservative, and valid for the extravasation of all the antiblastic drugs, administered both in monochemotherapy and polychemotherapy [12–14] and for extravasation occurring in neonatal intensive care. It founds its rational explanation because it addresses immunosuppressed and psychologically fragile patients. Furthermore, the drug dilution interrupts the chain of events leading to ulcer chronicization. It can be also used in neonates because it is minimally invasive [15].

19.1 Introduction

19.1.1 Chemotherapy Extravasation

Extravasation of an antiblastic drug is defined as the iatrogenic injury due to the chemotherapy extravasation from the vessel occurring during the infusion therapy [16].

The antiblastic drugs lead to tumor cell death, but, at the same time, they are able to damage

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Table 19.1 Classification of chemotherapy drugs according to their ability to cause local damage after extravasation

	DNA-binding	Non-DNA binding
Vesicants	*Alkylating agents* Mechlorethamine Bendamustine *Anthracyclines* Doxorubicin Daunorubicin Epirubicin Idarubicin *Antibiotics* Dactinomycin Mitomycin	*Alcaloids of Vinca* Vincristine Vinblastine Vindesine Vinorelbine Vinflunine *Taxanes* Docetaxel Paclitaxel *Others* Trabectedin Cabazitaxel Trabectedin
Irritans	*Alkylating agents* Carmustine Ifosfamide Streptozocina Dacarbazine Melphalan *Antracyclines* Liposomal oxorubicin Liposomal aunorubicin Mitoxantrone *Topoisomerase II inhibitors* Etoposide Teniposide *Topoisomerase I inhibitors* Irinotecan Topotecan *Antimetabolites* Fluorouracil Platinum salts Carboplatin Cisplatin Oxaliplatin	
Non-vesicants	Arsenic trioxide Asparaginase Bleomycin Bortezomib Cladrabine Cytarabine Eribulin Etoposide phosphate Gemcitabine Fludarabine Interferons Interleukin-2 Methotrexate Monoclonal ntibodies Pemetrexed Pentostatin Raltitrexed Temsirolimus Thiotepa Cyclophosphamide	

Table 19.2 Risk factors for extravasation

Infusion procedure-related	Type of catheter Cannula size selection Poor cannula fixation Unfavorable cannulation site (hand dorsum, antecubital fossa, site in proximity of joints, tendons, and neurovascular fascicules) Multiple attempts at cannulation Duration	*Pharmacological factors* Type of drug Excipients Osmolarity Concentration Volume Ph Vasoconstrictive potential Cytotoxicity
Patient-related	Skin color Hypotension Obesity *Extreme ages* (fragile veins, in child and old people, altered mental status) *Communication difficulties of pain* (sedation, intubation, young children) *Endothelium alterations*(elderly patients, atherosclerosis, arterial hypertension, advanced diabetes)	*Conditions associated with impaired circulation* Raynaud syndrome, Diabetes mellitus, superior cava syndrome, severe peripheral vascular disease, lymphedema, radiodermatitis Excessive patient movements, blood clot formation at cannula site
Staff-related	Inexperienced staff Knowledge lack of vesicant drugs Distraction or missing check during infusion and/or during shift change	

Common Terminology Criteria for Adverse Events, CTCAE, V5

also the healthy tissue, involving vessels, nerves, tendons, and muscles with severe sequelae [17].

Between the 1940s and the 1970s, the antitumor drugs were administrated in monochemotherapy for a palliative scope in case of advanced cancer always following surgery and/or radiant therapy. In the 1960s and early 1970s, a major breakthrough in cancer therapy occurred. The use of multiple drugs administered simultaneously in polychemotherapy showed encouraging results. It was at this time that the reporting about antiblastic drugs extravasation was common. Chemotherapy agents may be classified according to their ability to cause local damage after extravasation into three categories: vesicants, non-vesicants, and irritants (Table 19.1) [17, 18].

"Vesicants" are agents that have the potential to cause blistering, skin sloughing, tissue necrosis, and a diffuse damage to the perivasal tissue. They can be sub-classified into DNA-binding drugs and DNA-non-binding drugs. The agents that bind to the DNA in the cells are responsible of prompt cell death and, by remaining in the tissue, lead to a progressive tissue injury and necrosis. The components of the drug are released from dead cells in the tissue and are taken up by adjacent healthy cells through endocytosis. This process of cellular uptake of extracellular substances sets up a continuing cycle of tissue damage, and the drug is retained in the tissue for a long period and recirculates in the surrounding area. The wound healing process is obstacled by the progressive tissue damage, and extravasation lesions become larger in size, deeper, and more painful over time resulting in chronic ulcer. Agents that are not bound to DNA are metabolized in the tissue and more easily neutralized than DNA-binding agents. They generally don't cause tissue necrosis; the damage they cause remains localized, and it is associated with a mild-to-moderate pain. Tissue repair follows a normal healing process [10]. "Non-vesicants" do not cause inflammation or tissue necrosis. The "irritants" can cause pain at the infusion site and along the course of the vein chosen for the infusion. They may be responsible for painful local irritation of the venous endothelium, with reflexive vasospasm, which can cause obstacle to blood flow with a high risk of extravasation. They are often associated with chemical phlebitis.

Risk factors for extravasation are related to the chemotherapeutic agent, infusion procedure, patient, and staff [8, 9] (Table 19.2). Peripheral rather than central venous administration of antineoplastic agents is more likely to be associated with frequent cannulation, which is a risk factor for extravasation, and this should be avoided. There are various patient factors that contribute to the aetiology of extravasation injuries. Veins of people receiving chemotherapy for cancer are often fragile, mobile, and difficult to cannulate

[8–10]. Patients who receive chemotherapy at the same site as radiotherapy may experience a reactivation of skin toxicity known as "recall" phenomenon [19], and patients who have had an extravasation and receive further chemotherapy in a different site may experience an exacerbation of tissue damage in the original site [20, 21]. Patients who have undergone radical mastectomy, axillary surgery, or lymph node dissection may have impaired circulation in a particular limb, which reduces venous flow and may allow intravenous solutions to pool and leak out.

Sites most often implicated in extravasation injuries include the dorsum of the hand and foot, ankle, antecubital fossa, and near joints or joint spaces [1, 2, 5].

There is no standard treatment for the acute phase of extravasation injury. Treatment protocols for extravasations vary from conservative to aggressive management of the acute injury [2, 8, 10, 12–14, 16], with additional variations in wound management.

19.1.2 Extravasation Injury in Neonatal and Pediatric Patients

Extravasation injury represents a complication commonly seen in the neonatal intensive care unit, and it can cause scarring with cosmetic and functional sequelae. Most injuries (70%) occurred in infants of 26 weeks gestation and less [3, 4].

IV fluids and medications commonly implicated in extravasation injuries include parenteral nutrition fluids, cytotoxic drugs, vasopressors, inotropes, electrolytes (e.g., calcium chloride), and hyperosmolar medications. The most frequent causative agents are parenteral nutrition and IV antibiotics [3, 4, 22]. The neonatal and pediatric population is more susceptible to extravasation injuries, due to their smaller and thus more fragile veins. Further, their immature and fragile skin is predisposed to a major gravity of the damage. Newborns are also unable to express to the medical staff any pain they are suffering; therefore, inadvertent continuous infusion increases the risk for extravasation. These tiny patients require especially effective pressure-sensitive equipment for the early detection of extravasation injury, and an invasive treatment should be avoided, whenever possible. Common sites of extravasation injuries in neonatal and pediatric patients include the dorsum of the hand, the forearm, the cubital fossa, and the dorsum of the foot and scalp. These are the areas of the body where the skin and subcutaneous tissue are thinnest, which makes them the most suitable sites for IV access but also the most susceptible to injury [3, 4, 23]. However, no site is immune from the possibility of an extravasation injury.

19.1.3 Chemotherapy Extravasation Injury Classification

Extravasation injuries may range from erythematous reactions (Fig. 19.1) to skin sloughing and necrosis (Fig. 19.2). Early symptoms may be pain, itching, tingling, and burning sensation. Swelling, edema, erythema, induration, sloughing, and blistering could represent early signs (Fig. 19.3). Late signs may include ulceration and tissue necrosis (Fig. 19.4). According to the latest Common Terminology Criteria for Adverse Events [24], extravasation can be divided into five grades depending on the clinical gravity of damage because of toxic drugs (Table 19.3). Signs and symptoms are not always constant and do not always occur immediately after extravasation. In some cases, we can experience the so-called "silent" extravasation, showing signs of extravasation only a few days after the injury. If

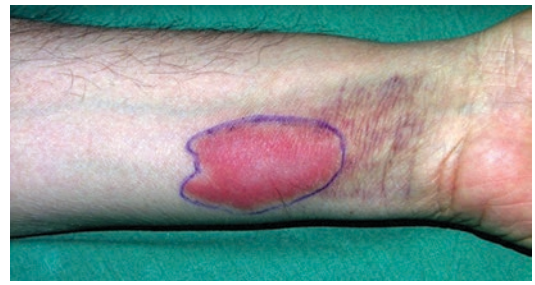

Fig. 19.1 Erythematous reaction after 6 days from extravasation marked with a dermographic pencil

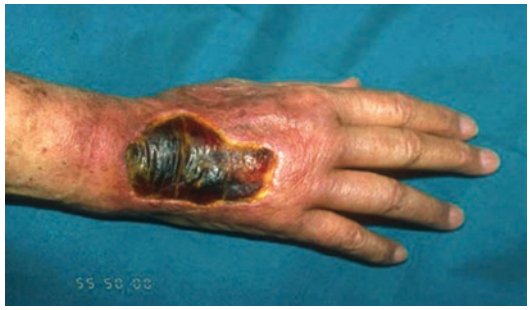

Fig. 19.2 Extensive tissue necrosis of the dorsum of hand after Doxorubicin extravasation

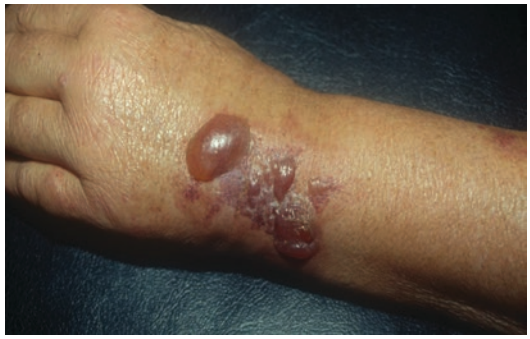

Fig. 19.3 Extravasation early signs: vesicles

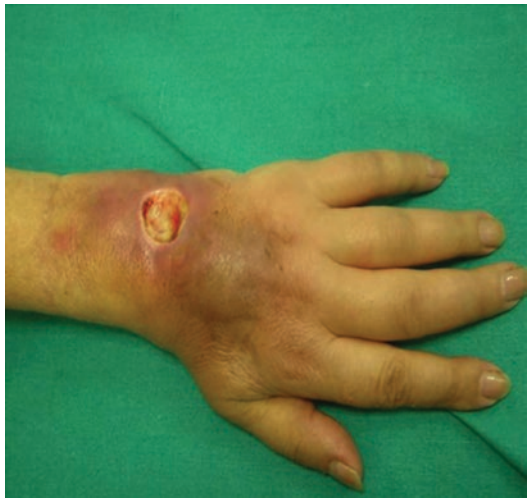

Fig. 19.4 Ulcer 1 week after anthracycline extravasation

the localized toxic action of the drug is not interrupted, the inflammatory lesion can be followed by tissue necrosis, with ulcer formation. The characteristics of an extravasation injury are the unpredictability of its evolution and the chronicity, because, depending on the type of agent, the substance responsible for the damage can be retained in the tissue for a long time [12–14].

Table 19.3 Extravasation injury classification

Grade	Clinical state
1	Painless edema
2	Erythema with associated symptoms (e.g., edema, pain, induration, phlebitis)
3	Ulceration or necrosis; severe tissue damage; operative intervention indicated
4	Life-threatening consequences; urgent intervention indicated
5	Death

19.1.4 Classification of Extravasation Injuries in Pediatric Patients [25–27]

They can be classified using an extravasation staging instrument with five stages:

- **Stage 0**. Absence of redness, warmth, pain, swelling, blanching, mottling, tenderness, or drainage. Flushes with ease
- **Stage 1.** Absence of redness and swelling. Flushes with difficulty. Pain at site
- **Stage 2.** Slight swelling at site. Presence of redness. Pain at site. Good pulse below site. 1–2 s capillary refill below site
- **Stage 3.** Moderate swelling above or below site. Blanching. Pain at site. Good pulse below infiltration site. 1–2 s capillary refill below site. Skin cool to touch
- **Stage 4.** Severe swelling above or below site. Blanching. Pain at site. Decreased or absent pulse. Capillary refill greater than 4 s. Skin cool to touch. Skin breakdown or necrosis

A staging system for grading injury severity is useful in guiding assessment, predicting injury prognosis, and determining a prompt treatment.

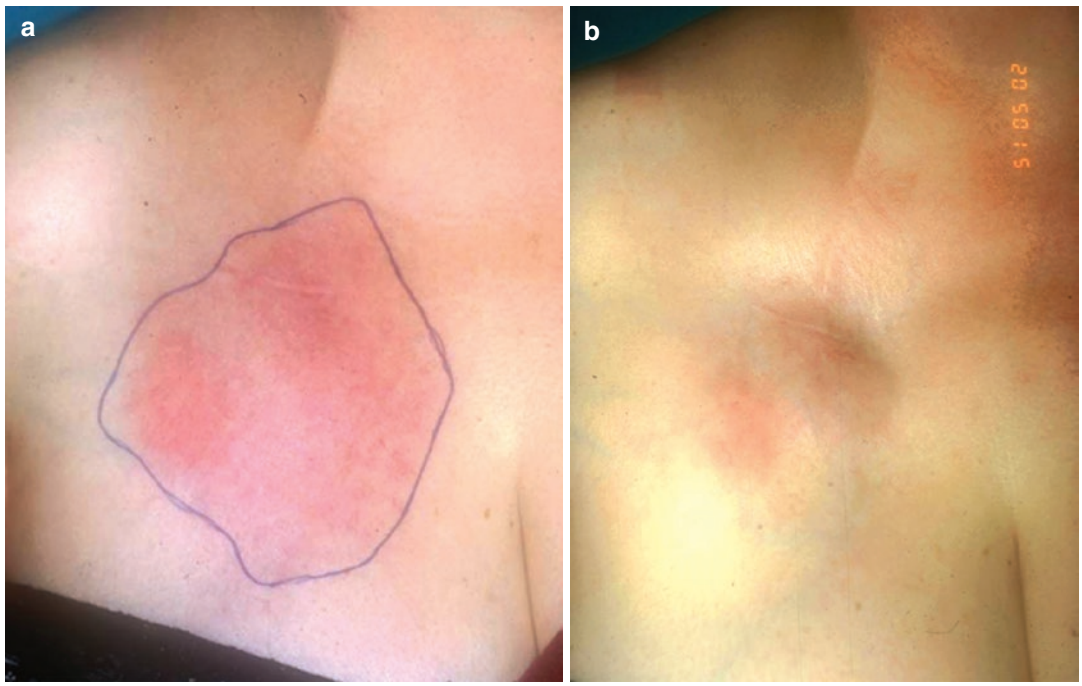

Fig. 19.5 (**a**) Antiblastic extravasation injury after 11 h on the site of central venous access marked with a dermographic pencil. (**b**) Result after saline infiltration, 2 weeks after the injury

19.2 Key Points

19.2.1 Extravasation Management

There is no consensus on the best approach to management, with guidelines offering conflicting recommendations [2, 8, 10, 12–14, 16, 28].

Step 1: Stop the infusion immediately when extravasation occurs or is suspected.

Step 2: Slowly aspirate as much of the drug as possible, without exerting pressure on the extravasation site (the aspiration may help limit the extent of tissue damage).

Step 3: Remove IV access, and mark the extravasation area with a dermographic pencil to monitor its evolution (Fig. 19.5a, b).

Step 4: Dilution with saline solution.

Step 5: Limb elevation in case of chemotherapeutic agents' extravasation on upper or lower extremities.

Step 6: Administer systemic analgesics, if necessary.

A meticulous documentation is crucial: record date and time of the extravasation, name of the drug extravasated, signs and symptoms (also reported by the patient), description of the IV access, extravasation area (and the approximate amount of the drug extravasated), and management steps with time and date. Photographic documentation can be helpful for follow-up procedures.

19.2.2 Technique of Saline Solution Infiltration [12–15]

19.2.2.1 Adults

In all cases of infiltration, the IV infusion should be stopped promptly, and any constricting bands or tapes should be removed.

The therapeutic protocol consists of infiltration of a 0.9% sterile saline solution at subcutaneous level within and around the affected area (marked with a pen) under sterile conditions. The

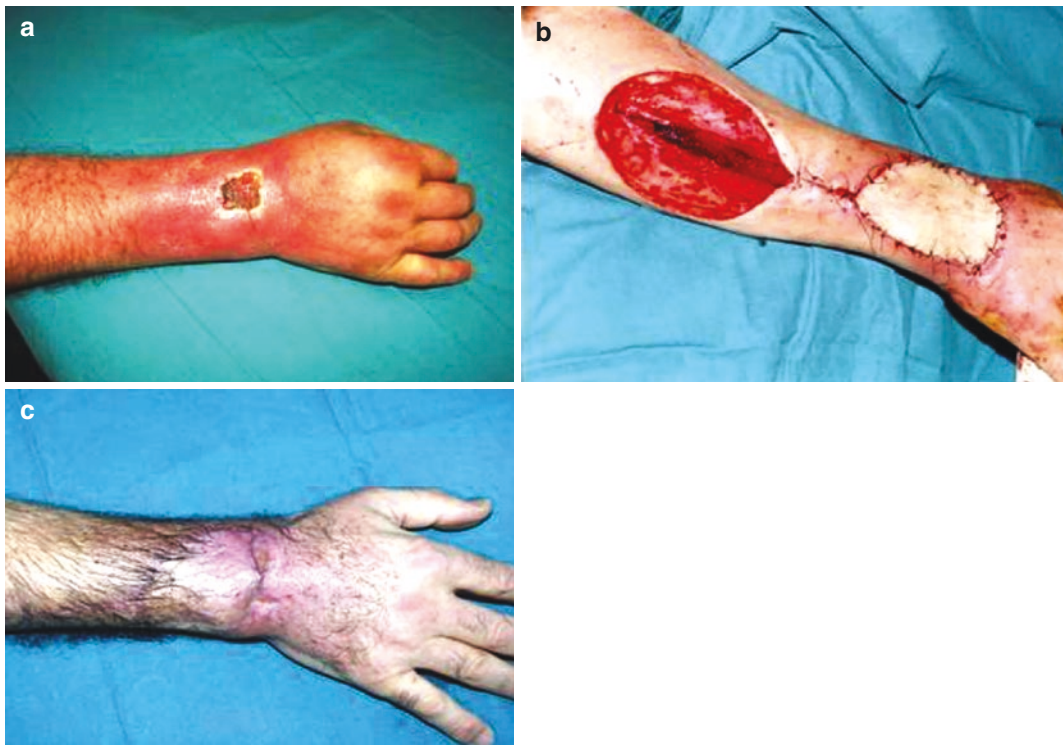

Fig. 19.6 (**a**) Ulcer of the dorsum of the wrist after extravasation of antiblastic drug in a 58-year-old male patient. (**b**) Repairing with regional pedicled flap. (**c**) Result at 6 months

amount of saline solution is around 20–30 mL for the hand; 20–50 mL for the forearm; and 40–90 mL for antecubital fossa. After infiltration, application of a steroid cream is provided. The infiltration is usually administered three times a week until clinical improvement. The affected area is covered with sterile gauzes and a bandage. In case of ulceration and necrosis observed at baseline, a debridement using chemical collagenases based on hyaluronic acid and/or escharotomy should be performed. Where primary closure was not possible, autologous skin graft, dermal substitute, local and regional pedicled flaps (Fig. 19.6a–c), and free flap should be considered depending on defect size.

19.2.2.2 Neonates and Infants

The saline solution injected is in total up to 10 or 20 mL; it is infiltrated around the affected area, with a thin needle, delivering a small amount of saline solution per each site of injection. In case of edema and extended lesions, a washout technique should be performed. This technique consists of infiltration of saline solution that allows irrigation of the wound and free flow drainage of the extravasated fluid through small skin puncture holes made with a needle in the area around the lesion. Silver sulfadiazine should be used in case of blistering and to prevent infections. In some cases, it is possible to observe eschar formation at 1 or 2 weeks after extravasation. This is treated with collagenases or escharotomy. In cases of partial- and full-thickness wounds, application of our treatment protocol and autologous skin grafts, dermal substitute, or local flaps can be used to repair the injuries. Neonates and infants are vulnerable populations requiring special attention, and every procedure should be as much minimally invasive as possible. The development of dermal substitutes and products of regenerative surgery allowed us to choose for less traumatic therapeutic options. They may acceler-

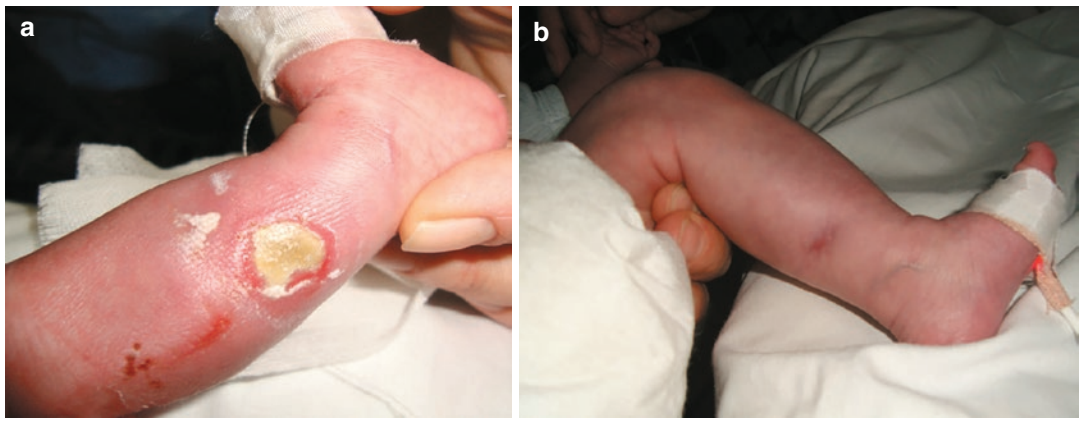

Fig. 19.7 (**a**) Estravasation injyry due to hypertonic solution. (Reproduced with permission from Wolters Kluwer Health, Inc.) (**b**) Result at 21 days following wound debridement and application of dermal substitute. (Reproduced with permission from Wolters Kluwer Health, Inc)

ate the wound healing process and finally delay and sometimes avoid more invasive surgical procedures [15, 29] (Fig. 19.7a, b).

Tips and Tricks

Central rather than peripheral administration of fluids/drugs should be preferred: peripheral rather than central venous administration of a fluid/drug is more likely to be associated with frequent cannulation, which is a risk factor for extravasation, and this should be avoided.

Veins of appropriate caliber should be chosen; tortuous, fragile, and tiny vessels are at a major risk to develop extravasation.

The site of cannulation should be chosen appropriately: joints and creases should be avoided as these often represent a "small" anatomical space, with nerves and tendons present. Avoid veins located on the dorsum of the hand, antecubital fossa, and all sites in proximity of joints, tendons, and neurovascular fascicles.

Avoid cannulation where there is little soft tissue protection for underlying structures.

Any constricting bands or tapes should be avoided above the area chosen for cannulation: they could represent obstacles to the flow.

Pearls and Pitfalls

Dilution with saline solution should be started as early as possible. It is especially effective when performed within 6 h of the extravasation injury occurring. One of the limits of this technique is the theoretical delay between the extravasation and the prompt treatment. Nevertheless, it is useful even within weeks following the extravasation, especially in cases misdiagnosed with phlebitis.

An experienced personnel is imperative: a nursing staff capable of early recognizing the extravasation injury is crucial. Personnel should have adequate knowledge of the causative agent. Nurses should be educated on the risk factors, preventative strategies, and treatment of drug/fluid extravasations, as well as practice safe and proper administration techniques. An early prevention may limit the severity of the damage.

The infusion should be slow and regular: a regulated delivery of intravenous fluids from continuous infusion pumps (usually limited to an hour at a time) may prevent the inadvertent infiltration of a large amount of fluid before detection.

If patients lament pain, infusion should be stopped, and the intravenous cannula

should be aspirated immediately: very often, an early warning sign of extravasation is represented only by pain.

Transparent bands should be used especially in neonates and infants: dressing to prevent movement could obscure possible swelling or erythema.

Take-Home Message

- Despite all the means we have at our disposal to prevent the leakage of antiblastic drugs/fluids outside the vein during infusion, extravasation is still possible, and it remains associated with very severe damages.
- Early recognition and treatment represent the most effective guns to avoid the probable deriving injuries.
- It becomes fundamental that nurses performing the infusion had appropriate theoretic knowledge and good practice.
- Extravasation can occur even after some days following the infusion, so if the patient notices an erythematous area at the site of the infusion, the physician should visit the patient as soon as possible to perform the therapeutic protocol.
- Extravasation is to be treated with all the possible therapeutic options at our disposal, to guarantee the better quality of life, never forgetting that the best therapeutic strategy is prevention.

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Radiodermatitis: Prevention and Treatment

20

Diego Ribuffo, Federico Lo Torto, and Marco Marcasciano

Background

Skin alterations due to radiation were reported since the beginning of the twentieth century. They have been associated with various diagnostic and interventional medical procedures and occupation-related environments. Above all, radiotherapy used in cancer treatment represents the main cause [1].

In 2018, there were more than 18 million of total cancer cases estimated worldwide [2]. About 50% of them are scheduled for radiation therapy, and some degree of radiodermatitis will occur in 95% of cases [3]. In particular, skin problems arise when head and neck region, perineum, or breast cancers are treated with ionizing radiation [4]. Patient's well-being and quality of life can be impaired by these side effects, and their cancer treatment may be inappropriate if pauses or quit of therapy becomes necessary [5].

20.1 Introduction

Ionizing radiations cause both direct cellular damage acting on DNA and proteins and indirect damage, thanks to reactive oxygen species creation. According to the fundamental law of radiobiology "Law of Bergonié and Tribondeau," actively proliferating cells as stem cells or epidermis basal cells are particularly radiosensitive [6]. Therefore, the skin presents a great susceptibility to radiation-induced damage [7].

Key Point

Being composed of actively proliferating cells, the skin is particularly a radiosensitive organ.

Skin pathologic changes due to ionizing radiations are commonly defined as radiodermatitis (RD), and they occur as a deterministic effect, when the threshold level of exposure is surpassed [8]. Severity and progression of damage depend on treatment-related and patient-related risk factors. Total radiation dose, its fractionation and type of external beam, irradiated site and surface area, eventual radiosensitizers, and chemotherapy are all treatment-related factors, while ethnicity, sex, age, body mass index, smoking habit, comorbidities, ultraviolet exposure, hormonal

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status, and genetics represent patient-related factors [9].

Due to great variability in timing and assessment of RD's presentation, it is fundamental to rule out differential diagnosis and exclude cases of contact dermatitis, dermatophytosis, radiation recall dermatitis and some cutaneous hypersensitivity syndromes as erythema multiforme, Stevens–Johnson Syndrome, and toxic epidermal necrolysis [10].

20.2 Clinical Presentation and Classification

According to timing of appearance, RD is defined acute when it occurs within the first 90 days of ionizing radiations exposure. The most common symptom is erythema, reported in more than 90% of patients [11]. Erythema may be transient if it occurs in the first 24 h, while it is more stable in time when it appears in the first month, along with dryness, hair loss, and hyperpigmentation. Twenty Gy is considered the threshold for dry desquamation development within 2 months after treatment. Skin dryness becomes even worse if radiation dose reaches 40 Gy, leading to pruritus, scaling, and flaking. Edema and bullae formation can cause dermis exposure with fibrinous exudate. This moist desquamation occurs in 30% of patients. Necrosis of the dermis can lead to pain, ulcer development, and infection [12].

Skin alterations that happen over 90 days after exposure are defined as chronic RD) [13]. The main clinical presentations include skin atrophy, fibrosis, telangiectasia, altered pigmentation, "dry papery skin" (tissue atrophy), dermal sclerosis, and tissue necrosis [14, 15]. Along with chronic RD, there comes a risk of 20–30% for secondary malignant tumor development, as sarcomas and non-melanoma skin cancers (basal cell carcinoma, keratoacanthoma, squamous cell carcinoma) [16–18]. Excessive and non-resting collagen and extracellular matrix components production characterize chronic RD, resulting in radiotherapy-induced fibrosis (RIF). Induration and thickening of dermal tissues are irreversible and progressive, and they can limit range of motion and significantly impair patient's quality of life [19].

Acute and chronic RD manifestations are not linked, and severity of acute injuries does not predict chronic RD development [20].

Key Point
RD is defined acute when it occurs within the first 90 days of ionizing radiations exposure, while skin alterations that happen over 90 days after exposure are defined chronic RD. Acute and chronic RD are not linked nor in occurrence nor in severity.

Accurate grading of pathologic lesions has purposes that go beyond the simple description of wound severity. It should give the possibility of early RD diagnosis, proper treatment, and precise monitoring in clinical trials. There are several classification systems proposed for RD clinical presentation. The most widely used scale in acute RD clinical practice is the National Cancer Institute's Common Terminology Criteria for Adverse Events (CTCAE), version 4.0, that assess injury from 0 to 4 (Table 20.1) [21].

Chronic RD is usually evaluated with the Radiation Therapy Oncology Group (RTOG)/European Organization for Research and Treatment of Cancer (EORTC) grading system [22] or the Late Effects Normal Tissue/Subjective, Objective, Management, and Analytic (LENT/SOMA) scale [23]. RTOG/EORTC tool can be applied in both acute and chronic RD grading (Table 20.2), while LENT/SOMA scale is the only one to evaluate pain intensity.

All these grading systems present large and simplified increments of 1, that fail to identify subtle pathologic changes. In order to capture these small RD developments, other scales have been introduced, as the Oncology Nursing Society (ONS) and Radiation Dermatitis Severity (RDS) scales [24, 25].

Despite the huge utility of these assessment tools, there is limited scientific evidence supporting their reliability. Therefore, more than

Table 20.1 CTCAE 4.0 grading of acute radiation dermatitis

Grade	Clinical presentation
0	No change over baseline/no symptoms
1	Faint erythema or dry desquamation
2	Moderate to brisk erythema, patchy moist desquamation, mostly confined to skin folds and creases, moderate edema
3	Moist desquamation other than skin folds and creases, bleeding induced by minor trauma or abrasion
4	Life-threatening consequences, skin necrosis or ulceration of full-thickness dermis, spontaneous bleeding from involved site, skin graft indicated

Table 20.2 RTOG/EORTC scale assesses both acute and chronic RD

Grade	Acute RD clinical presentation	Chronic RD clinical presentation
0	No change over baseline/no symptoms	No change over baseline/no symptoms
1	Follicular, faint, or dull erythema Epilation; dry desquamation Decreased sweating	Slight atrophy; pigmentation change; some hair loss
2	Tender or bright erythema Patchy moist desquamation Moderate edema	Patchy atrophy Moderate telangiectasia; total hair loss
3	Confluent, moist desquamation other than skin folds; pitting edema	Marked atrophy Gross telangiectasia
4	Ulceration; Hemorrhage; Necrosis	Ulceration

one scale should be used in order to precisely assess patient's skin damage due to ionizing radiations [26].

20.3 Prevention and Treatment

To date, there is no universally validated consensus for RD prevention and treatment. Every country and every single department have adopted different management strategies based upon various studies and personal experience [19]. In 2013, the Multinational Association for Supportive Care in Cancer (MASCC) published a review and proposed some general clinical guidelines for acute and chronic RD management [26].

Key Point

To date, there is no consensus for RD prevention and treatment, but Multinational Association for Supportive Care in Cancer (MASCC) published some general clinical guidelines.

For what concerns preventive measures, despite hygienic procedures with soap and deodorants were not allowed traditionally, recent studies have brought evidence that indeed recommend gentle washing practices of the exposed areas with mild soap and shampoo. Moreover, antiperspirant deodorants are not forbidden, as their toxicity failed to be proven.

In case of the appearance of initial symptoms as burning or itching, topical steroids (e.g., mometasone) are strongly recommended.

Alternative nonsteroidal anti-inflammatory agents as Trolamine or aAloe vVera received strong recommendations against their use in prophylaxis and treatment of RD. The same advice was given against the use of silver leaf dressings.

Other agents that were diffusely used in ionizing radiation damage prevention did not collect sufficient proofs to confirm their efficacy. Therefore, sucralfate, hyaluronic acid (HA), Aquaphor, ascorbic acid, almond oil, dexpanthenol, and calendula are neither recommended nor forbidden in these patients. The same lack of evidence is reported for light-emitting diode laser (LED) treatment use.

Pearls and Pitfalls

The only preventive topic treatments recommended for RD are:

- Mild soap and shampoo
- Topical steroids

Similarly, systemic oral therapy with proteolytic enzymes as papain or trypsin, oral sucralfate, zinc, and pentoxifylline is not supported by sufficient evidence to recommend its preventive usage in radiated patients.

In order to prevent skin damages in women that undergo radiotherapy for breast cancer treatment, the MASCC panel evidenced weak recommendation supporting the use of silver sulfadiazine cream.

Regarding RD treatment, various wound dressings have been proposed along the years: dry dressing, hydrous lanolin gauze, hydrocolloid dressings, moisture vapor permeable dressings (Tegaderm™), and gentian violet-based dressing. Despite their diffusion, the recent review did not find evidence pro- or against those dressings' efficacy. Alike, less known topic agents as sucralfate cream, hydrocortisone, honey, and trolamine did not met sufficient evidence for their recommendation.

Facing chronic RD effects, long-pulsed dye laser (LPDL) has been proven to have light efficacy treating telangiectasia.

Pentoxifylline and vitamin E have been used in an attempt to treat radiotherapy-induced fibrosis (RIF), but there is insufficient evidence to support a recommendation for or against them, at present. Other therapeutic options have been proposed for the difficult management of RIF, such as physiotherapy, pharmacotherapy, hyperbaric oxygen, and laser therapy, but they all lack scientifically proven efficacy.

There is no standard management protocol for chronic RD-induced skin ulcers. A multidisciplinary approach is useful, in selecting the most suitable treatment. The radiation oncologist, wound care specialist, dermatologist, and plastic surgeon should all take care of the patient [27].

In cases of chronic ulcers that do not respond to ambulatory wound dressings, surgical debridement is required, in order to clean the wound's bed and stimulate the healing process. In severe cases, surgical coverage becomes mandatory. Skin grafts represent a safe and easy-to-perform solution, but their use is limited. Radiated tissues present compromised vascularization even in peripheral areas that do not present clinical signs of damage. Scarce vascularization reduces grafts' survival abilities and makes their use limited to chronic ulcers of the hands' dorsum in professional RD.

Pedicled flaps, myocutaneous flaps in particular, may be used to cover the injury with non-radiated and well-vascularized tissue (Figs. 20.1 and 20.2).

Free flaps are hazardous in these patients for their vascular impairment, but technical innovations are making microsurgery applicable in chronic RD treatment [28–30]. Indeed, ionizing radiation is associated with fibrosis, impaired tissue healing, and diminished vascularity. Wide tissue excision is necessary before a free flap is transferred, and vascular anastomosis has to be performed at certain distance from radiated site, for a reliable recipient vessel may be hard to find and dissect (Figs. 20.3, 20.4, and 20.5) [31].

Key Point
Radiated tissues present compromised vascularization even in peripheral areas that do not present clinical signs of damage. Before reconstruction with a free flap, radiated tissues must be excised widely, in order to find reliable recipient vessels for vascular anastomosis.

In 2007, Rigotti et al. were the first to show the beneficial effects of fat grafting in irradiated skin [32]. Since then, therapies based on autologous stem cells gained popularity in chronic RD management. Autologous adipose tissue grafts are easily harvested, and they contain stem/progenitor cells (ASC) in the stromal vascular fraction. Once injected in the radiated tissue, ASC organize and differentiate, thus promoting the secretion of soluble factors that enhance angiogenesis, decrease apoptosis, and/or modulate the immune response [33, 34]. Fat grafting has been largely used in chronic RD management: non-healing ulcers [35], radiation-induced skin fibrosis [36], and radiation-induced joint contracture [37] showed encouraging improvements after treatment.

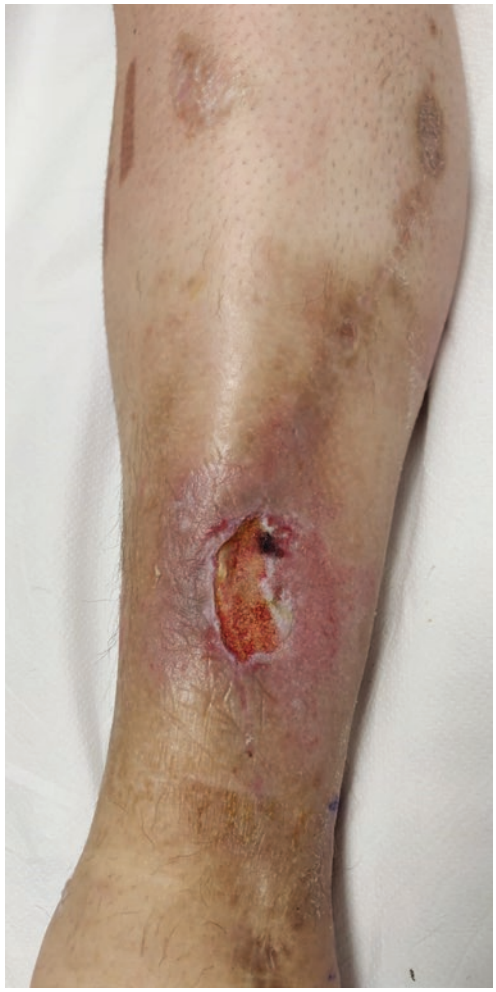

Fig. 20.1 Chronic ulcer of the leg in a patient suffering from sarcoma of the tibialis anterior muscle and underwent radiation therapy. Four years after, he presented with chronic RD with non-healing ulceration

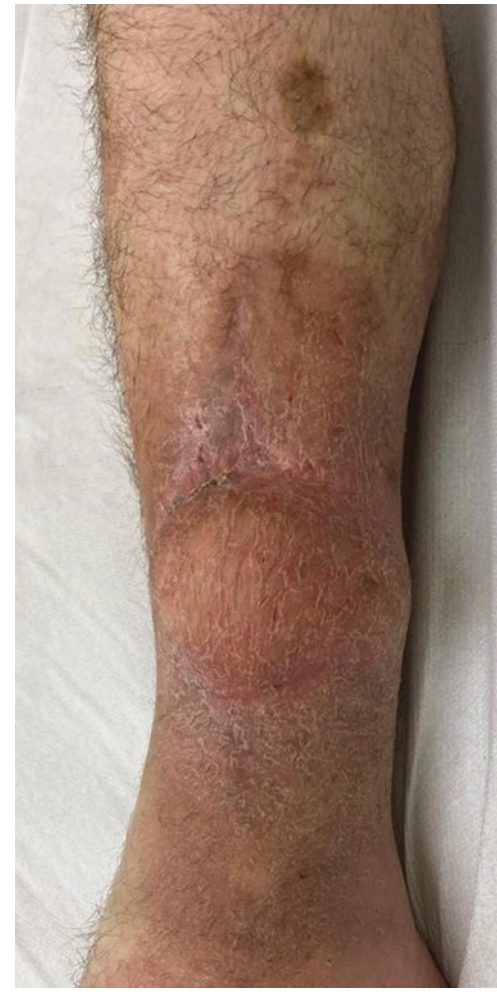

Fig. 20.2 After accurate wide surgical debridement, coverage was achieved with pedicled myocutaneous sural flap

Regarding breast cancer patients, both mastectomies and implant-based reconstruction rates presented constant increase in the last decades [38–40]. As a consequence, immediate and delayed complications caused by post-mastectomy radiotherapy are increasing as well. Capsular contracture, infection, ulceration, and implant exposure represent the radiation therapy-related complications that breast cancer-survival patients have to face. Capsular contracture, in particular, represents a frequent adverse event of radiation therapy, and it leads to breast distortion, pain, and unsatisfactory aesthetic appearance.

The exact pathogenic mechanism underlying capsular contracture is still unknown, but it is considered a multifactorial process, resulting from human body reaction, biofilm activation, bacteremic seeding, or silicone exposure [41]. In contrast with the numerous studies concerning the RT effects on biological tissues, only a few studies investigated the effect that ionizing radiation has on breast implants. The authors of the current session carried out multi-technique studies in order to characterize radiation-induced modifications in terms of surface morphology, mechanical properties, and material chemistry in breast implants that underwent standard and hypofractionated radiotherapy protocols [42, 43].

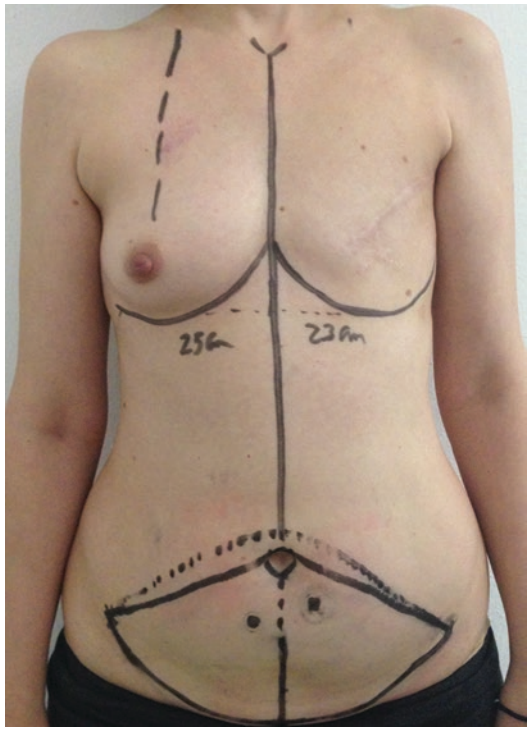

Fig. 20.3 Female patient that underwent skin-sparing mastectomy of the left breast, followed by radiation therapy. Two years after, she developed chronic RD with marked atrophy and telangiectasia. DIEP flap was scheduled for an autologous delayed breast reconstruction, and deep inferior epigastric perforators patency was assessed with CT angiography

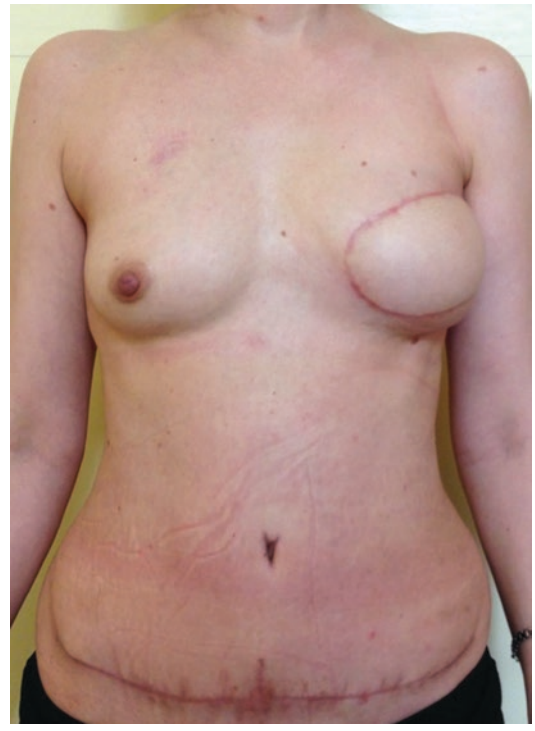

Fig. 20.5 Postoperative picture taken 2 months after surgery: thanks to a wide radiated tissue dissection and an accurate selection of reliable recipient vessels, the DIEP flap was transferred successfully

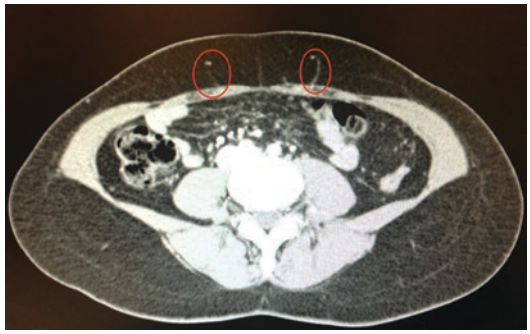

Fig. 20.4 Preoperative planning of D.I.E.P flap for left breast reconstruction and previous radiotherapy

These studies did not evidence significant mechanical or microstructural changes, while significant biomaterial modifications were registered, thanks to surface-sensitive spectroscopic techniques. They concluded that radiation-induced biomaterial alterations might play a role in the development of capsular contracture.

Key Point

It has been evidenced that ionizing radiation may induce biomaterial alterations in prosthetic materials, and they might play a role in the development of breast capsular contracture.

Tips and Tricks

Fat grafting protocol for the setting of immediate two-stage breast reconstruction in irradiated patients:

- Immediate sub-muscular reconstruction with temporary tissue expander.
- Two to six months after mastectomy, the patient undergoes radiation therapy.

- Six weeks after finishing radiotherapy, one or two sessions of lipofilling are scheduled.
- Three months after lipofilling, the patient undergoes the second reconstructive surgery: capsulectomy is performed in the lower part of the anterior capsule, and the expander is substituted with definitive prosthesis (Figs. 20.6, 20.7, and 20.8).

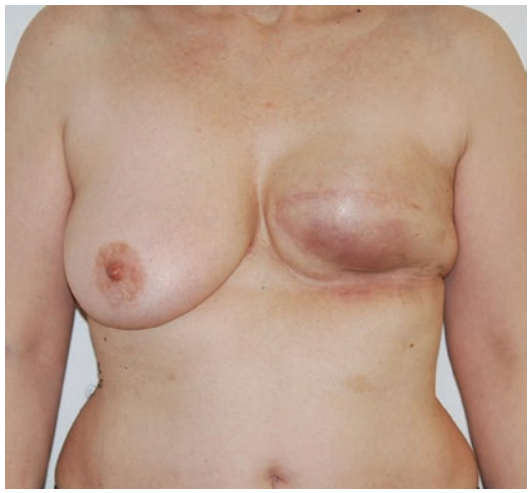

Fig. 20.6 A female patient underwent left breast mastectomy and immediate reconstruction with sub-muscular tissue expander. After radiation therapy, she presented chronic RD with breast distortion, pain, and capsule contracture

Following this successful trend, the authors identified some "key areas" on the expanded irradiated breast: they measured the irradiated tissue thickness to create a standard pattern of protective lipofilling infiltration that could re-establish a thickness similar to non-radiotreated tissue. This maneuver allowed to create a protective "fat belt" over the pocket that will host the definitive implant about 3 months after the fat grafting [44]. Thanks to the encouraging results of lipofilling in irradiated breasts, radiotherapy is no longer considered a contraindication to breast reconstruction.

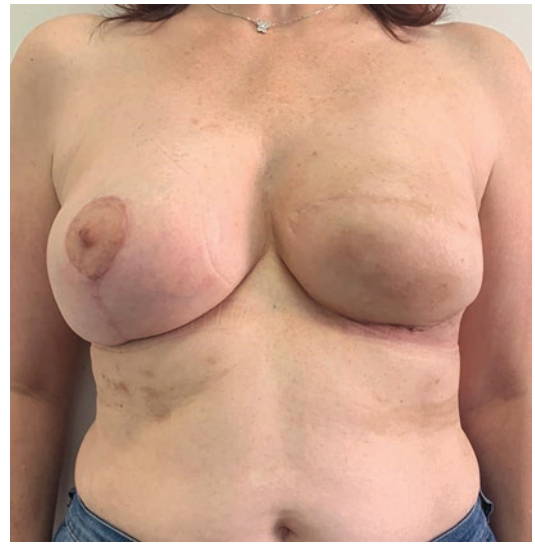

Fig. 20.7 The patient underwent authors' protocol for breast RD management: after one session of fat grafting over the irradiated breast with tissue expander, the second reconstructive timing was carried out. The expander was substituted with definitive prosthesis together with contralateral mastopexy

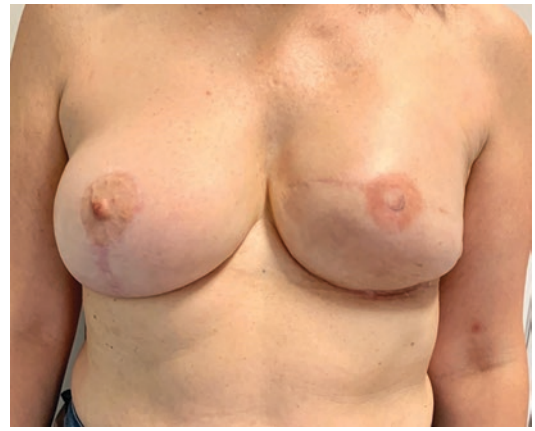

Fig. 20.8 Postoperative picture taken 1 year after definitive surgery: bilateral symmetry was achieved, and aesthetic appearance was improved with 3D nipple tattoo

Take-Home Messages

- Radiodermitis (RD) defines skin alterations due to radiation that can be acute or chronic.
- There is no universally validated consensus for RD prevention and treatment.
- Hygienic procedures with soap and deodorants are recommended as preventive measures.
- In case of RD-induced skin ulcers, various wound dressings are at disposal, but surgical debridement and coverage with pedicled myocutaneous flaps and free-flaps may become necessary.
- Autologous adipose tissue grafts contain stem cells and are used in managing breast RD complications, induced by post-mastectomy radiotherapy.

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Maxillofacial Surgery

21

Giuseppe Giudice and Erica Tedone Clemente

Background
The interest and treatment of craniofacial traumas are a recent acquisition. As a matter of fact, just in 1901, a French surgeon, René Le Fort, introduced a systematic classification for these traumas. Nevertheless, most of the patients would not reach treatment, because of the high mortality in case of high-energy traumas. Thanks to the introduction of newer safety systems, the improvement of the intensive care, and the introduction of higher-accuracy radiologic exams, such as the CT scan, a higher number of patients would survive, and, for this reason, better identification and treatment strategies were needed.

21.1 Introduction

Considering the treatment of craniofacial traumas, it is essential to perform an accurate "emergency" treatment (first aid at the site of the accident) and an "urgency" treatment as it is preferable to perform surgery within 24–48 h from trauma [1, 2].

A delayed surgery, in fact, usually evolves in unsatisfactory outcomes difficult to improve with secondary surgeries, also often more complex, and that sometimes cannot achieve a complete morpho-functional and aesthetic restoration for these patients.

In all patients with craniofacial trauma, given the high probability of finding associated injuries in other body districts, after evaluating the state of consciousness, the primary aim is maintaining the vital functions (Table 21.1).

21.2 Emergency Management

The patient affected by craniofacial trauma should be evaluated remembering the three levels of the diagnostic-therapeutic algorithms in emergency urgency:

1. At the site of the accident: "Primary diagnostic-therapeutic approach"
2. At the emergency department: "Secondary diagnostic-therapeutic approach"
3. At specialized trauma centers: "Tertiary diagnostic-therapeutic approach"

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Table 21.1 Glasgow coma scale (GCS). It is based on three types of response to stimuli (ocular, verbal, motor) and is expressed synthetically with a number whose sum indicates the patient's neurological status and evolution. The index can vary from 3 (A1-B1-C1) deep coma to 15 (A4-B5-C1) awake and conscious patients

Behavior	Response	Score
Eye opening response	Spontaneously To speech To pain No response	4 3 2 1
Best verbal response	Oriented to time, place, and person Confused Inappropriate words Incomprehensible sounds No response	5 4 3 2 1
Best motor response	Obeys commands Moves to localized pain Flexion withdrawal from pain Abnormal flexion (decorticate) Abnormal extension (decerebrate) No response	6 5 4 3 2 1

Minor brain injury, 13–15 points; moderate brain injury, 9–12 points; severe brain injury, 3–8 points; deep coma or death, 3

21.2.1 Primary Diagnostic-Therapeutic Approach

21.2.1.1 Upper Airway Obstruction

Obstruction of the upper airway requires immediate treatment at the site of the trauma. The severity of this event is linked to a state of hypoxia or hypercapnia which can cause "direct" brain damage due to neuronal suffering or an "indirect" injury due to an increase in respiratory efforts which can cause brain swelling and intraparenchymal bleeding leading to an increase of the intracranial venous pressure [3].

The causes of mechanical respiratory insufficiency for patients affected by craniofacial traumas can be due to:

- *Oropharyngeal obstruction* by liquid (vomit, blood, saliva) or solid (mold, teeth, dentures, bone fragments, foreign bodies). It is aggravated, in unconscious patients, by the loss of muscle tone and the absence of the laryngeal and pharyngeal reflex. For this reason, it is important to subluxate the mandible, force mouth opening, and remove any foreign bodies. If the presence of liquids is suspected, the patient must be placed in a lateral decubitus position.
- *Retroposition of the tongue*, caused by a hematoma of the floor of the mouth or, more frequently, by a bifocal fracture involving both parasymphysis of the mandible that causes a posterior displacement of the chin due to the loss of the anterior anchorage of the genioglossus and geniohyoid muscles. The tongue must be raised, anteriorly pulled and anchored to the teeth or cheek using a suture (in these cases, it is always useful to place a cannula of Mayo).
- *Occlusion of the oropharynx by the soft palate* due to back and inferior displacement of the maxilla in cases of Le Fort II–III fractures. Restoration of the airway patency can be achieved with a partial and forced manual reduction of the fracture, positioning the index and middle fingers of one hand inside the oropharynx, and pushing them posteriorly, with the thumb on the upper incisors and the other hand positioned on the forehead to stabilize the movement and exercise an opposite force; then, the reduction maneuver will be achieved pulling forward and upward. This maneuver, while not ensuring correct alignment of fractured segments, allows breathing restoration.

When patency of the upper airways cannot be achieved using these maneuvers, then we must rely on the endotracheal intubation.

21.2.1.2 Arrest of Bleeding

In patients showing craniofacial traumas, *hemorrhages* are due to skin wounds and/or lesions of vessels that run in the soft tissues or inside the bone channels. The bleeding wounds should be treated using sterile gauzes soaked in saline. In severe cases, the ligation of the facial artery may be necessary. A very serious circumstance is the rupture of the internal maxillary artery, the terminal branch of the external carotid artery, which runs into the pterygo-palatine

fossa. In this case, the external carotid ligation is necessary shortly after its origin from the common carotid.

Bleeding from the nasal fossae is much more frequent for these patients for obvious anatomical reasons. Epistaxis can be mono- or bilateral and is divided into:

– *Anterior*: due to lesion of vessels of the mucous membrane of the nasal septum and turbinates, caused by minor trauma. An anterior epistaxis is treated with an anterior nasal packing using Merocel™ nasal tampon, which is usually removed after 3–4 days.
– *Posterior*: due to lesions of the sphenopalatine artery, caused by major trauma. In this case, a posterior nasal packing should be performed, using a Bivona® catheter or, if not available, a Foley catheter. This packing is also maintained for a period not exceeding 3–4 days.

21.2.2 Secondary Diagnostic-Therapeutic Approach

Acquire the following:

- History
- Neurological evaluation (Glasgow coma scale)
- New cardiorespiratory assessment
- General examination
- Instrumental evaluation (CT scan, X-rays, etc.)

District clinical evaluation:

- Rhinorrhea
- Otorrhea
- Hemotympanum
- Subcutaneous hematomas
- Evaluation of the cranial nerves

In case of persistence of upper airway obstruction:

- Percutaneous/surgical tracheotomy
- Surgical cricothyroidotomy

21.2.3 Tertiary Diagnostic-Therapeutic Approach

"Multidisciplinary Center"

- Treatment of soft tissues
- Treatment of hard tissues

21.3 Maxillofacial Fractures

The first known author to classify facial fractures was Le Fort in 1901 [4]. Nowadays, fractures are more complex, because facial traumas are usually due to a greater energy. Patients' survival has increased due to safety systems, and they can receive surgical treatment. Therefore, the classification has been integrated with greater detail (thanks to a better diagnostic tool, such as CT scan).

Fractures of the facial skeleton can be classified using different systems of classification, such as dividing the facial skeleton into three horizontal thirds—upper, middle, and lower—(IMAGE) or considering fractures that can involve each district or bone, etc. Fractures can also be classified according to their characteristics (Table 21.2).

21.4 Fractures of the Upper Third

Fractures of the upper third mainly involve the frontal bone and can be:

Table 21.2 Classification of facial fractures according to their characteristics

Characteristics of facial fractures	
Simple Linear fracture line	*Complex* Bone is fragmented
Closed	*Open*
Incomplete Greenstick fracture	*Complete*
Non-displaced	*Displaced*
Un-complicated	*Complicated*
Without soft tissue involvement	*With soft tissue involvement*

- Isolated (squama, sinuses, roof, or supraorbital margin)
- Associated with fractures of other bones (nose, orbit, ethmoid)

Due to its structure, the frontal bone is the most resistant bone of the splanchnocranium; a fracture at this level requires a force 4–5 times greater than the force required to produce a fracture in the cheekbone or nasal bones. Such violent traumas can cause injuries to the noble structures, protected by the frontal bone, located in the anterior cranial fossa (frontal brain lobes).

Fractures usually occur at the level of the *loci minoris resistentiae*, such as the roof of the orbit and the frontal sinuses (up to 10% of all cranial fractures). In one third of the cases, the trauma causes a fracture only of the anterior wall of the sinuses; in the remaining two thirds of the cases, there is a fracture of the posterior wall, and the frontonasal ducts are involved. These fractures must be suspected and promptly treated in order to avoid relevant neurological complications (due to the frequent involvement of the frontal lobes and ocular globes) [5].

The frontal bone is often involved in the context of a trauma that also affects the nose and orbits (fronto-naso-orbito-ethmoid fractures) [6, 7]. Often, this kind of fracture is not diagnosed and therefore erroneously treated as a simple nasal fracture. Clinical examination must be thoroughly carried out to assess the presence of suggesting clinical signs that may be associated with those fractures of the frontal bone (Fig. 21.1).

21.4.1 Clinical Presentation

Clinically, the following can be observed:

- *Edema* of the frontal and eyebrow region.
- *Bruising* and/or conjunctival and eyelid *hematomas*, particularly in the presence of a fracture of the orbital roof.
- *Depressed areas*, especially in the case of fractures of the frontal sinuses or the supraorbital margin (uncommon finding due to generally massive soft tissue edema).
- Exophthalmos, with difficult complete closure of the eye and consequent corneal exposure; this clinical sign is characteristic of a displaced fracture of the orbital roof. Pulsating exophthalmos occurs due to transmitted brain pulsations.
- *Ptosis*, due to paralysis of the levator palpebrae superioris muscle with obstruction of the movements of the levator and upper rectus muscles.
- Diplopia, due to incarceration of the muscular bellies between the fractured segments, or due to paralysis caused by an involvement of the third cranial nerve caused by external compression (hematoma, bone fragment) or by direct damage.
- *Superior orbital fissure syndrome*: cluster of signs and symptoms due to a fracture of the orbital roof up to the upper orbital fissure, passage channel of the III, IV, and VI cranial nerve and the ophthalmic branch of the V cranial nerve. *Orbital apex syndrome*: due to the involvement of the optic foramen, the passage point of the optic nerve.

Pearls and Pitfalls

Superior orbital fissure syndrome:

- Paralysis of the muscles innervated by the oculomotor nerve: the levator palpebrae with ptosis, the superior rectus, the inferior rectus, and the inferior oblique
- Paralysis of the muscle innervated by the trochlear nerve: the superior oblique
- Paralysis of the muscle innervated by the abducens nerve: the lateral rectus
- Sensory deficit of the areas innervated by the ophthalmic branch of the trigeminal nerve: the eyebrow, the upper eyelid, the glabella, and the homolateral frontal skin

Orbital apex syndrome: superior orbital fissure syndrome + blindness

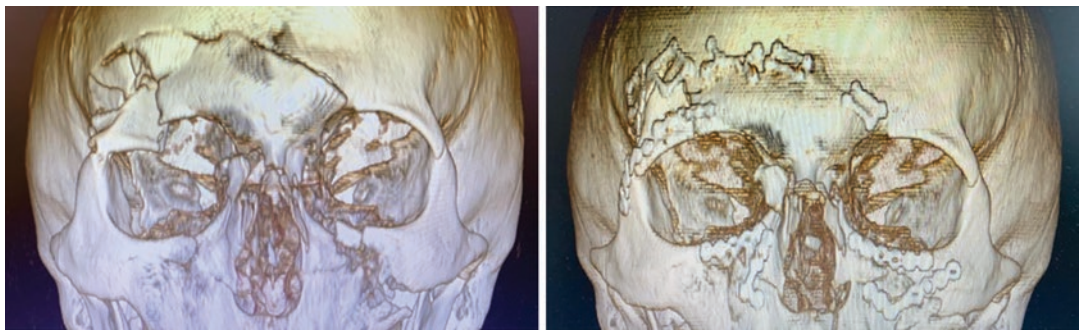

Fig. 21.1 Pre- and postoperative CT scan showing multiples and comminuted fractures of the frontal bone and midface fractures

- *Hypoesthesia* in the distribution area of the supraorbital nerve (branch of the ophthalmic n.)
- *Liquorrhea* due to the communication of the anterior cranial fossa with the orbital cavity or with the nasal and paranasal cavities
- *Neurological signs* due to frontal lobe involvement, such as alterations of the state of consciousness, spatial-temporal disorientation, and up to coma

In case of fronto-naso-orbito-ethmoid fractures, the following can also be clinically observed:

- *Saddle nose deformity*, which causes the characteristic upward rotation of the tip of the nose with subsequent traction of the upper lip filter.
- *Tension of the internal canthi* to palpation.
- Hypertelorism *and traumatic telecanthus* (intercanthal distance greater than 35 mm): respectively, an increase in the distance between the center of the eyes and the lateral dislocation of the medial canthal ligament. This clinical sign is often not visible due to the intense edema of the soft tissues, but it can be detected through the finding of an increased tension of the adjacent skin which causes an accentuation of the nasojugal groove.
- *Craniofacial disjunction* (LeFort III fracture) typical of bilateral fractures: the patient has the characteristic elongated facies.

The basic instrumental diagnosis is done using CT scan with axial and coronal projections for the identification of fracture sites and the evaluation of the involvement of soft tissues (frontal lobes, cranial nerves, eye muscles, ocular globes).

21.4.2 Surgical Treatment

The treatment of frontal bone fractures or fronto-naso-orbito-ethmoid fractures always involves an "open" reduction through a pre-existing wound or a surgical incision. The technique that allows effective exposure of the fracture sites is the coronal approach. This approach allows the combined surgeries of the maxillofacial surgeon and neurosurgeon. The frontal bone is completely exposed as well as the root of the nose, the upper supraorbital margin, and the frontozygomatic suture. Using this approach, lateral and medial walls of the orbits, and even the zygomatic arches, can be accessed. After bone synthesis with microplates and screws, the coronal flap is repositioned to cover the skull. The suture will result in a scar hidden by the hair.

Tip and Tricks

In the distal third of the frontal bone, the periosteum is peeled off to the supraciliary arches and the glabellar region: at this stage, it is important to identify and preserve the supraorbital nerves.

In order not to damage the frontal branch of the facial nerve, the dissection must be performed between the deep temporal fascia and the temporal muscle, taking care to lift the frontal flap without excessive traction, to reduce the time of any transient paresis.

Pearls and Pitfalls

A fracture of the frontal sinus can cause obstruction of the frontonasal duct by the bone fragments and consequent mucocele from accumulation of the secretions of the lining mucosa. The treatment of this complication involves the removal of the sinus mucosa, the obliteration of the nasal-frontal ducts with autologous (temporal fascia or muscle) or heterologous (hydroxyapatite) material, and the reconstruction of the frontal bone.

21.4.3 Complications

Early Complications

- *Brain lesions* can occur at the time of the trauma or subsequently. Primary post-traumatic expansive brain lesions, such as epidural, subdural, or intracerebral hematomas, begin to develop at the moment of impact and must be considered. Secondary brain lesions subsequently develop and include hypoxia, shock, intracranial hypertension, cerebral edema, and cerebral flow disturbances.

Late Complications

- *Mucocele* due to obstruction of the frontonasal ducts and accumulation of secretions inside the frontal sinuses.
- *Abscess forming of the mucocele* and propagation of the infectious process to the surrounding bone (osteomyelitis) or to the cranial content (meningitis, intra/or extradural abscess).
- *Depression of the frontal bone*.
- *Exophthalmos or enophthalmos*.
- *Diplopia*: it can appear even few days after the trauma; it will manifest in different fields of view according to the structures involved.
- *Telecanthus*
- *Damage to tear drainage*: disorders due to obstruction and/or interruption of the canaliculi and/or the lacrimal sac following penetrating wounds or comminuted fractures of the medial wall of the orbit; these can then result in cysts, skin fistulas, and abscesses.
- *Nasal deformity* (saddle nose, twisted nose).

21.5 Fractures of the Middle Third

The middle third of the face, due to its peculiar position, is involved in an ever-increasing number of traumas. Outcome of a high-energy impact, maxillofacial fractures are often multiple, comminuted, and involved in order of frequency: the orbital-malar-zygomatic complex (O.M.Z.C.) and the maxilla.

The classification described by Le Fort in 1901, although it is still valid from a didactic point of view, requires, in clinical practice, some modifications. Currently, numerous authors describe fractures based on the interest and involvement of the buttress systems [8].

Key Point

Buttress systems

Vertical (paired, one for each side)

- Nasomaxillary (NM)
- Zygomaticomaxillary (ZM)
- Pterygomaxillary (PM)

Horizontal/transverse

- Frontal bar
- Infraorbital rim and nasal bones
- Hard palate and maxillary alveolus

Sagittal

- Hard palate

Fractures of the middle third can be:

- Orbito-malar-zygomatic fractures

  Fractures of the orbital-malar-zygomatic complex (O.M.Z.C.) are frequently associated with maxillomandibular and/or cranial lesions. The clinical diagnosis of a fracture in this district can sometimes present difficulties as the soft tissue edema can prevent a precise physical

examination, hiding the signs of bone interruption. Even diplopia, often present, may not manifest immediately after the trauma as intra- and/or periorbital edema can support the ocular globe, keeping it in line for a few days.

- Maxillary fractures

  Less frequent than O.M.Z.C. fractures, being the maxilla less exposed to traumatic insults, these fractures occur due to traumas of particular intensity which are mainly exercised in an anteroposterior direction. Rarely isolated (sports injuries) are more frequently associated with fractures of other districts.
- Associated maxillo-orbital-malar-zygomatic fractures

  As a result of a high or medium energy, the maxillo-orbital-malar-zygomatic fractures are often associated with trauma of:
  - The anterior cranial fossa (due to an injury to the cribriform plate of the ethmoid or the anterior and/or posterior wall of the frontal sinus);
  - The middle cranial fossa with lesions of the petrous part of the temporal bone (associated with paralysis of the facial nerve)
  - The fronto-nose-orbital region
  - The mandible

These fractures, usually multiple and comminuted, are often very unstable and characterized by a remarkable hypermobility of the bone segments followed by a severe deformity of the skull and face.

21.5.1 Clinical Presentation

Clinically, the following can be noted:

- *Edema*.
- *Bruising*, both exterior and submucosal.
- *Epistaxis* following laceration of the mucous membrane of the nose or maxillary sinus and/or rupture of the sphenopalatine or ethmoid arteries.
- *Septal hematoma*.
- *Displacement of the external canthus* associated with subscleral hemorrhage
- *Pain*, spontaneous or not, is the constant symptom; it can be exacerbated by palpation of the fractures and/or during swallowing movements.
- *Diplopia*.
- *Enophthalmos* (blow-out fracture).
- *Exophthalmos* (blow-in fracture).
- *Hypertelorism/telecanthus*.
- *Depression* of the zygomatic bone or arch.
- *Limitation of the opening of the mouth* due to the interference between the coronoid process of the mandible and the posterior face of the depressed zygomatic arch.
- *Elongation and flattening* of the face with depression of the nasal pyramid and of the zygomatic regions associated with the deformation of the orbital region (flat face) in the event of a craniofacial disjunction (elongated face).
- *Malocclusion* (e.g., post-traumatic open bite).
- *Intraoral pathological mobility* due to fracture of one or more portions of the upper alveolar process.
- *Diastema* of the central incisors for fracture of the palate.
- *Coronal lesions* associated with dental avulsions.
- *Nasal deformities*: "C" or "S" deformity of the nasal pyramid, saddle nose, and twisted nose.
- *Crepitus* due to rubbing of bone fragments and/or presence of emphysematous bubbles in soft tissues.
- *Liquorrhea*.

Instrumental diagnosis can be provided by CT scan, with axial, coronal, and sagittal reconstructions and, if possible, with three-dimensional reconstructions. CT scan replaced traditional radiography for a more complete and accurate diagnosis.

21.5.2 Surgical Treatment

Nasal fractures can be reduced with closed technique, using some tools, such as:

- Walsham forceps: and/or surgical forceps to manipulate the bones of the nose and the frontal processes of the maxilla
- Asch forceps: to manipulate the nasal septum

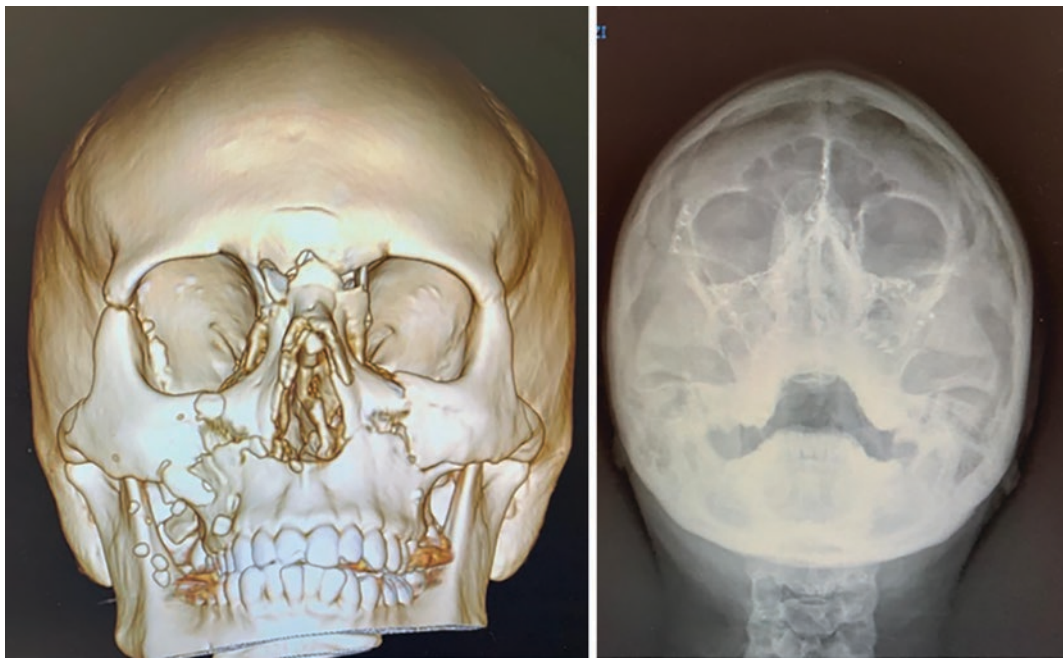

Fig. 21.2 Le Fort I fracture associated with a zygomatic fracture and NOE fracture. The reconstruction of the buttresses is shown in the postoperative X-ray

Sometimes for complex, comminuted, or multifragmentary lesions involving other bone structures of the middle third, it is necessary to use open reduction techniques through pre-existing wounds or coronal incisions. The fractures will be then synthesized using "X"- or "Y"-shaped microplates. Regardless of the technique used and the access mode, after the reduction, an anterior nasal packing is applied for 3 days and an external splinting for about 10 days. The surgical protocol that aims to an accurate repositioning of all bone structures and the restoration of the buttresses and vertical, sagittal, and transverse dimensions following a sequential order is the "key" to success in treating these fractures (Fig. 21.2).

Pearls and Pitfalls

The frontozygomatic suture represents the key point. As a general rule, reduction and synthesis of the facial fractures should begin from the highest to the lowest. Reducing the fracture that involves the frontozygomatic suture will allow for a sequenced reduction of the other fractures.

In cases of fractures of the maxilla, incision of the upper vestibular fornix allows to completely expose the buttresses and to reduce the fractures that are then synthesized using internal rigid fixation systems. Other useful surgical accesses are transconjunctival, subciliary incision, supraorbital incision (to access the "key point"), and coronal incision in cases where a large exposure is needed.

The goals of the orbital fracture treatment are not only to free incarcerated soft tissue but, mainly, to restore the anatomy and volume of the internal orbit and to prevent long-term damages like permanent paresthesia and enophthalmos (Fig. 21.3). The surgical approach and the material chosen to reconstruct the orbital floor should aim to a minor morbidity and greater stability for the patient.

Pearls and Pitfalls

Remember to identify and preserve the infraorbital nerve. It is also very important to preoperatively identify a sensitive deficit due to the involvement of the nerve in the fracture line, so that the deficit cannot be linked to the surgical procedure.

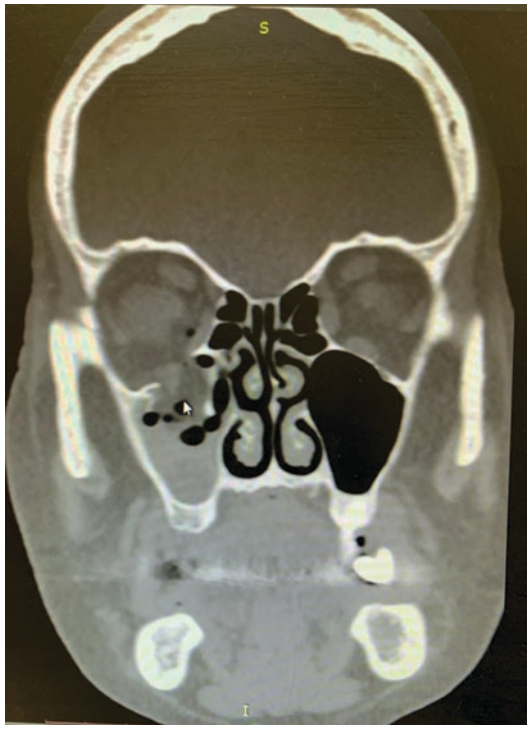

Fig. 21.3 CT scan in a coronal plane reconstruction, showing an orbital floor fracture. Arrow points to the inferior rectus muscle incarcerated between the two bone fragments, causing diplopia

21.5.3 Complications

Early Complications

- *Ocular globe injury*: even if it is not frequent, it can heavily affect the patient's prognosis quoad valetudinem, leading to serious anatomical and/or functional permanent damage.
  Ocular globe trauma is distinguished in:
  - *Closed globe trauma*: a clinical condition characterized by an absence of wound (contusion) or a partial wound of the eyewall (lamellar laceration).
  - *Open globe trauma:* the cornea and/or sclera presents a full-thickness wound.
- *Injury of the* optic nerve: reversible if due to compressions (hematomas, bone fragments) or irreversible if due to direct complete or incomplete injury of the nerve caused by a sharp object or a bullet or following fractures involving the optic foramen.
- *Brain injury.*

Late Complications

- *Enophthalmos*.
- *Diplopia*.
- *Telecanthus*.
- *Depression of the frontal bone* (if involved in a fracture that affects the middle third of the face).
- *Nasal deformities*.
- *Depression of the zygomatic arch* that can cause limitation to the movements of the mandible.
- *Deformity of the zygomatic bone* due to impaired reduction of a fracture of the O.M.Z.C. can cause dystopia of the ocular globe.
- *Impaired sensitivity* due to damage to the nerves that pass through the zygomatic body.
- *Sinus infections* of the frontal, ethmoidal, and maxillary sinuses.
- *Obstruction of the nasal cavities* due to deviation of the nasal septum following a poorly consolidated fracture.
- *Malocclusion*.
- *Lesions of the tear apparatus*.
- *Lagophthalmos* due to scar retraction of post-traumatic or surgical wounds (marginal or subciliary incision) or fractures of the orbital margin or the orbital floor, badly treated or untreated.

Pearls and Pitfalls
Remember that three nerves pass through the zygomatic bone:

- Infraorbital nerve
- Zygomaticotemporal nerve
- Zygomaticofacial nerve

21.6 Fractures of the Lower Third

The position, protrusion, and anatomical configuration of the mandible make this bone particularly exposed to fractures. Due to the ever-increasing number of road accidents, the fracture of the mandible has become one of the most frequently encountered pathologies in

trauma centers around the world. From the epidemiological point of view, in order of frequency, in addition to road accidents, they can be due to trauma, falls, assaults, sports injuries, gunshots inflicted by others or self-inflicted, or difficult tooth extractions.

The mandible as a whole is a very robust and resistant bone, but it does have some "loci minoris resistentiae." The body is mainly made of dense cortical bone with a small amount of cancellous bone; the presence of a canal through the thickness of the body ending at the level of the mental foramen constitutes a weak point and therefore a frequent fracture site; the mandible is thin at the level of the angles, particularly exposed to fracture especially if a third molar is included, contributing to the fragility of the area; the condyle, particularly at the neck, is the weakest point (Tables 21.3 and 21.4). This is due to the necessity to protect the brain, at the middle cranial fossa, from the deleterious effects of the traumatic energy transmitted by the condyle during a trauma. In fact, while condylar fractures represent over 35% of all mandibular fractures, only

Table 21.3 Classification of mandibular fractures

Criteria	Characteristics
Site of fracture	• Condyle neck (35%) • Body (21%) • Angle (20%) • Parasymphysis (14%) • Ramus (3%) • Alveolar crest (3%) • Coronoid process (2%)
Type of fracture	• *Green wood fractures*: incomplete discontinuity of the mandibular bone (involvement of the inner or outer cortex) • *Simple or closed fractures*: stumps are aligned, and there is no communication with the surrounding tissues • *Complex or open fractures*: numerous fracture segments and lines. Can present laceration of the mucous membranes and skin (open fractures). Sometimes the fracture is characterized by the presence of numerous bone fragments (comminuted fractures), some of which are poorly vascularized
Type of trauma	• *Direct fracture*: at the site where the force of impact acted • *Indirect fracture*: where the energy of the force of impact has been discharged, often opposite to the direct one
Conditions of the teeth	According to Kazanjan and Converse classification, mandibular fractures can be classified as: • Class I: teeth on both fracture segments and can be used as a guide for the reduction and synthesis of the fracture itself • Class II: teeth only on one of the fractured segments and are used to fix the mandibular bone to the maxillary bone. Useful to use a splint to stabilize the edentulous segment in order to ensure adequate occlusion with the mandible • Class III: no teeth on both segments of the fracture
Direction of the fracture line	Due to the direction of the fracture, the result of the displacement of the segments, or the direction of traction of the muscles inserted on the mandible that tend to oppose or favor dislocation of the segments, fractures can be: • *Favorable fractures* – Horizontal: directed downward and forward. The posterior and anterior muscle groups contract in opposite directions giving stability to the fracture site – Vertical: the fracture line crosses the lateral surface of the mandible posteriorly and medially, and therefore the direction of the muscular force is opposed to the dislocation of the bone segments • *Unfavorable fractures* (Fig. 21.4) – Horizontal: the fracture line runs from top to bottom and from front to back. The contraction of the two antagonist muscle groups breaks down the fracture creating diastasis between the two segments – Vertical: the fracture line runs from the back to the front, and medially, there will be a medial shift due to the medial traction of the levator muscles

Table 21.4 Classification of condylar fractures

Criteria	Characteristics
Site of fracture	• *Intracapsular fracture:* direct involvement of the TMJ can result in ankylosis • *Extracapsular fracture:* there is the displacement of a more voluminous skeletal fragment, and morpho-functional alterations will be more evident, since the action of the external pterygoid muscle causes an anteromedial dislocation of the condylar fragment
Type of fracture	• *Not displaced fracture* (no movement of the fractured bone) • *Displaced fractures* (medially or laterally)

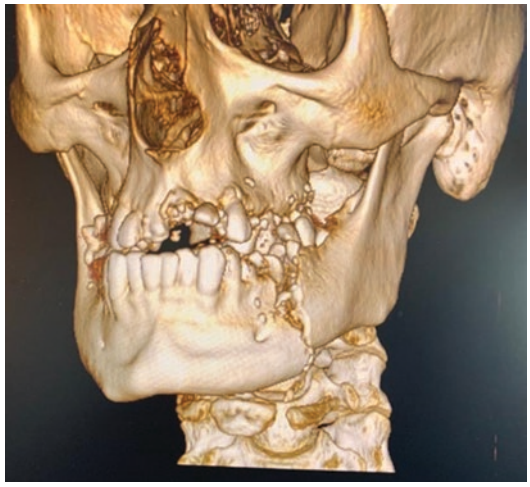

Fig. 21.4 CT scan showing an unfavorable mandibular fracture

15 cases of intracranial dislocation of the mandibular condyle have been described in literature.

It is interesting to note how total or partial edentulism constitutes a further weakening factor. In fact, with tooth loss, the alveolar bone changes, becoming atrophic; this is the reason why this bone, in an edentulous patient, is particularly exposed to the risk of fractures, just as the fracture is more frequent at the level of edentulous areas in a mandible that has only a partial dentition, rather than at the level of areas best supported by adequate dental structures. Furthermore, the lack of dental elements represents an obstacle to the subsequent reduction and synthesis of the fracture. Other conditions, local and systemic, predisposing to the fracture of the mandible are:

- Osteomalacia
- Metastasis
- Infection
- "Fragilitas ossium"
- Benign/malignant tumors
- Cysts
- Osteomyelitis
- Drugs (e.g., bisphosphonates)

In case of condyle fractures [9] (Fig. 21.5), the alteration of the physiological relationship between the condyle and the glenoid fossa has an impact on the structure of the stomatognathic system. In case of a patient that is still in growing age, in additioncondylar fractures to the structural damage resulting from the trauma, clinical pictures may arise resulting from a deficit of mandibular growth, which can affect the development of the lower and middle third of the facial skeleton. In the case of an adult patient, great importance will be given to the direct consequences of structural damage.

21.6.1 Clinical Presentation

Clinically the following can be observed:

- Malocclusion: any condition characterized by alteration of normal dental occlusion. It can be very evident presenting itself with clinical scenarios, or it can simply be a subjective symptom of the patient, who reports that he "does not close his mouth normally, as usual." A post-traumatic open bite with mandibular retrusion, with patient's inability to close his mouth, can result from a bilateral fracture of the mandibular body, with an unfavorable direction of the fracture, since the suprahyoid muscles exert a downward pulling force of the mandibular segment placed medially at the fracture site. It can also occur when the condylar fracture is bilateral in case of a displaced bicondylar fracture, due to the displacement

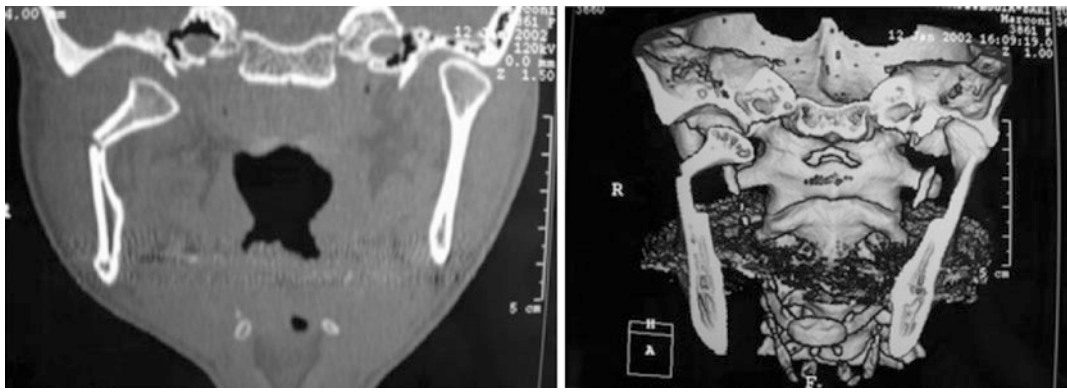

Fig. 21.5 CT scan in a coronal reconstruction (left) and 3D reconstruction (right), showing a condylar fracture with a medial displacement

of the two condyles, which causes a reduction of the posterior vertical height of the two mandibular rami (due to the action of the pterygoid, temporal, and masseter muscles on the fractured segments). In a monocondylar fracture, structural alteration and muscle dysfunction manifest with an open bite contralateral to the lesion, with an ipsilateral cross-bite and a lateral-deviation of the lower incisor line toward the side of the lesion due to the unilateral reduction of the vertical height of the mandibular ramus. From a functional point of view, there is a functional deficit of the external pterygoid muscle on the side of the fracture which is at the origin of the mandibular lateral-deviation and a deficit of the contralateral lateral movement.

- *Functional limitation* in the opening and closing movements of the mouth.
- *Edema*
- *Bruising/hematoma* (which can extend to the floor of the mouth and/or neck due to lesion of the facial artery).
- *Deformity of the face*: in addition to the massive swelling of the soft tissues due to alteration of the vertical and sagittal dimensions.
- *Pathological mobility* of bone segments due to fracture of one or more portions of the alveolar process.
- *Crepitus*.
- *Fetor oris*, caused by the patient's inability to swallow, is an indication of an intraoral hemorrhage.
- *Sialorrhea*: the patient avoids any swallowing movement, which causes severe pain; salivary secretion is also increased due to painful stimulation of the salivary glands.
- *Pain* spontaneous or stimulated by palpation.
- *Coronal lesions* and/or *dental avulsions*.

Instrumental diagnosis:

– Orthopantomography (OPT) is the first radiographic assessment to be performed as it allows identification of the site and number of fractures and vertical displacement of the fractured segments. This examination provides a bidimensional overview of the mandible.
– CT scan, with coronal and sagittal reconstructions and, if possible, with three-dimensional reconstructions, provides a more accurate diagnosis, especially if the condyle is involved. It is important to underline that the most accurate exam for the temporomandibular joint (TMJ) and its delicate fibrocartilaginous components is the MRI, but is not performed in emergency [10].

21.6.2 Surgical Treatment

The treatment of a mandibular fracture must aim to achieve three goals:

1. Normocclusion
2. Chewing functionality
3. Facial eurythmy

Treatment of mandibular fractures can be conservative or surgical.

21.6.2.1 Conservative Treatment

It is indicated in the case of fractures characterized by a modest displacement of the bone segments and of fractures of the neck of the condyle. The treatment consists of an intermaxillary fixation performed after restoring a maximum intercuspation and therefore an acceptable occlusion. It must be kept in place for 2–3 weeks. An intermaxillary fixation can also be performed using orthodontic devices (brackets) and elastic bands to connect them. An alternative is the intraosseous intermaxillary fixation using 4–6 bicortical screws, generally applied under local anesthesia or under general anesthesia if needed to treat associated fractures. The benefits of this technique, compared to the external intermaxillary fixation, are:

- Speed and ease of application
- Greater acceptance by patients
- Reduction of trauma to the oral mucosa and gums
- Reduction of the risk of skin puncture with reduction of the risk of transmission between patients and surgeon of viral diseases (HBV, HCV, and HIV)
- Ease and less painful removal

Key Point
It is sufficient to fix each arch of the external intermaxillary fixation system to four dental elements avoiding, if possible, the incisors. These teeth, in fact, tend to extrude if fixed to the arch due to the morphology of their root.

21.6.2.2 Surgical Treatment

Except from those of the condyle (with some exceptions), surgery is needed every time there is a displaced fracture that causes a misalignment of the bone segments [11]. In these cases, therefore, it is necessary to use an open approach and osteosynthesis by internal fixation, using plates and screws of various shapes and sizes. An intermaxillary blockage can, in certain cases, be a phase of the surgical treatment, because it allows an excellent intraoperative dental intercuspation which promotes good alignment of bone segments in comminuted fractures.

Pearls and Pitfalls
Remember: when a condyle is surgically treated, the approach is through the parotid gland, and it can cause temporary or permanent facial nerve damage.

The use of internal rigid fixation systems is also particularly suitable in the cases of:

- Fracture of the mandible in partially or totally edentulous patients, which are not good candidates for intermaxillary fixation
- Fractures of the mandibular angle with displacement of the segments
- Absolute contraindications for the intermaxillary fixation (respiratory failure, risk for abingestis pneumonia)

The purpose of osteosynthesis using internal rigid fixation is to achieve an effective reduction of the fracture, avoiding a prolonged postoperative intermaxillary fixation which can lead to:

- Reduction of the TMJ functionality
- Difficult recovery of functions such as language and chewing
- Aggravation of the respiratory conditions of patients with chronic obstructive pulmonary disease or asthma

Pearls and Pitfalls
Remember, if a patient asks if he should remove the titanium internal fixation system, you should highlight that titanium is:

- Biocompatible
- Osseointegrated
- Does not interfere with MRI or body scanners

It should be removed in case of:

- Infection
- Cutaneous fistula formation
- Persistent sensation of foreign body/ dysesthesia

Three types of surgical approach can be used to treat a mandibular fracture:

- *Extraoral or transcutaneous approach*: conditioned by the presence of deep wounds concomitant to bone trauma. If a closed fracture occurred, it would be preferable to avoid making skin incisions that cause scars at the level of the lower profile of the face.
- *Intraoral approach*: is considered as the standard approach; surgical access is achieved by an incision of the mucosa at the level of the lower vestibular fornix (Fig. 21.6).

Pearls and Pitfalls

Remember to identify and preserve:

- Marginal branch of the facial nerve, with the artery and facial veins. Damage can occur when a transcutaneous approach is used. This nerve is responsible for the motility of the lower lip, and since it is not provided with collateral branches, once dissected, it cannot recover its function. The course of the marginal nerve follows the lower profile of the angle and the mandibular body and crosses the facial vessels at the level of the pregonial notch.
- Mental nerve: an iatrogenic damage would cause the anesthesia of the affected lower hemi-lip. It is also very important, in case the nerve has been damaged by the fracture itself, to preoperatively identify a sensitive deficit so that the deficit cannot be linked to the surgical procedure and repair it, if possible, during surgery.

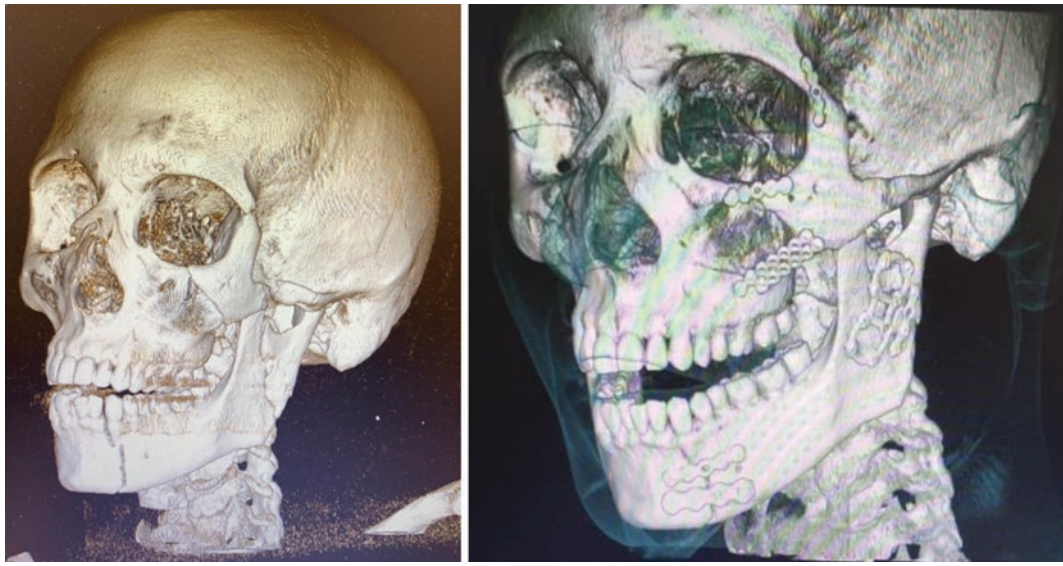

Fig. 21.6 CT scan in a 3D reconstruction showing preoperative and postoperative multiple mandibular fracture of the left parasymphysis, left ramus, left O.M.Z.C. treated with internal fixation

21.6.3 Complications

Early Complications

- *Obstruction of the upper airways*, due to retroposition of the tongue.
- *Subcutaneous hematoma*, when the fracture of the mandible is accompanied by a massive bleeding, the blood vessels must be ligated or clamped. A hematoma at the level of the floor of the mouth can lead to obstruction of the passage of air at the level of the oropharynx; therefore, it might be necessary to perform an emergency tracheotomy.
- *Emphysema*: the air that has entered the soft tissue can cause respiratory obstruction.

Late Complications

- *Malocclusion*: may need reintervention.
- *Osteonecrosis*: can be due to infection or ischemia. The infection may be due to local factors (persistence of foreign bodies or nonvital teeth in the fracture, contamination of the metal screws, preexisting gingivitis) or systemic (cachectic state from polytrauma).
- *Pathological mobility*: can occur due to an inadequate reduction and/or synthesis of the fracture and is an indication for reintervention.
- *Ankylosis of the TMJ*: can occur in case of intracapsular condylar fracture. The bone repair can cause a progressive adhesion of the condyle to its joint cavity, with a gradual alteration of the opening movements of the mouth, and in case of trauma in infants can cause asymmetry of the face. Cases of bilateral ankylosis can cause severe "bird face deformity."
- *Impaired sensitivity* due to damage of the mental nerve.

Take-Home Message

- Appropriate medical care for a patient with a facial fracture can not only optimize aesthetic outcomes but also prevent the potential morbidity and mortality of delayed treatment.
- The most common type of orbital fracture is the orbital floor fracture; it is thought to be from increased intraorbital pressure, which causes the orbital bones to break at their weakest point.
- Mandibular fractures are among the most common traumatic injuries of the maxillofacial region which jeopardize both aesthetic and function.
- The occlusion, form, and function should all be considered in the management of mandibular fracture with the internal fixation as the most common surgical treatment.

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Further Reading

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Part IV

Plastic Surgery in Cancer Therapy

Plastic Surgery for Skin Cancer

22

Michelangelo Vestita, Pasquale Tedeschi, and Domenico Bonamonte

Background
More non-melanoma skin cancers (NMSCs) are diagnosed annually worldwide than all the other cancers combined, and they result in about 2000–2500 deaths annually. Those at risk for skin cancer are fair-skinned people who are tanning poorly and who have had any chronic or sporadic exposure to the sun. Other risk factors include skin cancer history, prior radiation therapy, treatment with phototherapy, arsenic exposure, and systemic immunosuppression. If a person has developed a NMSC, the chance of a second is ten times greater. More than 40% of BCC and SCC patients develop a BCC, and 18% of SCC patients develop another SCC over the 3-year period following the initial NMSC diagnosis. Patients with an NMSC history should be regularly screened.

Ultraviolet (UV) radiation is a major cause of actinic keratoses and non-genital NMSCs. The UV radiation effect appears to be mediated by mutation of the p53 gene, which is found mutated in a significant percentage of NMSCs and actinic keratoses. Most skin cancers are highly immunogenic, but continued actinic exposure suppresses the immune response. Both chronic exposure to the sun and sporadic, intense exposure are risk factors for NMSC growth. Concordantly, avoiding sun exposure is thought to reduce NMSC risk. The use of sunscreens in NMSC prevention has been controversial; they can unintentionally result in prolonged deliberate exposure to the sun, negating their possible beneficial effect.

22.1 Introduction

The main types of NMSC are keratoacanthoma, basal cell carcinoma, and squamous cell carcinoma. A thorough description of each type of tumor and their characteristic features will ensue in the following paragraphs, as well as an overview of the gold standard surgical techniques used to resect NMSC and reconstruct the resulting defects.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-82335-1_22) contains supplementary material, which is available to authorized users.

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22.2 Keratoacanthoma

Historically, keratoacanthoma was considered a reactive disorder or pseudo-malignancy that could be treated with a wait and see approach. Now, the preferred view is that keratoacanthomas are low-grade SCCs which might regress in many situations; such regression can be partly mediated by immunity. However, these tumors are unpredictable in their path and often hard to differentiate from higher-grade SCCs. That is why any lesions with clinical suspicion of keratoacanthoma should be treated with full eradication. Sunlight appears to play an important role in etiology, predominantly affecting light-skinned persons. Cases of keratoacanthoma following trauma, tattoos, fractional thermolysis, and erosions of imiquimod, and along the distal ends of surgical excisions, suggest an isomorphic phenomenon to be common.

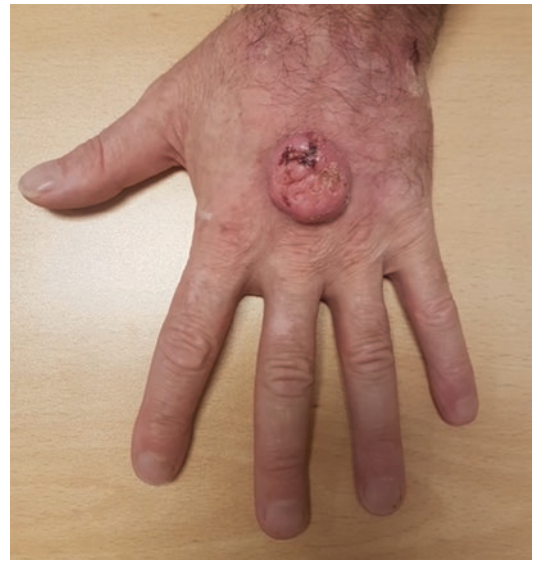

Fig. 22.1 Keratoacanthoma

22.3 Solitary Keratoacanthoma

Key Point

Solitary keratoacanthoma is a rapidly growing papule that extends in 3–8 weeks from a 1 mm macula or papule to as large as 25 mm. When fully grown, it is a skin-colored, hemispheric, dome-shaped nodule that has a smooth crater filled with a central keratin plug. Telangiectasias may be noticeable. Solitary keratoacanthoma occurs mostly on sun-exposed skin, most frequently involving the central portion of the face, the back of the hands, and the arms (Fig. 22.1). Elderly fair-skinned individuals experience keratoacanthomas the most commonly.

The most remarkable characteristic of this disease is its rapid growth for 2–6 weeks, followed by a stationary phase for another 2–6 weeks, and eventually a spontaneous involution for a further 2–6 weeks, leaving a slightly depressed scar. The stationary and involuting process is variable; some lesions can take 6 months to 1 year to fully resolve. There is an average 5% recurrence of treated lesions. Invasion along nerve trunks has been documented and after an apparently adequate excision can result in recurrence.

22.4 Histopathology

The histological findings of keratoacanthoma and a low-grade SCC are so similar that a definite diagnosis on the histological findings alone is often difficult to make. When analyzing a correctly sectioned specimen under low magnification, a depression filled with eosinophilic keratin is seen in the lesion core. A “lip” or “marginal buttress” of epithelium extends over the keratin-filled crater over the sides of the crater. The epithelium is acanthotic at the base and sides of the crater and is composed of extremely keratinized keratinocytes with an eosinophilic, glassy cytoplasm. A thick inflammatory infiltrate is usually seen around the keratinocyte proliferation.

The most definitive histological feature is evidence of terminal differentiation, where the

tumor's scalloped outer border has lost its infiltrative character and is reduced to a thin rim of keratinizing cells lining a large crater filled with keratin.

It may not always be possible to differentiate a benign-behaving keratoacanthoma versus a potentially aggressive SCC. Even if one sees the classic histological characteristics of keratoacanthoma, the diagnosis of SCC should be considered if the lesion is not behaving as expected.

22.5 Treatment

Tips and Tricks
Even though keratoacanthomas involute spontaneously, it is difficult to predict how long it will take. More importantly, it is not always possible to clinically exclude SCC. Hence, in most cases, excisional biopsy of the typical keratoacanthoma should be considered.

Nonsurgical treatment can also be considered for maintaining function or enhancing cosmetic results in some locations. Intralesional 5-FU, bleomycin, or methotrexate may be efficient. Low-dose systemic methotrexate can be considered when there are multiple lesions, and no contraindication is present. Radiation therapy can also be used on giant keratoacanthomas when surgical excision is not possible.

22.6 Basal Cell Carcinoma

Key Point
Basal cell carcinoma (BCC) is the most prevalent cancer associated with moderate sun exposure worldwide, especially in countries with a predominantly white, fair-skinned population.

Intermittent extreme sun exposure as identified by previous sunburns, radiation therapy, BCC's positive family history, immunosuppression, fair complexion, particularly red hair, easy sunburning (skin types I or II), and childhood blistering sunburns are risk factors for BCC development. Indoor tanning is a considerable risk factor for early BCC. Actinic elastosis and wrinkling are not risk factors for BCC's growth. These results indicate that the process by which BCC is caused by UV radiation is not strictly related to the total amount of UV obtained. Unlike actinic keratoses and SCCs, it's more difficult to demonstrate prevention with regular use of sunscreens. Having had a BCC, the risk for a subsequent BCC is high: 44 percent over the next 3 years.

22.6.1 Clinical Features

There are many clinical BCC morphologies. Medical diagnosis relies on the clinician being able to recognize the various forms that BCC can take.

The classic or nodular BCC makes up 50–80% of all BCCs. Nodular BCC consists of one or a few thin, semi-translucent papules that form around a central depression that may or may not be ulcerated, crusted, and bleeded (Fig. 22.2). There is a typical rolled border to the edge of larger lesions. The path of telangiectases is through the lesion. When development continues, crusting occurs over a central erosion or ulcer, and bleeding happens when the crust is broken or pulled off, and the ulcer becomes visible. The ulcer over time becomes chronic and faces a progressive enlargement (Fig. 22.3). The lesions are asymptomatic, and the only problem experienced is bleeding. The lesions are found most frequently on the face and particularly on the nose (25–30%). Forehead, ears, periocular areas, and cheeks are also often involved.

Morpheaform BCC is a white sclerotic plaque, mostly occurring on the head and neck. Ulceration, a pearly rolled line, and typically no crusting are typical features. Telangiectasia is variably present. Hence, the lesion is often for some time missed or misdiagnosed. The differen-

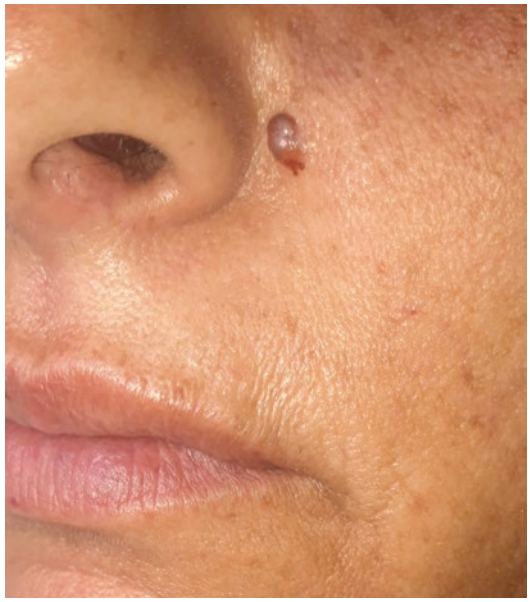

Fig. 22.2 Nodular basal cell carcinoma

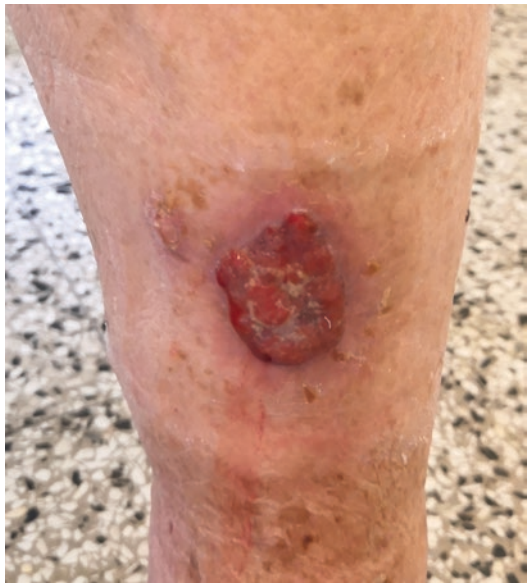

Fig. 22.3 Ulcerative basal cell carcinoma

tial diagnosis includes desmoplastic trichoepithelioma, a scar, adnexal microcystic carcinoma, and desmoplastic melanoma. Morpheic BCCs make up 2–6% of all BCCs.

Infiltrative BCC is an aggressive subtype characterized by a deep infiltration in a fibroblast-rich stroma of the spiky basaloid epithelium islands. Clinically, it lacks morpheiform BCC's scar-like appearance. The stroma is hypercellular, and squamous differentiation is common.

Superficial BCC is a frequent BCC form (15% of all BCCs). This prefers trunk or distal extremities. This type of BCC most often presents as a scaly, dry lesion. The lesions grow very gradually and can be misdiagnosed as dermatitis. These erythematous plaques with telangiectasia may often show atrophy or scarring. Some lesions may develop an infiltrative portion and expand into the deeper dermis. Often, the lesion heals with a white atrophic scar at one spot and then aggressively spreads to the neighboring tissue. A patient can experience several of these lesions at the same time or over time.

Pigmented BCC has all of the features of nodular BCC, but there is also dark or black pigmentation in its clinical appearance. BCCs with pigmentation make up 6% of all BCCs.

Also known as Jacobi ulcer, ulcus rodens is a neglected BCC that has produced an ulceration. The lesion's pearly border cannot be recognized. When this happens at the lower extremity, it may be misdiagnosed as a vascular ulcer (Fig. 22.3).

22.6.2 Natural History

The lesion gradually enlarges and continues to become more ulcerative, in a chronic course. It might bleed without discomfort or other symptoms. The ulceration can burrow deep into subcutaneous tissues, or even into the cartilage and bone, resulting in extensive destruction and mutilation. At least half of BCC deaths arise from direct extension into a critical system instead of metastases.

Metastasis is highly rare and occurs in 0.0028–0.55% of BCCs. This low incidence probably depends on the tumor cells needing stroma in order to survive.

Immunosuppression for organ transplantation raises the risk of BCC tenfold. An elevated risk for BCC exists in patients diagnosed with HIV, those taking immunosuppressive medication, and those affected with chronic lymphocytic leukemia. A history of blistering sunburns in the infancy in the immunosuppressed population is a clear risk factor for BCC production after immunosuppression.

22.6.3 Etiology and Pathogenesis

It appears that BCCs originate from immature pluripotential cells linked to the hair follicle. Mutations are found in most BCCs which activate the hedgehog signaling pathway, which controls cell development. The genes affected are those used for sonic hedgehog, patched 1, and smoothened.

22.6.4 Histopathology

The common opinion is that there is a link between histological BCC subtypes and the biological behavior. BCCs are known as low risk or high risk, based on their probability of causing potential problems: subclinical expansion, incomplete elimination, violent local invasive activity, and local recurrence. The typical patterns of histology are nodular, superficial, infiltrative, morphic, micronodular, and mixed. The type of nodular is low risk. High-risk forms include trends that are infiltrative, morphic, and micronodular due to aggressive local invasive activity and a propensity to recur. Superficial BCC is vulnerable to higher recurrence due to inadequate removal.

The early lesion shows small, dark-staining, polyhedral cells which resemble those of the epidermis' basal cell layer, with large nuclei and small nuclei. The columnar cells can be characteristically arranged at the periphery of cell masses like fence posts (palisading). Dermal stroma is an integral part of the BCC and is essential. The stroma is loose and fibromyxoid.

22.7 Differential Diagnosis

Key Point
The distinction between small BCCs and small SCCs is simply an analytical exercise. Both are mainly caused by radiation, they are not likely to metastasize, and both require removal by surgical excision.

BCC is fairly characterized by a waxy, nodular, rolled edge. SCC is a nodular dome-shaped, elevated, and infiltrated lesion. The early BCC can be easily confused with sebaceous hyperplasia. In addition, Bowen disease, Paget disease, amelanotic melanoma, and actinic and seborrheic keratoses can mimic BCC. Ulcerated BCC on the shins is often misdiagnosed as a vascular ulcer, so a biopsy may be the only way to separate the two. Pigmented BBC is also misdiagnosed as melanoma or as a melanocytic nevus. The superficial BCC can easily be confused with patches of dermatitis such as psoriasis or eczema.

22.7.1 Treatment

In all patients with suspected BCC, a biopsy should be performed to determine the histologic subtype and confirm the diagnosis. Since the face is BCC's most popular site of involvement, treatment aims for a permanent cure with the best cosmetic outcomes. Recurrences result from inadequate treatment and are usually seen after treatment in the first 4–12 months.

BCC treatment is typically surgical, but certain types of BCC are appropriate for medical care, photodynamic therapy, or radiation therapy. In multiple locally advanced or metastatic BCC, vismodegib, which targets the hedgehog pathway, has antitumor activity and clinically meaningful response.

22.8 Squamous Cell Carcinoma

Key Point
The second most common type of skin cancer is squamous cell carcinoma (SCC). Chronic, long-term exposure to sunlight is the main risk factor, and areas with such exposure (face, scalp, back, dorsal hands) are preferred locations. Immunosuppression greatly increases the risk of SCC development, approx. 80-fold to 200-fold among organ transplant recipients.

High-risk genital HPVs, especially 16, 18, and 31, play a role in genital and periungual SCCs. Chronic ulcers, hidradenitis suppurativa, recessive dystrophic epidermolysis bullosa, autoimmune dermatitis, burns, and previous exposure to radiation and phototherapy treatment often tend to raise the likelihood of developing SCCs. Metastasis, with 18% mortality, is very rare for SCCs resulting from chronic sun damage, while it is relatively high in SCCs arising from abnormal scarring processes (20–30%). Metastatic SCC is the most common cause of death at adulthood in recessive dystrophic epidermolysis bullosa. Since the vast majority of cutaneous SCCs are caused by UV radiation, sun protection is advised.

22.8.1 Clinical Features

SCC starts on sun-exposed areas such as the hands, face, and back. The lesion may be superficial, discrete, and rough, resulting in an indurated, rounded, high base. This is slender red, and it contains telangiectasias. The lesion gets deeper, profoundly nodular, and ulcerated within a few months. The ulcer is superficial at first and is covered by crusting. The tumor is elevated and freely mobile over underlying structures in the early stages; later, it gradually becomes diffuse, more or less depressed, and fixed. The tumor above skin level may be dome-shaped, with a core-like center prone to ulceration. The surface may be cauliflower-like in advanced lesions, with a viscous, purulent, malodorous exudate (Fig. 22.4).

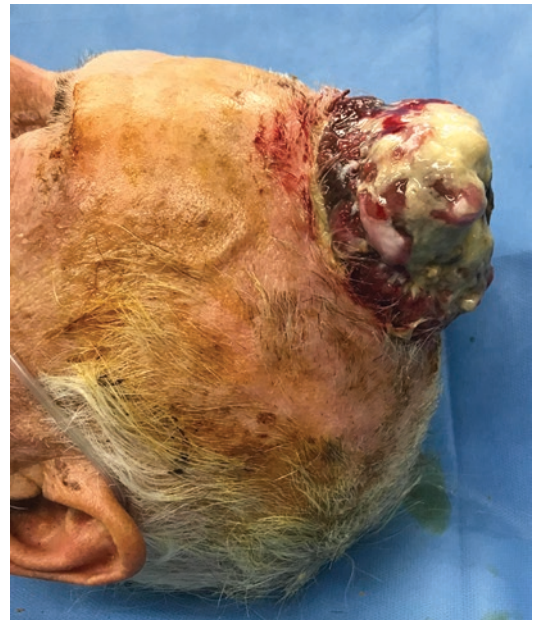

Fig. 22.4 Exophytic ulcerative squamous cell carcinoma

SCC often develops on actinic cheilitis at the lower lip (Fig. 22.5). The vermilion surface is brittle, scaly, and scratched from prolonged sunburn. From a localized thickness, it then grows into a solid nodule. A smoking history is a recurrent and important predisposing factor. Lower lip lesions greatly outnumber upper lip lesions.

Periungual SCC often presents signs of erythema and scaling which may resemble a wart superficially.

Given the numerous presentations of SCC on the skin, any suspected keratotic, ulcerated, or nodular lesion, particularly in the context of chronic sun exposure, should be at a low threshold for biopsy.

22.8.2 Histopathology

SCC is distinguished by irregular nests, neoplastic keratinocyte cords, or sheets that penetrate the dermis to various depths. Thickness is a major risk factor for metastasis, with thickness > 2 mm

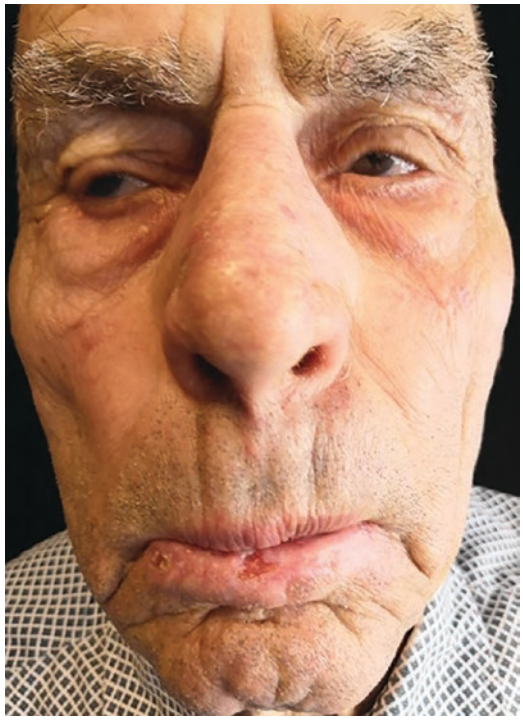

Fig. 22.5 Squamous cell carcinoma on actinic cheilitis

associated with a metastatic rate of 4% and >6 mm associated with a metastatic rate of 16%. Immunosuppression, location on the ear, and increased horizontal size all increase metastasis risk by double- to fourfold. Desmoplasia and thickness also increase the risk of local recurrence. Other types of neoplasms, such as melanoma, need to be excluded in tumors which are poorly differentiated. Weak prognostic characteristics are the identification of perineural or vascular invasion and recurrence.

22.8.3 Differential Diagnosis

For most cases, the separation of SCC from keratoacanthoma is of relative importance, because on most of these lesions, surgical excision is performed. The rapid growth and presence of a rolled border with a central keratotic plug indicate the keratoacanthoma diagnosis, as does exponential development. The early SCC can be confused with an actinic keratosis, and indeed the two can be clinically indistinguishable.

Histological differentiation of pseudoepitheliomatous hyperplasia from true SCC is necessary. Chronic stasis ulcers, as well as ulcerations which occur in thermal burns or various granulomatous skin conditions, are often mistaken for SCC. Pseudoepitheliomatous hyperplasia arises from adnexal structures and from the epidermis of the surface. Adjacent hair follicles often have hyperkeratosis and hypergranulosis.

Key Point

Lesions at high risk of recurrence and metastasis are those of the lip, ear, or anogenital skin; those developing in scars or irradiation sites; those of 2 cm or more in diameter; those of more than 4 mm thickness; those with low histological differentiation or perineural invasion; and those of patients with organ transplantation or hematological malignancy. Such patients may be considered for a more intensive surgical approach and adjuvant radiotherapy treatment. Careful attention should be provided to regional lymph nodes which drain the SCC site.

22.8.4 Treatment

The key treatment for cutaneous SCC is surgical removal. Pembrolizumab can play a role in the treatment in advanced illness. For patients for whom traditional therapies are not feasible alternatives, electrochemotherapy has been used as palliative therapy, as with BCC. Organ transplant recipients should be informed about sun safety and skin cancer risk and should have frequent skin exams.

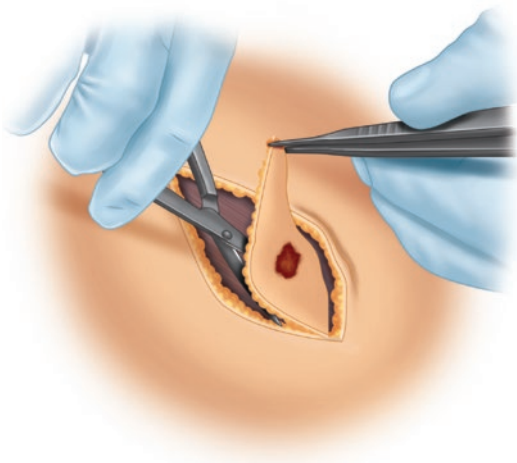

Fig. 22.6 Fusiform excision. Ellipse is designed along relaxed skin tension lines with a 3:1 length-to-width ratio and extends down to the subcutaneous tissue

22.9 Excisional Technique

Key Point
Fusiform excision is the common technique used to treat skin cancers. The basic concept of the fusiform ellipse is the excision of a specimen which is aligned along skin tension lines (Fig. 22.6, Video 22.1).

Non-melanoma skin cancers (NMSCs): Squamous cell carcinoma.

To fit the final scar better with skin tension lines, the ellipse may be bent in a crescentic or "lazy S" shape. If the procedure is done with the appropriate proportions (usually a length/width ratio of 3:1) and an angle of 30° at each end, standing cutaneous cones are normally avoided at the two ends of the excision. Standing cutaneous cones reflect excess bunching of tissue at the poles of a skin closure and should be "stitched out" or excised with triangulation or M-plasty, if necessary. Undermining, using sharp or blunt skin dissection, decreases tension in the wound and helps with eversion of the wound edges.

22.10 Wound Healing, Flaps, and Grafts

Pearls and Pitfalls
In clinical practice, it can be difficult to choose whether to close a wound by linear closure, local skin flap, or skin grafting or whether to allow it to heal by second intention. Important considerations include patient concerns and the ability to perform the required wound care, local tissue movement, adjacent structural and functional anatomical preservation, as well as cosmesis.

22.10.1 Healing by Second Intention

In selected clinical settings, wound healing by second intention is excellent, such as superficial wounds in concave areas, partial-thickness wounds involving lip mucosa, or other clinical conditions, such as elderly or vulnerable patients with reduced cosmetic issues. Wound treatment is simple, and there are few postoperative restrictions.

22.10.2 Dermal Matrices

Acellular dermal matrices are a class of biological and/or synthetic scaffolds used to replace deficient or missing sub-epidermal soft tissues. In clinical practice, they are often used to substitute for dermis and soft tissues after full-thickness removal of wide cutaneous malignancies in sites not amenable to immediate reconstruction (Video 22.2). They are usually left in place to integrate

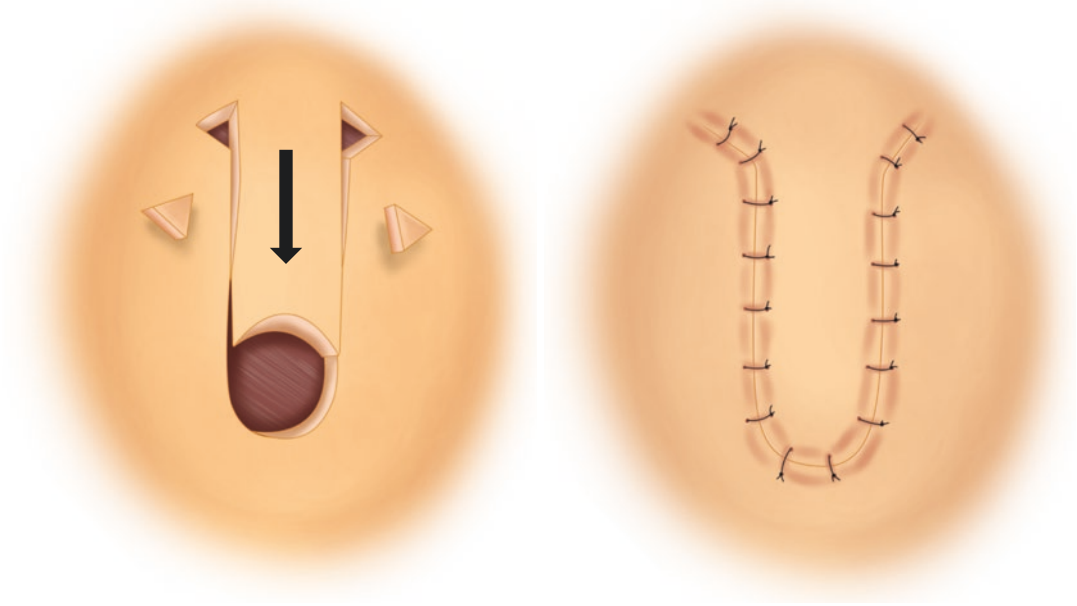

Fig. 22.7 Advancement flap

and revascularize for 2–3 weeks and are then covered with a split-thickness skin graft.

22.10.3 Flaps

Key Point
Local skin flaps are geometric tissue segments surrounding a skin defect which are advanced, rotated, or transposed to close a wound. The benefits of flaps include improved approximation of skin texture and color, concealment of incision lines, redirection of tension vectors, and preservation of exposed cartilage and bone.

Survival of flaps is dependent on preserving random blood supply around the pedicle. Consideration of both the primary flap movement (actual flap movement through defect) and secondary movement (movement of surrounding tissue in response to flap movement) is important when designing the repair.

22.10.3.1 Advancement Flap (Fig. 22.7)

An advancement flap moves mostly in one linear direction. The classic advancement flap involves the formation of a rectangular pedicle, slipping over the primary surgical defect to place. The main suture carries the flap forward and covers the primary defect. Tissue redundancies can be removed via triangulation (Burow triangles) at the base of the flap. Survival of the distal tip of the flap is based on the base blood supply, and thus a maximum length/width ratio of 3:1 should be planned.

If insufficient movement with a single advance flap is obtained, a bilateral advancement (O–H) can be used, so that each flap advances to cover half the defect. This can be used in repairs to the eyebrow or helical surface. Single-arm advance flaps (O–L) and bilateral single-arm advance flaps (O–T) are similar to classic advance flaps, except that only one incision is made and the standing cone is removed through triangulation. Such flaps have the advantage of a wider pedicle providing blood supply and allowing a linear portion of the flap to be concealed for better cosmetic outcome in existing wrinkling.

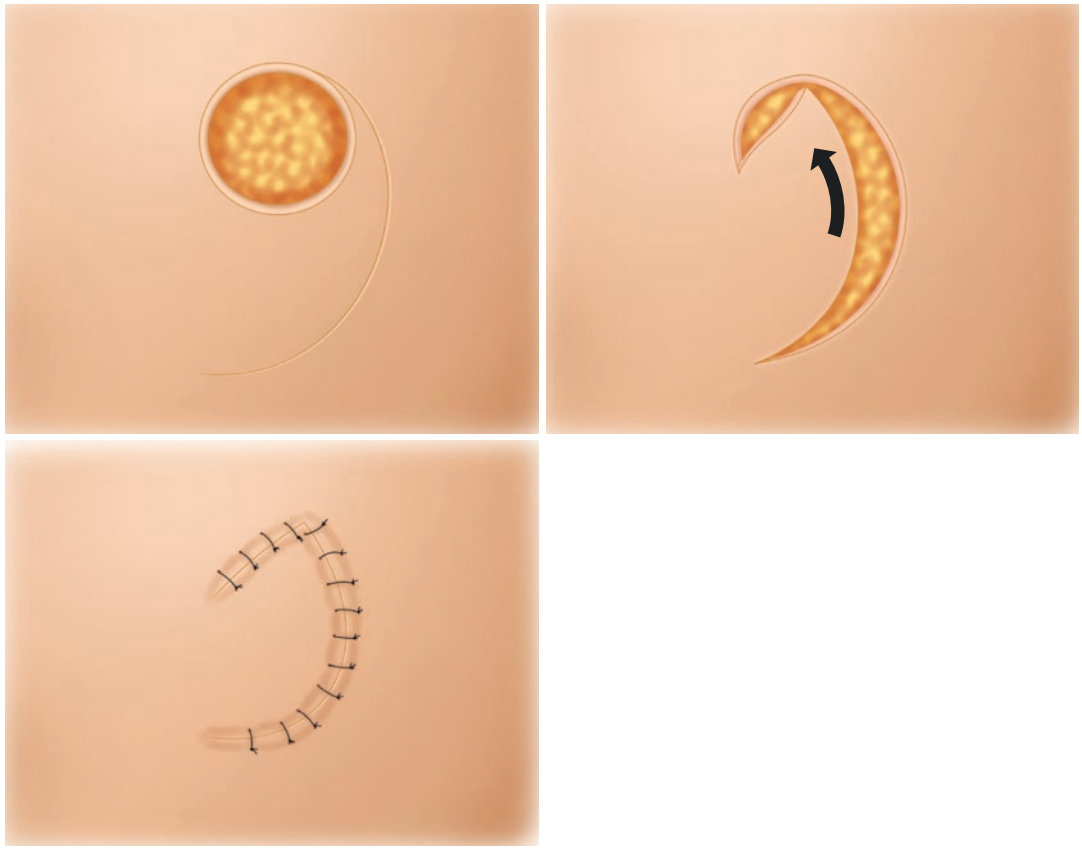

Fig. 22.8 Rotation flap

The pedicle island flap (or "V–Y flap") is a special variant of an advance flap. For its blood supply, this flap is dependent on a subcutaneous vascular pedicle and has all the epidermal connections severed by incisions.

The best cosmetic results are obtained when it is possible to conceal at least one of the incision lines inside a defined wrinkling or anatomic boundary.

22.10.3.2 Rotation Flap (Fig. 22.8)

Conceptually, the rotation flap can be considered a variation of the advancement flap, in that it slides into position in a similar way, albeit in an arcuate manner. Tension vectors from this pulling motion are directed along the rotation arc. The flap has the advantage of strong survival, thanks to the big pedicle and the ability to recruit skin from a long distance. A back cut can be used to minimize critical restriction and provide greater mobility of the tissue, but this may weaken the vascular pedicle. The bilateral variation is known as the bilateral rotation flap (O–Z).

22.10.3.3 Transposition Flaps (Fig. 22.9, Video 22.3)

In the case of the transposition flap, the flap is transposed over intervening tissue and sutured into the primary defect. The tension vector is distributed through the secondary defect closure (area originally occupied by flap). This type of flap is especially useful for defects which are adjacent to free anatomical margins. The key suture closes the secondary defect, and the flap is then lifted and transposed into position over the primary defect. That flap's prototype is the rhombic flap. Other examples include bilobed flaps, nasolabial/melolabial flaps, banner flap, and the Z-plasty.

The choice of a particular type of flap involves multiple factors, including location of defect, availability of tissue movement, surrounding structures, effects of tissue movement, and blood supply.

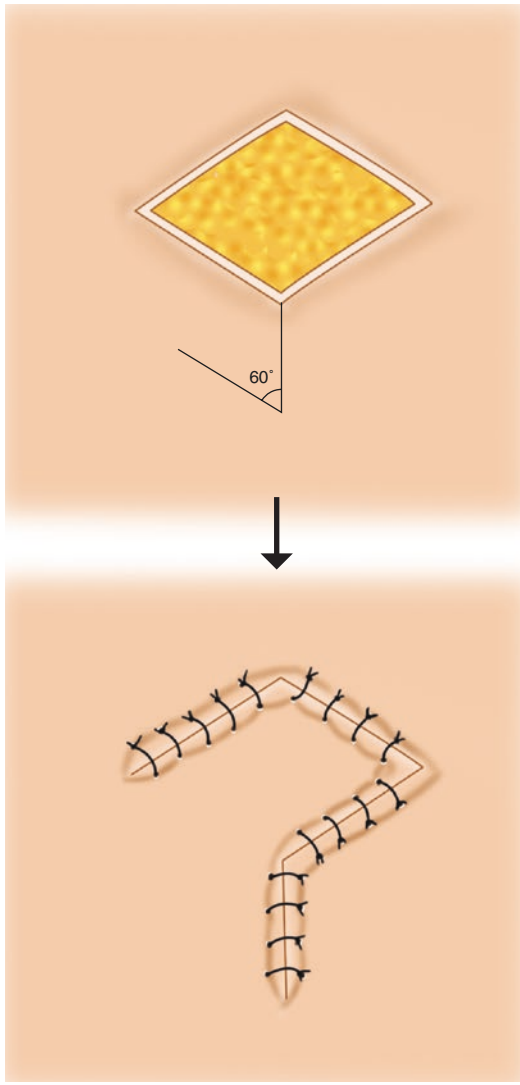

Fig. 22.9 Classic rhombic transposition flap

22.10.4 Skin Grafts

Key Point
A graft is by definition completely excised from the donor site and devitalized (no inherent blood supply). Success depends on reattaching the vascular supply from the defect to the graft. A possible drawback is the lack of color and texture fit depending on the distant donor position of the grafts.

Tips and Tricks
Skin grafts are used when there is no available option for primary closure or flap closure.

22.10.4.1 Split-Thickness Skin Grafts

Split-thickness skin grafts have a partial dermis only and are useful for covering large areas or improving surveillance in tumors with high recurrence risk. A dermatome is usually used to harvest such grafts (Fig. 22.10). Grafts can be meshed to provide coverage for larger defects, resulting in an expanded size. Split-thickness grafts have a higher survival rate and shorter healing time compared with full-thickness skin grafts, do not require donor site repair, and are a good choice for areas that are poorly vascularized due to lower metabolic demand. However, they have a higher degree of contraction, lack skin appendages, and yield a worse cosmetic match than full-thickness grafts.

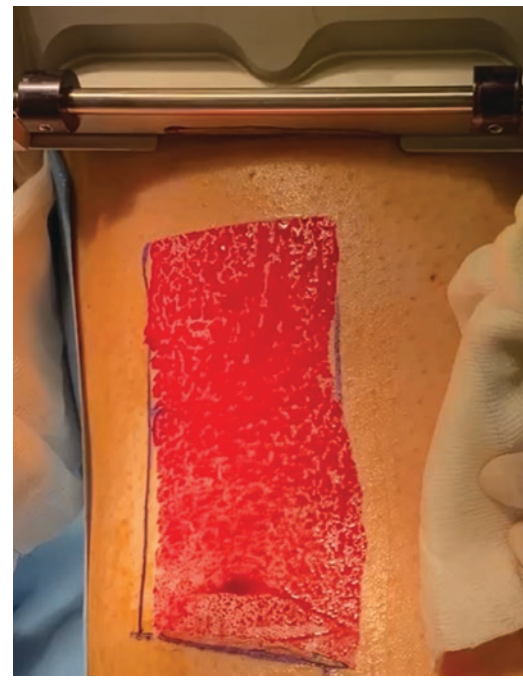

Fig. 22.10 Harvest of split-thickness skin graft with a dermatome

22.10.4.2 Full-Thickness Skin Grafts

Full-thickness skin grafts have a complete dermis and are the most commonly used grafts in skin cancer surgery. The graft is defatted, trimmed to match the defect, anchored with peripheral and basting sutures in place, and covered by a tie-over covering. Popular donor sites include pre- and post-auricular, conchal, upper eyelid, upper inner arm, and clavicle. Full-thickness grafts can yield an excellent cosmetic result if properly executed. The increased skin thickness, however, results in increased metabolic demand and a higher necrosis rate and failure rate.

Imbibition occurs within the first 24–48 h following placement of the graft. During this point, the graft is maintained by passive distribution of nutrients from the wound surface. The graft becomes edematous, and the network of fibrins attaches the graft to the bed. In the following stage, revascularization results from the connection of dermal vessels to the wound bed in the graft. Total circulation can be restored within 7 days.

22.10.4.3 Composite Grafts

Composite grafts typically consist of skin and underlying tissue (such as cartilage) and are primarily used to heal such wounds as nose alar rim full-thickness defects. These grafts have an increased need for nutrients and are thus more likely to fail. Cartilage grafts may be used for ear and nasal ala, or tip reconstruction.

22.11 Mohs Micrographic Surgery

This technique was developed by Frederic Mohs at the University of Wisconsin in the 1930s as a way to thoroughly control margins during skin cancer surgical excisions. The fundamental principles of surgical practice in Mohs micrographic surgery are similar to those used in traditional excision, although Mohs surgery poses specific challenges.

Key Point

Mohs micrographic surgical excision is a tissue-sparing technique that employs 100% of the surgical margin frozen-section control (Fig. 22.11). This measurement of the entire surgical margin using horizontal sections (not vertical, as used in normal section allocation) combined with accurate mapping enables the highest cure rate of skin neoplasms. Therefore, the sparing of normal adjacent tissue can enhance cosmesis and reduce the risk of functional defects in a sensitive anatomical position.

Immunohistochemical stains can be used to help distinguish tumor residuals in difficult cases.

The National Comprehensive Cancer Network indications for Mohs micrographic surgery are listed in Table 22.1. These indications should be followed to prevent Mohs surgery being overused in inappropriate clinical situations. Mohs operation provides 99% cure rates for primary BCCs and 96 percent for recurrent BCCs. Locally recurrent SCC has also reduced recurrence compared to other modalities when treated with Mohs surgery (9 vs. 24%). Certain other tumors that Mohs surgery can successfully treat include dermatofibrosarcoma, atypical fibroxanthoma, and microcystic adnexal carcinoma. Melanoma micrographic surgical excision with Mohs is also currently under investigation.

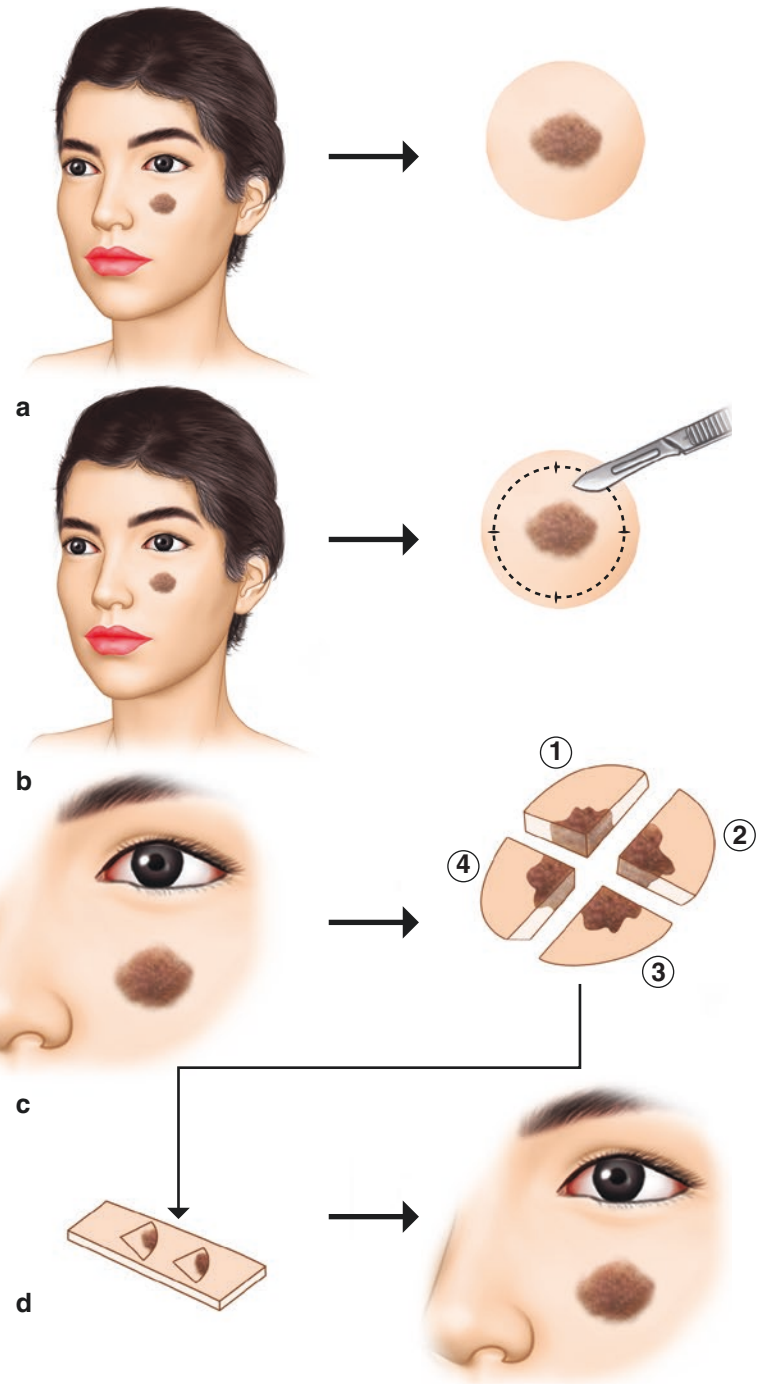

Fig. 22.11 Mohs micrographic surgery's phases. (**a**) Tumor debulked and delineation of clinical extent; (**b**) tumor excised with a minimal margin of normal tissue; (**c**) tumor mapping and sectioning; (**d**) frozen sections are prepared and microscopically reviewed. Further resections and reviews are performed until tumor is completely removed

Table 22.1 Indications for Mohs micrographic surgery

High-risk anatomic location (eyelids, nose, ears, lips, genitalia, fingers)
Large tumors (20 mm or more in diameter) on the torso and extremities
Recurrent tumors after previous excision or destruction
Tumors occurring in previous sites of radiation therapy
Tumors with aggressive histologic patterns (small-strand, infiltrative, or morphea-like growth in basal cell carcinomas; perineural invasion; or poorly differentiated histology or deep invasion in squamous cell carcinomas)
Tumors in immunosuppressed patients
Tumors with involved borders or vague clinical margins or incompletely excised tumors (positive histologic margins after resection)

Take-Home Messages

- More NMSCs are diagnosed annually worldwide than all the other cancers combined, and they result in about 2000–2500 deaths annually.
- Keratoacanthomas are low-grade SCCs which might regress but are preferably treated with surgical excision just like other SCCs.
- BCCs and SCCs are both mainly caused by UV radiation, rarely metastasize, and both require removal by simple surgical excision or Mohs surgery in selected cases.
- Advanced reconstruction techniques such as skin grafts or flaps can be used when primary closure is not possible/advisable in order to preserve functional anatomy and cosmesis.
- Mohs micrographic surgical excision is a tissue-sparing excisional technique that allows for control of 100% of the surgical margin, greatly enhancing both BCCs and SCCs cure rates.

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Plastic Surgery in Melanoma Patients

23

Eleonora Nacchiero and Fabio Robusto

Background

Malignant melanoma (MM) is a malignant cancer arising from the melanocytes, the skin's melanin-producing cells. It typically occurs in the skin, but it may rarely appear also in the uveal membrane of the eyes, mucosa of nose, mouth, or genitalia, and, rarely, in the internal organs.

The incidence of MM is higher in the Caucasian race, and nearly 85% of the MM that occur yearly in the world affect the populations of North America, Europe, and Oceania. To date, MM is the third most frequent cancer in both sexes under 50, and it represents the tenth most common cancer in men and seventh in women. However, these data must be considered underestimated due to the presence of a number of small or in situ superficial spreading melanomas that are removed and not analyzed from a histopathological point of view or are not recorded in cancer registries.

The frequent use of tanning lamps has been proved to be an important risk factor in the development of MM, and this risk is even greater if the exposure occurs before the age of 35 years. However, although the association between the risk of malignant melanoma and the frequent and intense exposure to ultraviolet rays has now been proven, it can occur in areas of the body without a significant sun exposure.

23.1 Introduction

Malignant melanoma (MM) is the most lethal form of skin cancer. While it was historically considered a rare cancer, in the last decades, its incidence continues to increase dramatically. Currently, more than 160,000 new cases of MM are diagnosed yearly worldwide.

If melanoma is diagnosed in early stages, resection of the lesion is associated with favorable survival rates; otherwise, MM is an aggressive malignancy that tends to spread with local, lymphatic, and hematic metastasis. In advanced melanomas, surgery is no longer sufficient, and recent use of target therapy, immunotherapy, and radiotherapy has demonstrated to improve sur-

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vival of these patients. On the other hand, these new expensive pharmacologic treatments have reached considerable costs in melanoma management; moreover, as incidence rises, in the next decades, costs of direct and indirect care are projected to concurrently rise. Currently, epidemiological studies try to better stratify populations at risk and to implement population-based prevention strategies.

23.2 Etiology and Risk Factors

Exposure to ultraviolet rays—even more if it is intense, frequent, and intermittent—is the principal risk factor in the development of malignant melanomas. The association between a frequent use of tanning lamps and MM, particularly if the exposure occurs before the age of 35, has been already demonstrated. Nevertheless, sun exposure without an adequate use of skin protection creams, particularly in more sunny hours of the day, is an important risk factor.

Population considered at high risk of developing MM are:

- People with Fitzpatrick skin type 1 (pale white with blond or red hair, blue eyes, and freckles who always burns and never tans)
- People with many moles (clinically atypical or dysplastic nevi)
- People with a positive family history of MM
- People with a personal prior diagnosis of MM
- People with environmental factors including excess sun exposure and UV tanning with sunburns

Regarding genetic susceptibility of hereditary melanomas, two genes are important:

- CDKN2A gene (cyclin-dependent kinase inhibitor 2A gene) codes for two proteins responsible of the negative control of the cell cycle: p16 and p14 (mutations of CDKN2A are present in 20–30% of families suspected of having an hereditary MM).
- CDK4 gene (cyclin-dependent kinase 4 gene): mutations of this gene alter the site of interaction with the p16 protein, with a consequent deregulation of the cell cycle (a mutation of the gene has been described in a few families of subjects affected by MM).

Individuals with a mutation in one of these genes may have up to a 67% or 74% lifetime risk to develop a melanoma, respectively, and they may also present multiple dysplastic or atypical nevi.

23.3 Clinical Evaluation

In clinical management of melanomas, it is essential to promptly identify suspicious lesions that need further diagnostic investigation and an appropriate surgical treatment. A commonly used algorithm for the detection of a suspicious MM is the so-called ABCDE criteria.

Key Point

ABCDE Criteria

Asymmetry: If you draw a line through the middle, the two sides will match, meaning it is symmetrical.

Border: A benign mole has smooth, even borders, unlike melanomas. The borders of an early melanoma tend to be uneven. The edges may be scalloped or notched.

Color: Most benign moles are all one color—often a single shade of brown. Having a variety of colors is another warning signal. A number of different shades of brown, tan, or black could appear. A melanoma may also become red, white, or blue.

Diameter: Benign moles usually have a smaller diameter than malignant ones.

Commonly, benign moles look the same over time. Be on the alert when a mole starts to evolve or change in any way.

Evolving or changing: A melanocytic nevus is usually stable and does not change in size, shape, or color, whereas a melanoma changes over time.

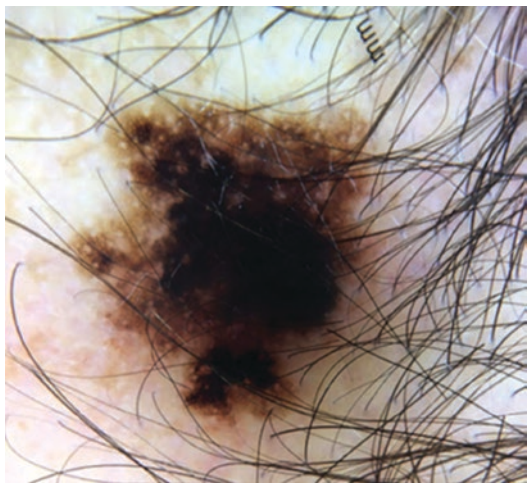

Fig. 23.1 Superficial spreading melanoma on the scalp

Self-skin examination by patients is an important tool to detect MM in early stages. Regular self-examinations have been shown to decrease the depth of melanomas at diagnosis and facilitate a lower risk of melanoma if coupled with regular visits with a physician.

In patients with numerous or atypical nevi, identifying new or changing melanocytic lesions can be challenging. Mole mapping with a dermoscopy is a noninvasive imaging technology used to improve diagnostic accuracy and surveillance and to detect earlier-stage melanomas, particularly in these patients.

Superficial melanomas have usually shown one or more of the following dermoscopic features (Fig. 23.1):

- **Broad network:** melanoma shows a thick reticular structure with irregular meshes which stops peripherally dividing into multiple branches of brown or black color.
- **Radial streaming:** peripheral structures which occur in closely spaced linear and radial oriented groups.
- **Pseudopods:** peripheral finger-shaped structures
- **Blue-white veil:** it can appear as a uniform and diffuse veil with focal irregularities. It is typical of MM.
- **Peripheral black dots/globules:** peripheral or oval brown or black structures that appear uniform in moles but are very inhomogeneous in MM.
- **Multiple brown dots:** small focal pigmented structures. They are often intensely black due to the presence of numerous melanocytes or free melanin.
- **Scar-like depigmentation:** they are white areas with fibrosis or pink areas with neoangiogenesis. In melanoma, regression can also occur with isolated gray-blue spots.
- **Multiple (5–6) colors, especially red and blue:** diffuse areas with no structures that appear very irregular in MM.
- **Focal sharply cutoff border:** while the border of the skin lesion fades out in atypical nevi, in MM, it is sharply demarcated in a small segment.
- **Negative network:** consists of serpiginous lighter grid lines that connect between hyperpigmented, elongated-to-curvilinear globules.
- **Irregular vascularity:** vascular structures can appear as globules or point-like or in other polymorphic aspects.

23.4 Histological Classification

To date, the reference for the histopathological definition of MM is provided by the diagnostic categories of the classification of skin tumors of the World Health Organization.

Key Point

Histological Classification

Superficial spreading melanoma (Fig. 23.2): the most common MM variant; it has often an initial slow radial growth phase before becoming invasive and begins a vertical growth phase. Usually it begins as an asymptomatic brown or black spot (but it can also be melanocytic) that can evolve changing in size, shape, or color. Often it may have asymmetry and irregular borders and sometimes ulcerations.

Nodular melanoma (Fig. 23.3): it is the second most common type of MM. It is characterized by not having a radial growth phase, but it progresses rapidly as a vertically growing tumor in a few months. It typically presents blue to black nodules, although it can sometimes be pink or red in color. These lesions also may have ulceration and bleeding.

Lentigo maligna: it appears usually as a large lesion that can occur in elderly patients with heavily sun-damaged skin. It begins as an irregularly shaped macule that slowly grows to form a larger spot. In situ forms can slowly grow in 5–15 years before becoming invasive. A typical sign of invasive changes is the formation of papules arising on the area of the lesion.

Acral lentiginous melanoma (Fig. 23.4): although it is equally frequent in all races, it represents the most common variant of MM in people with dark skin. It typically arises on the digits (frequently under nails), on the palms, and on the plantar aspects of the feet. In case of subungueal lesions, the differential diagnosis between melanoma and post-traumatic hematoma should be taken into account.

Desmoplastic and desmoplastic neurotropic melanoma: it is a rare form of MM in which the malignant cells within the dermis are surrounded by fibrous tissue. Desmoplastic melanoma often involves nerve fibers, when it is called neurotropic melanoma.

Melanoma arising from blue nevus: melanomas arising in association with or mimicking a blue nevi are a rare and heterogeneous group of melanomas.

Melanoma arising on a giant congenital nevus: giant congenital nevus is found in 0.1% of live born infants. If present, the lesion has a chance of about 6% to develop into malignant melanoma.

Melanoma of childhood: childhood melanoma usually refers to melanoma diagnosed in individuals under the age of 18 years. In this category are classified congenital melanomas, malignant blue nevus, spitzoid melanomas, and MM developing in brown birthmarks or in atypical or dysplastic moles.

Nevoid melanoma: a rare variant of MM characterized by morphologic features of nevus.

Persistent melanoma: the term recurrent melanoma has been abused, defining melanomas that returned after their visible portion has been excised, and for both local and distant metastasis.

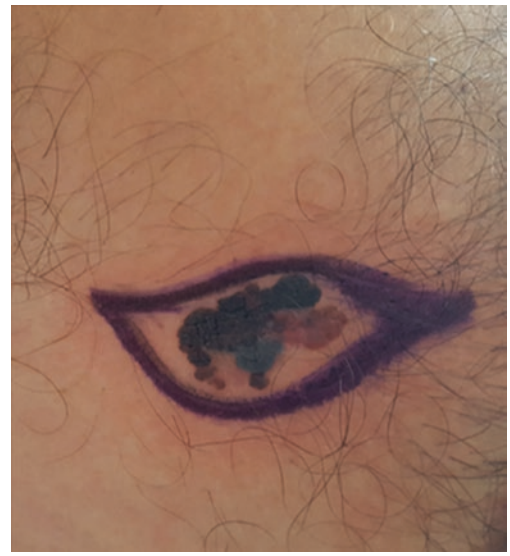

Fig. 23.2 Superficial spreading melanoma on the chest wall

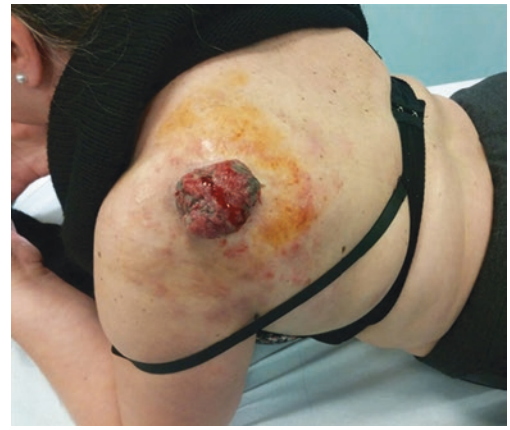

Fig. 23.3 Nodular melanoma on the shoulder

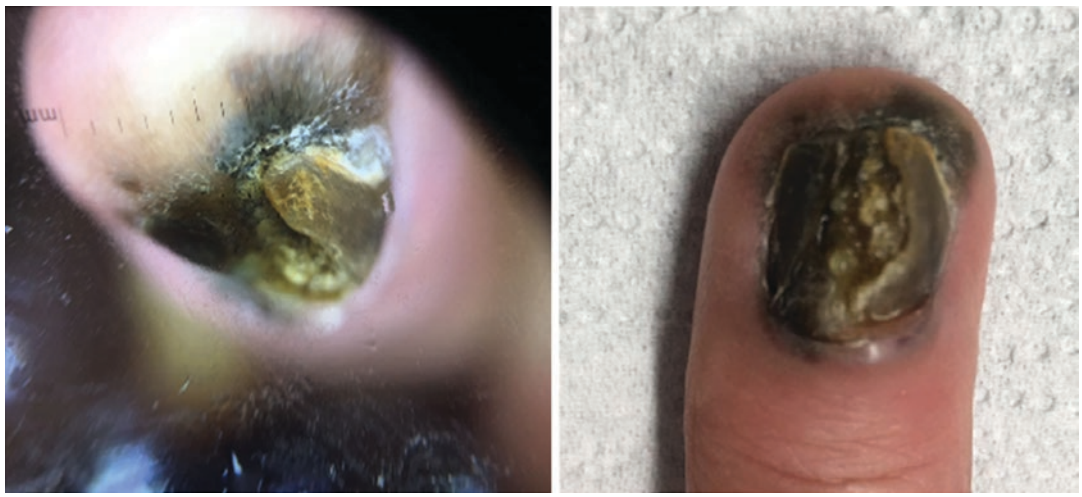

Fig. 23.4 Clinical and dermatoscopic aspect of a subungual melanoma

It's important to underline that although the histopathological classification is still in use, histotype is not currently considered an independent prognostic factor.

23.5 Surgical Biopsy of a Suspicious Lesion

The biopsy is essential for diagnosis and microstaging of the primary tumor, determining the choice of further therapy and establishing basic prognostic factors.

Any suspected skin lesion should be resected with an elliptical-fusiform full-thickness excisional biopsy. Superficial or incisional shaving is not recommended because it compromises the pathologic diagnosis and a complete and correct assessment of thickness of the primary lesion. Surgical incision should be oriented following the lymphatic drainage of the anatomical area. Thus, it should be parallel to the long axis of the limbs when surgery is performed on extremities, and it should be oriented toward the nearest lymphatic basin when surgery is performed on the trunk. Excisional biopsy should include the entire visible lesion plus a 2–3 mm of healthy margins. Wider margins are not recommended because they can affect the accuracy of the subsequent sentinel lymph node biopsy.

Tip and Tricks
In the preoperative surgical planning, it's important to keep in mind the need for a possible subsequent radicalization of the affected site if the histological examination confirms the diagnosis of MM. This is even more important in case of a wide primary lesion or in case of lesions located in areas with an esthetic or functional importance (Fig. 23.5), in which the use of skin grafts or cutaneous flaps could be required to cover the residual defect.

Complex surgical reconstructions using skin grafts or rotational flaps to cover the loss of substance of the primary site are not recommended because these surgical procedures unavoidably compromise the lymphatic drainage and, consequently, the lymphatic mapping affecting the accuracy of the sentinel lymph node biopsy (SLNB) procedure. Thus, the simple direct suture of the loss of substance is definitely preferred.

Tip and Tricks
In patients with a wide primary lesion at high clinical-dermatoscopic suspicion for invasive MM in anatomical region in which

a reconstruction with a skin graft or a flap should be needed, it can be proposed to perform a confocal microscopy examination and an incisional biopsy of the primary lesion. If these diagnostic methodologies confirm the suspicion of an invasive MM, the wide excision of the primary lesion and the sentinel lymph node biopsy can be performed during the same operative procedure (Fig. 23.6). Of course, the execution of an incisional biopsy could understage the thickness of the entire melanoma; for this reason, also in the case in which histological analysis of specimens prove in situ/thin melanoma lesions, the excisional biopsy of the primary lesion would become indispensable.

Anatomically, superficial spreading MMs show an initial radial growth phase within the epidermis and sometimes within the papillary dermis, which may be followed by a vertical growth phase with deeper extension, while, in nodular MM, the radial growth phase is absent or rapidly overrun by the vertically growing tumor. Theoretically, lesions in the radial growth phase are incapable of metastasis; however, there are numerous examples of thin melanomas that have behaved aggressively, even without convincing evidence of vertical growth.

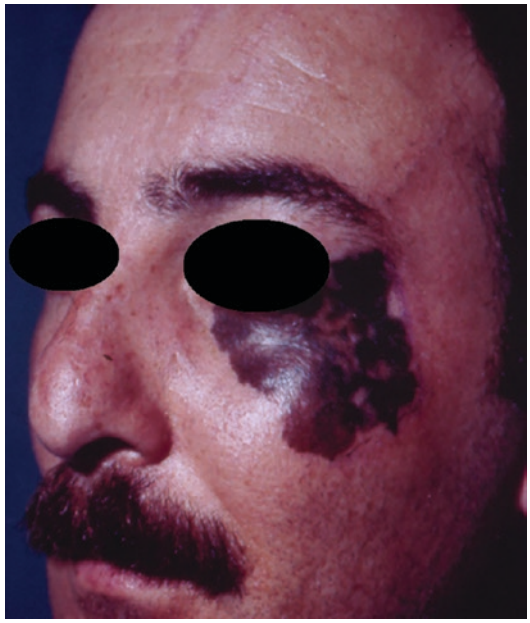

Fig. 23.5 Wide melanoma on the periocular region

23.6 Prognostic Factors for Primary Lesion

Microstaging of primary lesions is indispensable to guide further management and to determine prognosis of melanoma patients. In fact, clinicopathologic characteristics are associated with the clinical course of primary cutaneous melanoma, including metastases, and overall survival.

Key Point

Prognostic Factors for Primary Lesion

Clark's Level: it is a staging system, which describes the level of anatomical invasion of the MM in the skin. Level of anatomical involvement is assessed in 5°:

- *Level 1:* lesion affects only the epidermis (in situ melanoma).
- *Level 2:* lesion affects the papillary dermis, spearing the papillary-reticular dermal interface.
- *Level 3:* lesion fills and expands the papillary dermis, but it does not penetrate the reticular dermis.
- *Level 4:* lesion invades the reticular dermis.
- *Level 5:* lesion affects also the subcutaneous tissue.

Breslow's depth: it is a measure of the depth of primary lesion. Breslow's depth is determined by measuring the distance from the granular layer of the epidermis to the deepest part of the primary lesion. It is calculated following the right angle to which tumor cells have invaded the skin, and it is expressed in millimeters. The depth of the primary

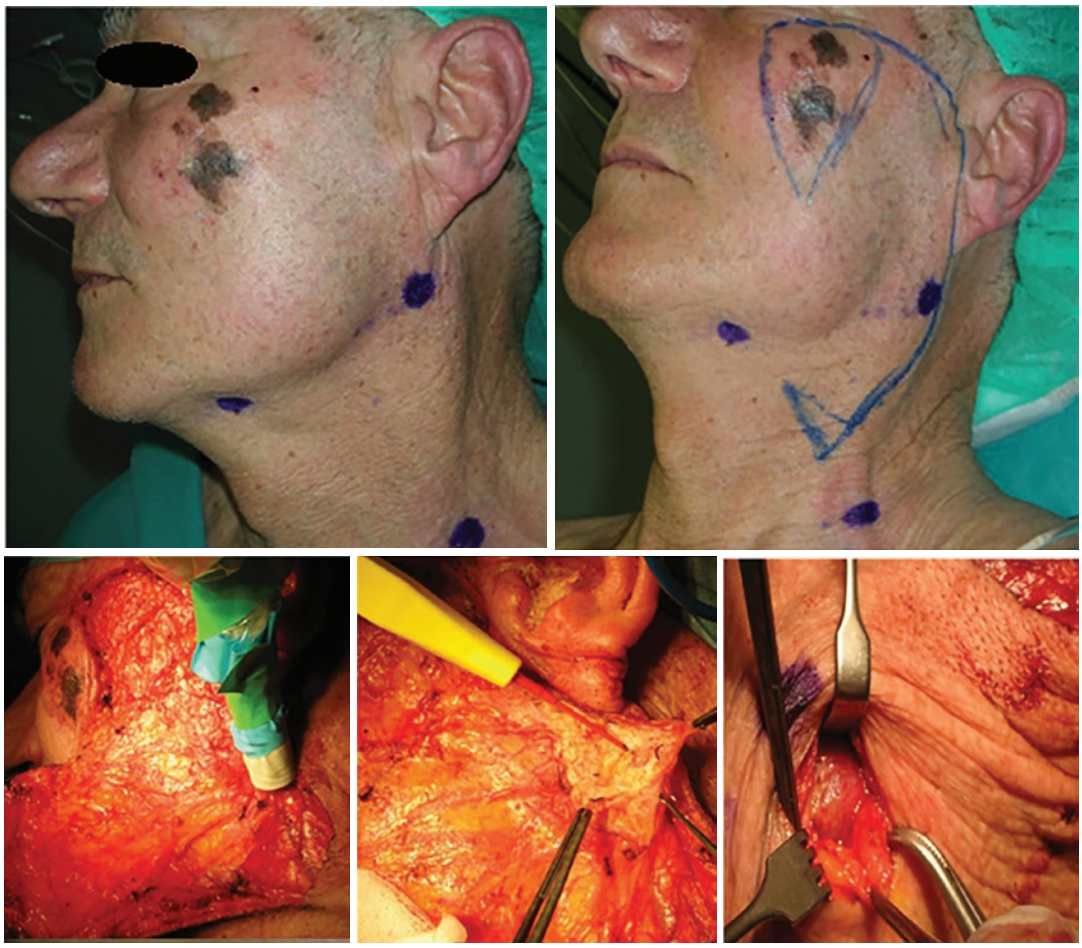

Fig. 23.6 Single stage procedure for the surgical treatment of a wide melanoma on the face

lesion is strongly correlated with survival, and it is an indispensable factor of the staging system for melanoma. To date, Breslow's depth is the preferred classification system to determine local invasion of primary lesions because of its more standardized measurement. With regard to the Breslow's death of local invasion, it is possible to individuate the following classes of risk:

- *<0.8 mm:* in situ *melanomas*
- *0.8–1 mm: thin melanomas*
- *1–4 mm: intermediate-thickness melanomas*
- *>4 mm: thick melanomas*

Ulceration: it is defined as the absence of an intact epidermis overlying a significant portion of the primary lesion. Its presence is a negative prognostic factor.

Mitotic rate: it is measured as the number of mitoses per square millimeter, and it is an indicator of tumor proliferation.

Regression (Fig. 23.7): it is defined as replacement of tumor tissue with fibrosis, telangiectasia, lymphocytic proliferation, and atypical melanoma cells.

Lymphovascular invasion: it describes the presence of absence of tumor cells invading the microvascular system of the dermis. Its presence increases significantly

the risk of local, lymphatic, or hematic metastasis.

Microsatellites (Fig. 23.8): they are defined as discontinuous nests of neoplastic melanocytes measuring more than 0.05 mm in diameter that are clearly separated by normal dermis from the main lesion.

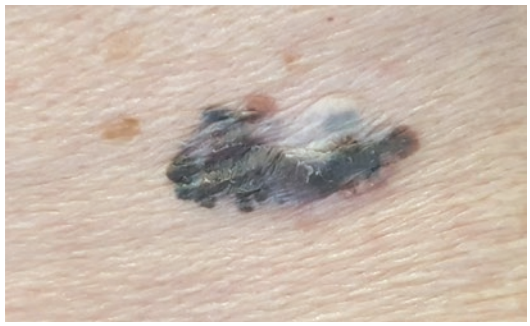

Fig. 23.7 Melanoma with a regression area

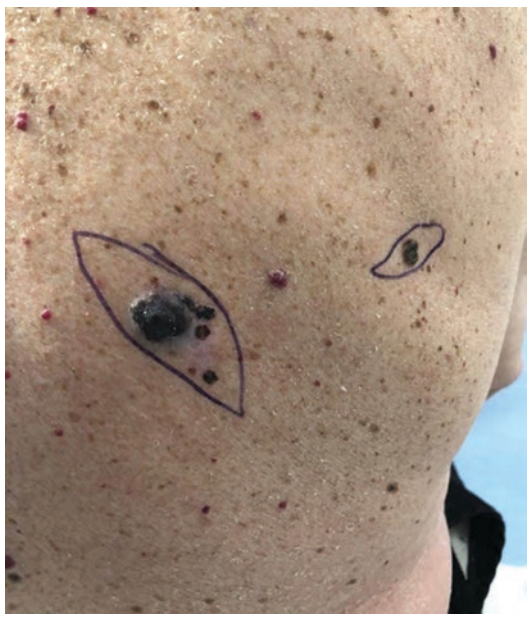

Fig. 23.8 Two primary melanomas on the back with satellite lesions identifiable in the proximity of the larger one

Another mandatory histopathological feature to be included in the pathology report is deep and peripheral margin status; the finding of tumor-positive margins requires a new excisional biopsy and restaging of primary lesion.

23.7 Wide Local Excision

After histological diagnosis of melanoma, the remaining skin scar must be re-excised. The wide re-excision is a therapeutic procedure, aimed to prevent the local recurrence and to cure patients in cases of local disease.

The excision should include the subcutaneous tissue up to the *muscularis fascia*, and margins of healthy tissue to be removed are established on the basis of the primary tumor thickness.

Key Point
Margins of Wide Excision
In situ melanoma: 0.5 cm
Breslow's depth ≤ 2 mm: 1 cm
Breslow's depth > 2 mm: 2 cm

Margins of the wide local excision may be modified to accommodate individual anatomic or functional considerations.

23.8 Sentinel Lymph Node Biopsy

The sentinel lymph node (SLN) is the first lymph node draining the region of the skin affected by MM. Sentinel lymph node biopsy (SLNB) is a minimally invasive surgical procedure useful in the detection of metastatic lymph nodes; it allows to better evaluate lymph node status identifying patients with metastatic involvement of lymphatic basin, clinically not palpable. SLNB is an indispensable tool for a correct and complete staging of melanoma, tailoring the better path-

ways of care for melanoma patients. Moreover, the status of regional lymph nodes is an important prognostic factor in patients affected by MM: the presence of micro-metastasis (presence of metastatic deposit ≤2 mm) or worst macro-metastasis (metastatic deposit >2 mm) affects sensibly prognosis of patients undergoing SLNB.

SLNB is indicated in patients with a Breslow's depth > 0.8 mm or in patients affected by melanoma associated with adverse prognostic features like regression, ulceration, high mitotic rate, vertical growth phase, or Clark's level 4–5.

Key Point

Indications for SLNB

Breslow's depth: a primary lesion thickness > 0.8 mm

Clark's level: Clark's level 4–5

Regression

Ulceration

High mitotic rate: ≥1 mitosis/mm^3

Vertical growth phase

Age: in young subjects, SLNB is always recommended

Preoperative lymphoscintigraphy provides accurate information about lymphatic drainage patterns, allowing a less invasive surgical procedure through a direct incision over the node, based on the images and probe counts. To date, lymphoscintigraphy is carried out using technetium 99 m-nanocolloid human serum albumin injected closely around the primary lesion or around the scar of the previous excision. The use of ultrahigh-resolution collimators is recommended to imagine all the territories between the primary melanoma site and the recognized draining node field or fields. Acquisition of static and dynamic images after the radiolabeled colloid injection and then after every lymph node visualization is important to be sure that all sentinel nodes were marked. The surgical procedure is simple and safe: a handheld gamma probe is used during surgery to guide sentinel lymph node detection; then, through a minimal skin incision,

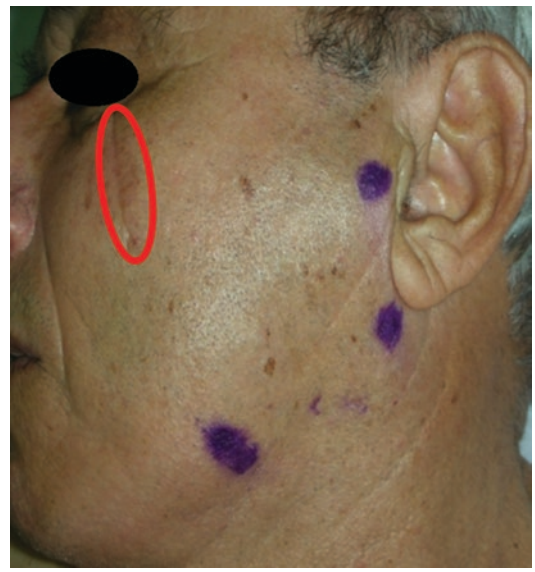

Fig. 23.9 Preoperative marking of 3 sentinel nodes in a malanoma on zygomatic region

the sentinel lymph node and the afferent lymphatic collector are isolated. Sometimes, lymphoscintigraphic features can reveal the identification of more than one sentinel node (Fig. 23.9): in these cases, all the marked lymph nodes must be surgically removed. Usually, these multiple sites occur in MM of the midline, and in these cases, two first lymphatic drainage pathways can lead to two different first sentinel lymph nodes from the initial tumor site.

Complications related to surgery are rare and usually not associated with significant morbidity. Usually, they are local, and the most frequents are wound dehiscence and infection, seroma, hematoma, lymphedema, and lymphocele; others more important but rare associated complications are nerve injury and thrombophlebitis, deep vein thrombosis, and hemorrhage. SLNB is the gold-standard procedure to assess lymphatic involvement in MM because of its high diagnostic sensitivity; use of CT, US, PET, or other imaging procedure has no similar sensitivity in the detection of lymph node metastases.

In some anatomical sites or in patients with wide primary lesions located in areas with an aesthetic or functional importance, execution of SLNB is more complex and less accurate. This is

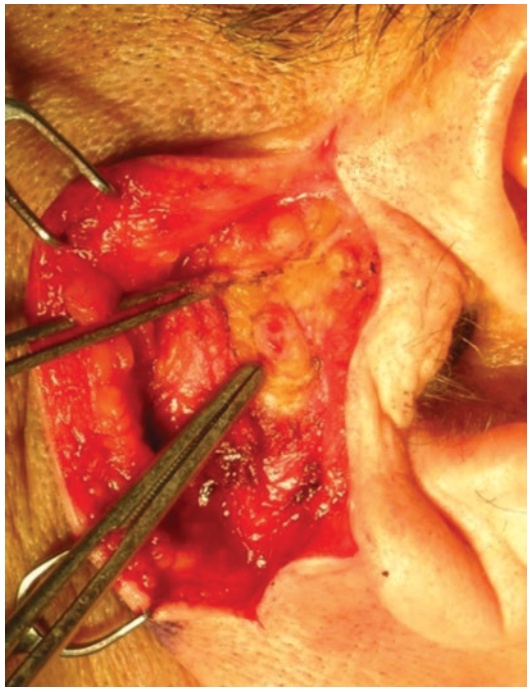

Fig. 23.10 Intraparotid sentinel lymph node

even true in MM in head and neck district, because of the extreme variability in the lymphatic drainage among different patients but also between the two hemispheres of the same patient. Moreover, frequently sentinel nodes of the head and neck melanomas are located into the parotid gland (Fig. 23.10); in these cases, surgeons should be very careful in SLNB execution because of the risk of facial nerve lesions. Finally, also the extreme proximity between the primary lesion and the latero-cervical lymphatic basin in head and neck MM and the possible complex reconstruction with flaps or grafts of the loss of substance can affect accuracy of lymphoscintigraphy. In these cases, it is rather advisable to perform in the same surgical procedure both wide excision of the MM and the SLNB and the reconstruction with flaps or grafts.

Tip and Tricks
Sometimes, the sentinel lymph node is not located in a common lymph node drainage basins (latero-cervical, axilla, groin) but outside of these areas between the primary MM and the standard drainage lymph node basin; this lymph nodes are called "Interval Sentinel Lymph Node." It has been demonstrated that these lymph nodes can contain metastasis (as well as the lymph nodes of the usual sites), and that's why they must be carefully researched and analyzed.

23.9 Lymph Node Dissection

Complete lymph node dissection (CLND) consists in the surgical remotion of lymph nodes from a lymphatic drainage field (axillary, latero-cervical, groin/iliac obturator). Traditionally, CLND was indicated for every patient with positive SLNB; but, to date, its indications are debated.

Arguments in favor of execution of CLND are:

- Improvement of regional lymphatic control of melanoma
- Prognostic value of additional positive non-sentinel lymph nodes
- Low morbidity of CLND
- Potential improvement of long-term disease-free period

Arguments against CLND include:

- Cost and morbidity of the procedure
- Absence of a demonstrated clinical benefit in all patients with positive SLNB

Recently, two prospective randomized trials have demonstrated that the performance of CLND did not improve prognosis of melanoma patients with positive SLNB, reserving the use of this procedure also in case of clinically evident lymphatic metastases.

When indicated, CLND should be radical, involving all anatomical levels of the lymphatic basin. In fact, the number of excised lymph nodes is a quality assurance measure for lymphadenectomy and a prognostic factor in melanoma patients.

Key Point

Extension of CLND in the Different Drainage Basin

Groin CLND: skin incision should be extended from the anterior-superior iliac spine to the inguinal ligament and vertically up to the apex of Scarpa's triangle. Superficial and deep inguinal lymph nodes, extended to the external and internal iliac up to the obturators nodes, are removed. If there is evidence of tumor-positive common iliac lymph nodes, they are removed up to the aortic carrefour. In the crural region, the fascia of the long adductor muscle and sartorius muscle is incised, and the adipose tissue that contains lymph nodes after dissection of the superficial and common femoral vessels is removed. The probability of clinically occult positive pelvic nodes is increased when there are clinically positive inguinofemoral nodes, three or more inguinofemoral nodes involved, or Cloquet's node is positive.

Axillary CLND: skin incision should be performed along the anterior pillar of the axilla, at the lateral margin of the pectoralis major muscle, sparing the pectoralis minor muscle when possible. Lymph nodes of level I (located laterally or below the lower margin of the pectoralis minor muscle), level II (located deeply in relation to the pectoralis minor muscle), and level III (located medially or superiorly to the upper margin of the pectoralis minor muscle) should be removed, extending lymphatic dissection laterally to the margin of the latissimus dorsi muscle, inferiorly to the subscapularis muscle, and medially along the chest wall up to the IV rib.

Latero-cervical CLND: dissection should provide the removal of the lymph nodes of I, II, III, IV, V, and VI levels, but it should spare, if possible, functional important anatomical vessels, nerves, or muscles. Parotidectomy should be performed only in case of certain positivity of the intraparotid lymph nodes.

23.10 Melanoma Metastases

MM could metastasize not only via the lymphatic pathways (Fig. 23.11) but also via the blood system (Fig. 23.12). The organs most frequently targeted by hepatic metastases of melanoma are the liver, lung, and brain but also the cutaneous and subcutaneous tissues.

Pearls and Pitfalls

The differential diagnosis among cutaneous and subcutaneous hematic metastasis of MM and in-transit metastases and/or satellitosis is important.

In-transit metastasis and satellitosis are secondary lesions located in cutaneous or subcutaneous tissue from the primary tumor and the nearest regional lymph node basin. These nosological entities are part of the regional lymphatic involvement, and prognosis of patients affected by melanoma in-transit metastasis and satellitosis is similar to that of patients with clinically positive lymph nodes.

23.11 TNM Staging

Currently, the American Joint Committee on Cancer criteria provide the following classes of staging of MM patients:

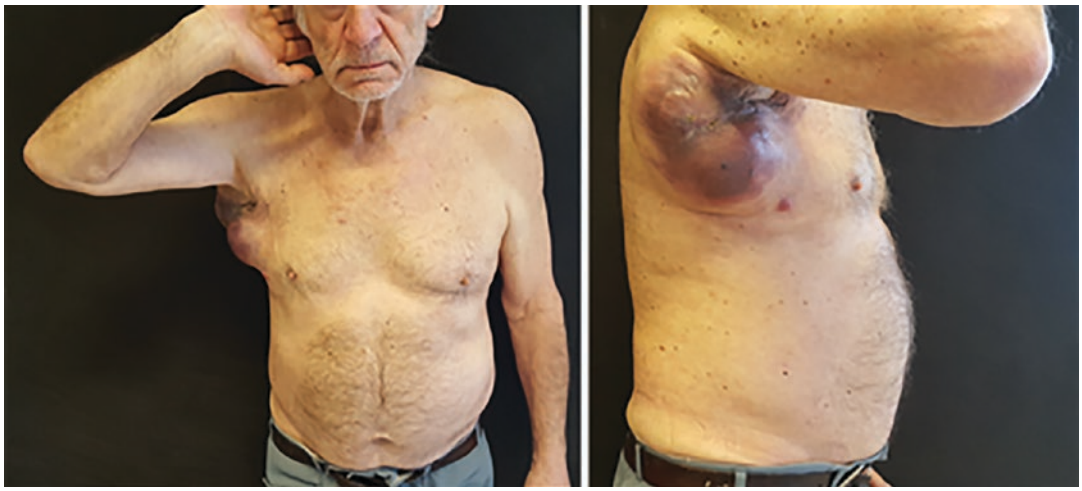

Fig. 23.11 Lymphatic metastasis of melanoma

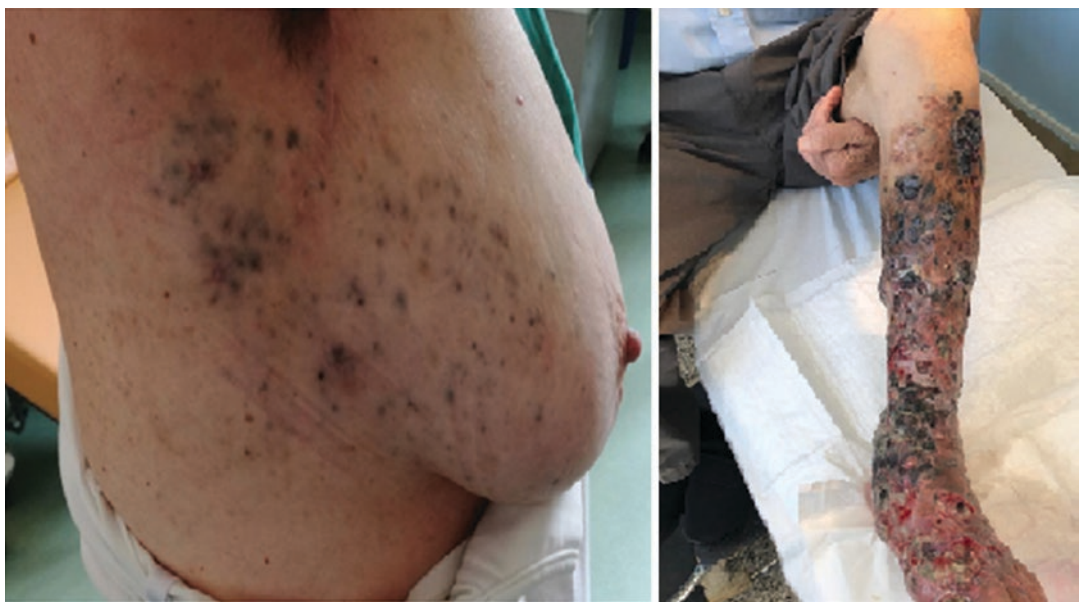

Fig. 23.12 Hematic metastasis of melanoma

- Stage 0: in situ melanomas
- Stage I: patients with primary lesion Breslow's depth $\leq$ 2.0 mm and without ulceration
- Stage II: patients with primary lesion Breslow's depth > 2.0 or presence of ulceration
- Stage III: patients with palpable regional nodes, as well as those with in-transit disease or microsatellites
- Stage IV: patients with distant metastases

Key Point

Molecular Characterization

To date, molecular characterization is crucial in management of MM patients, identifying mutations in specific genes correlated with melanoma development and tailoring therapeutic strategies. The most frequently involved genes are **BRAF** (present in approximately 50% of MM), **NRAS** (present in 30–40% of MM), and **c-KIT** (present in 1–3% of MM, especially in acral and mucosal melanomas).

23.12 Locoregional Treatment

In the last years, treatment of patients affected by locoregional metastasis of MM has been improved with the use of the following oncological procedure:

- **Hyperthermic-antiblastic perfusion** represents the first therapeutic option in patients with in-transit or unresectable metastases of the limbs.
- **Electrochemotherapy** is indicated in patients at high surgical risk for limited metastases arising on the trunk or in the head and neck districts, and it could be a complementary treatment after hyperthermic-antiblastic perfusion.
- **Radiation therapy** is indicated in case of in-transit metastases which are not eligible for other locoregional treatments.

23.13 Follow-Up

Accurate follow-up visits should be performed in reference centers with the multidisciplinary team.

Self-examination of any cutaneous or subcutaneous lesion is strongly recommended in patients with a prior MM. Moreover, an annual dermatological visit for life (preferably with a male mapping) is recommended. The indication to perform instrumental examinations and the frequency of periodic visits depend on the stage of the disease. The radiological investigations for the first 5 years after diagnosis include abdominal and lymphatic US every 6 months and chest X-ray once a year. For the subsequent 5 years, abdominal US, lymph node US, and chest X-ray will be performed once a year. In advanced stage, clinical and instrumental examination should be executed every 3 months for the first 2 years, every 6 months from the third to the fifth year, and annually after the fifth year. Any further specialistic instrumental exams will be requested when indicated.

Take-Home Messages

- Intense exposure to ultraviolet rays is the principal risk factor in the development of malignant melanomas.
- ABCDE criteria are a commonly used algorithm to detect suspicious lesions. Dermoscopy is an important tool to improve diagnostic framework.
- The excisional biopsy of suspicious lesions is essential for diagnosis and microstaging of melanoma.
- A proper microstaging of primary lesions is indispensable to guide further management and to determinate prognosis of melanoma patients.
- The wide re-excision of primary lesion is a therapeutic procedure to prevent local recurrences and to cure patients in cases of local disease.
- Sentinel lymph node biopsy is indicated in all patients with a Breslow's depth of >0.8 mm or in case of adverse prognostic features.
- To date, complete lymph node dissection is reserved to patients with clinically evident lymphatic metastases.
- Follow-up visits should be performed in reference centers with a multidisciplinary team.

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Sarcoma

24

Thomas Wright, Paul Wilson, Roba Kundahar, Tim Schrire, and James Coelho

24.1 Introduction and Background

Sarcomas are amongst the most diverse types of tumour encountered. Defined as any tumour arising from connective tissue, or embryologically of mesenchymal origin, they represent a fascinating mix of tumour types and therapeutic challenges. The word sarcoma arises from the ancient Greek word 'sarkoma' meaning fleshy growth. Whilst identified as forms of tumour since antiquity, sarcomas only gained specific definitions and cataloguing in the middle of the nineteenth century, with the advent of advanced microscopes and the birth of cellular pathology.

Sarcomas can arise almost anywhere in the body, commonly in the trunk or limbs, but also in the peritoneum and abdominal organs. Sarcomas are often sub-classified for the purposes of management into bone sarcomas or soft tissue sarcomas. Around 88% of sarcomas are of soft tissue origin and, in the UK at least, are managed primarily by plastic surgeons working within a multidisciplinary team (MDT). Soft tissue sarcomas include more than 50 distinct sub-types, but common tissue origins include fat, blood vessels, muscle and fibrous tissue. Sarcomas are malignant tumours, with the ability to metastasize, classically to the lungs. The propensity to recur and metastasize is largely dependent on grade rather than type of sarcoma.

24.2 Aetiology and Incidence

The majority of sarcomas are caused by de novo or new mutations in genes. These sporadic, random mutations lead to disorganized cell division and tumour formation. Processes that increase likelihood of mutation increase the risk of sarcoma—this includes exposure to ionizing radiation, which may be iatrogenic, age and additionally some rare genetic syndromes, such as Li-Fraumeni syndrome. Despite their multitude of sub-types, and varied body locations, sarcomas are generally a rare type of tumour. They amount to approximately 1% of all cancers. They can occur in all age groups, with various extremely rare sub-types showing a propensity for children rather than adults, such as Ewing's sarcoma. The majority of soft tissue sarcomas, however, affect the middle aged and older. This pattern lends itself to management in specialist centres that also provide soft tissue reconstruction.

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24.3 Soft Tissue Tumour Classification

Most sarcoma patients present with an enlarging mass. It is important to be aware that the vast majority of such 'lumps' are benign. Surgeons should be familiar with the variety of benign or 'intermediate' lumps that may still require treatment and confuse the diagnostic picture in patients referred with sarcoma. Plastic and reconstructive surgeons, with their intimate knowledge of anatomy, tissue-handling techniques, management of 'dead space' and knowledge of the reconstructive ladder, are in a superlative position to counsel patients as to the options of treatment.

24.3.1 Benign Lumps

These are lumps that grow locally, and slowly, and are not aggressive or invasive, with a low recurrence rate after resection. Surgery can be considered to confirm the diagnosis, for functional reasons such as local pressure effects or for purely cosmetic reasons. They are classified according to their predominant tissue type.

Adipocytic (fatty) tumours include lipomas (or multiple lipomatosis, known as Dercum's disease), angiolipomas (often painful) and hibernomas (composed of brown fat).

Fibrous tumours include nodular or ischaemic fasciitis, myositis ossificans (a calcified lump following trauma), elastofibromas (classically arising in a subscapular location in the elderly) and fibromas of tendon sheath. Many such types can be treated conservatively.

Muscle tumours may arise from striated muscle, such as rhabdomyomas (cardiac or extracardiac), whereas leiomyomas are derived from smooth muscle and referred to as fibroids if present in the uterus, but cutaneous leiomyomas are also found.

Vascular tumours include haemangiomas and lymphangiomas. Many such types are increasingly treated non-invasively by interventional radiologists.

Benign nerve sheath tumours include schwannomas and neurofibromas (often associated with neurofibromatosis and less commonly plexiform neurofibromas).

24.3.2 Intermediate Lumps

These tumours are characterized by their locally aggressive growth and a higher risk of local recurrence after excision. This locally aggressive nature can make surgical resection challenging to avoid damaging vital structures, or inadvisable if excision is more morbid than clinical observation. However, these tumours rarely metastasize.

Atypical lipomas are distinct from simple lipomas as they have a propensity for local recurrence after resection, but dedifferentiation to liposarcoma is extremely rare. They may have clinical and radiological features that indicate their atypical nature (large size, deep to fascia or MRI findings of septation or heterogeneous enhancement), but this may need to be confirmed with a core biopsy or excision. Cytological characterization with fluorescent in situ hybridization (FISH) reveals amplification of the murine double minutes (MDM2) gene in atypical lipomatous tumours and can therefore guide prognosis.

Desmoid-type fibromatosis can be locally aggressive but does not metastasize. It is usually sporadic but can be associated with familial adenomatous polyposis or Gardner syndrome. Progression of the disease can be unpredictable, and local recurrence following resection may occur in up to half of cases despite clear margins. For these reasons, watchful waiting is usually recommended in the first instance. Medical therapy, surgery or radiotherapy may be considered for progressive disease.

Dermatofibrosarcoma protruberans is a tumour of the dermis that is locally aggressive but rarely metastasizes. It has a high incidence of recurrence after resection unless widely excised, and clear pathological margins are confirmed.

Atypical fibroxanthoma (AFX) is a low-grade spindle cell tumour of the dermis. If they are larger than 2 cm with other pathological fea-

tures, then they are classified as pleomorphic dermal sarcomas. Local recurrence is common but they rarely metastasize.

Tenosynovial giant cell tumour is a benign tumour of the synovium and may be localized or diffuse (previously known as pigmented villonodular synovitis, PVNS). Complete excision is recommended, but recurrences are common.

24.3.3 Sarcomas

Malignant soft tissue tumours are known as sarcomas. They are invasive and may metastasise distantly via a haematogenous route or, less commonly in certain sub-types, to regional lymph nodes.

Liposarcomas are soft fatty tumours that can occur anywhere in the body.

Fibrosarcomas have a variety of sub-types, but their cells are known as histiocytes or fibrocytes and are most commonly diagnosed in the limbs.

Undifferentiated pleomorphic sarcoma is a high-grade fibroblastic subtype that was previously known as malignant fibrous histiocytoma.

Leiomyosarcomas develop from smooth muscle cells and are the most common soft tissue sarcoma. They may arise anywhere in the body as smooth muscle forms the walls of blood vessels and many other organs. They may also arise within the uterus.

Rhabdosarcoma are less common and are derived from striated muscle cells. They are aggressive and more commonly found in children and younger adults, depending on the subtype.

Synovial sarcoma is a less common variety, which is more commonly found associated with large joints, is usually high grade and can metastasize via the lymphatics.

Epithelioid sarcoma is another variety that is associated with a young adult age group, is usually high grade and is uncommon in that may spread via the lymphatics.

Angiosarcomas are derived from blood or lymphatic vessels. They are often aggressive and metastasize locally and to distant sites. They can arise in sites of chronic lymphoedema or previous radiotherapy and are commonly seen in the breast.

Malignant peripheral nerve sheath tumours (also known as neurofibrosarcomas) arise in the connective tissue around the nerve and may therefore give rise to neurological symptoms associated with that nerve. Around half of cases are associated with a diagnosis of neurofibromatosis type 1.

24.4 Diagnosing Sarcoma

Multidisciplinary meetings (MDTs) are central to the management of sarcoma patients and are considered gold standard in cancer care. Introduced to the NHS in 1995, MDTs improve overall patient outcome by reducing variation in access to services and allowing for better continuation of care. The National Institute of Healthcare Excellence (NICE) recommends all patients in the UK with a suspected soft tissue sarcoma are managed within a sarcoma MDT [1].

In these weekly meetings, a wide range of health professionals come together to discuss each patient and formulate an agreed management plan. Sarcoma MDTs will usually consist of oncologists, surgeons, radiologists, pathologists, specialist nurses and physiotherapists. Surgeons from multiple sub-specialties (orthopaedics, general surgery, urology, thoracics) may be involved depending on the site of the sarcoma. In the UK, it is generally plastic and reconstructive surgeons that lead the surgical MDT, due to their knowledge of anatomy and reconstructive options that can guide what is feasible for each patient and tailor treatment according to needs.

24.5 Referral Pathway for Suspected Sarcoma

Soft tissue masses are common in the population, and fortunately, most lesions are benign. A diagnosis of sarcoma should be suspected in anyone with a soft tissue lump with any of the following features, as these make a sarcoma more likely as the underlying diagnosis.

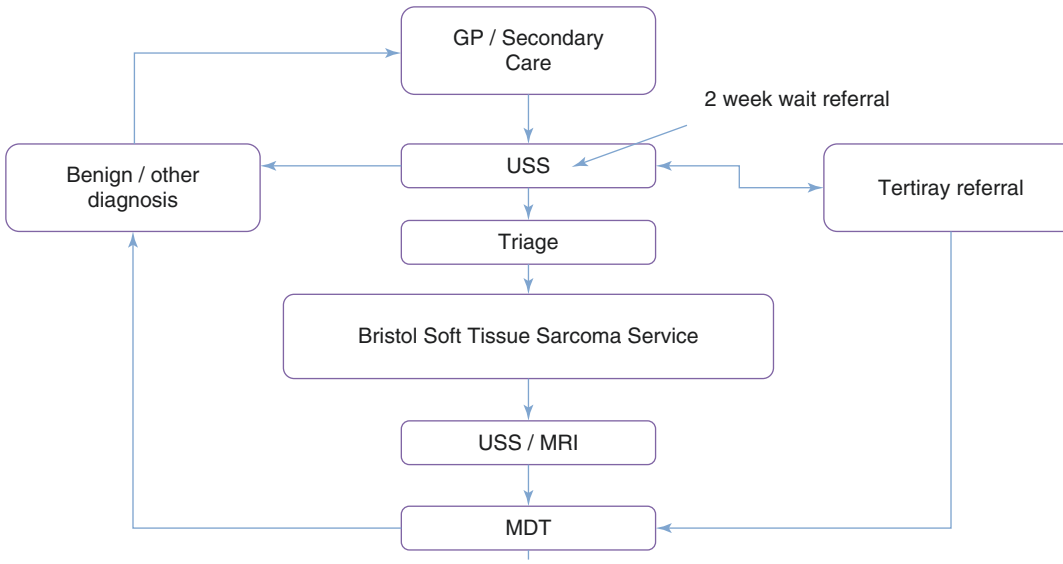


Fig. 24.1 Example of a regional suspected soft tissue sarcoma referral pathway

- Increasing in size
- Size more than 5 cm
- Painful
- Appears deep clinically or on a scan (Fig. 24.1)

Referred patients are clinically assessed through history and examination by a sarcoma specialist. Imaging and biopsy then complete the clinical picture, followed by re-discussion at MDT to formulate a treatment plan.

Diagnostic Imaging: Ultrasound scan by a specialist is normally the first-line investigation, ideally performed simultaneously with history and examination assessment. If there continues to be suspicion of sarcoma, further imaging, usually an MRI (Fig. 24.2), is performed. Additional scans such as X-rays if bone involvement is suspected or CT scans for retroperitoneal masses may be performed.

Biopsy: An urgent biopsy is performed of anyone with a suspected soft tissue sarcoma. The aim of tissue biopsy is to confirm malignancy and provide information on grade and subtype of sarcoma, which in turn directs subsequent management.

Usually a percutaneous core needle biopsy is performed under ultrasound or CT guidance by an experienced sarcoma radiologist. The biopsy is planned in a way that allows removal of the biopsy track during definitive surgery. Multiple core biopsies are taken from different parts of the lesion, especially if it appears heterogeneous on imaging to provide maximum diagnostic yield. A fine needle aspiration (FNA) is not usually recommended for suspected primary soft tissue sarcoma. Small lesions (<2 cm) often have non-specific features on ultrasound and MRI scans. The diagnostic yield can be low on core biopsy. Therefore, an excision biopsy may be considered for these lesions. Excision or incision biopsies may also be considered to confirm recurrent or metastatic disease. If open biopsy is performed, longitudinal incisions are made in the extremities and in line with the eventual definitive resection incision and minimal contamination of the surrounding tissues.

24.6 Staging and Grading Sarcoma

The grade of a tumour is a description based on how abnormal the cell looks on histology and provides crucial prognostic information. The Fédération Nationale des Centres de Lutte Contre le Cancer (FNCLCC) grading system [2] is generally used for soft tissue sarcomas. This system provides categories (well, moderate and poor) depending on tumour differentiation, necrosis and mitotic count (Table 24.1).

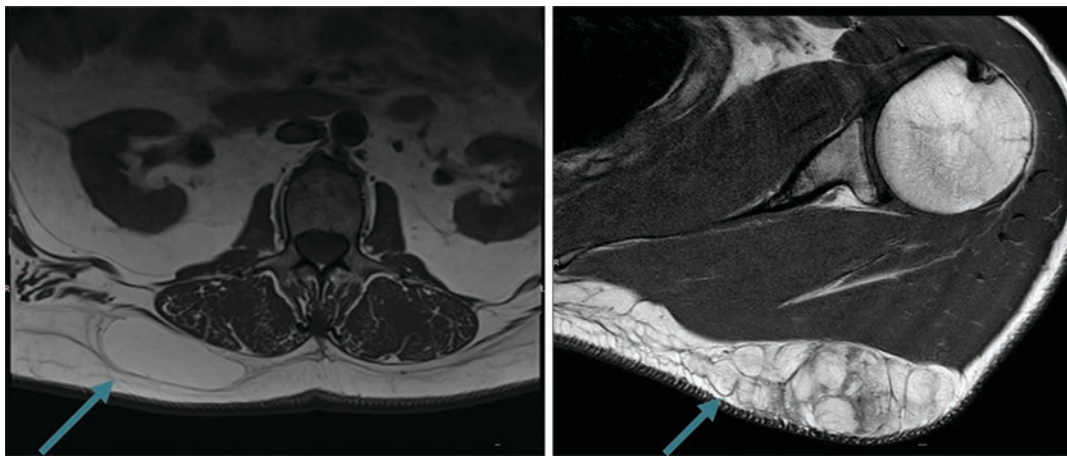


Fig. 24.2 Appearance of lipomatous lesions on MRI. (Left): Homogeneous appearance likely to be benign. (Right): Heterogeneous appearance suspicious of malignancy

Table 24.1 FNLCC histological grading criteria

Tumour differentiation	Necrosis	Mitotic count (*n* per high-power fields)
1. Well	0:Absent	1:$n < 10$
2. Moderate	1:<50%	2:10–19
3. Poor (anaplastic)	2:≥50%	3:$n \geq 20$

The sum of the scores of the three criteria determines the grade of malignancy. Grade 1 = 2 or 3; Grade 2 = 4 or 5; Grade 3 = 6

It is important to note that some sarcomas may have uniform histological features despite being higher grade. Increasingly, molecular pathology-based tests such as fluorescent in situ hybridization (FISH) are used to complement traditional techniques (based on morphology and immunohistochemistry) to aid diagnosis of sarcoma. For example, A FISH test for the MDM2 locus can be used to differentiate between a lipoma and a well-differentiated liposarcoma.

Staging of a cancer indicates the extent of the disease by describing its size and spread to other parts of the body. The most widely used staging system for soft tissue sarcoma is from the American Joint Committee on Cancer (AJCC). Findings from physical examination, imaging scans and grade of the sarcoma are used as part of the staging process.

Once all information is available, the final staging as per AJCC [3] is as follows (Table 24.2):

Table 24.2 AJCC staging system for soft tissue sarcoma. The eighth version sub-classifies the system for different anatomical locations

Stage I	
1A	Low grade, small (G1/X, T1a/b)
1B	Low grade, large (G1/X, T2a/b, N0)
Stage II	
IIA	Intermediate or high grade, small (G2/3, T1a/b, N0, M0)
IIB	Intermediate grade, large (G2, T2a/b, N0, M0)
Stage III	High grade, large, (G3, T2a/b, N0, M0) Regional node involvement, with any size and grade of primary tumour (G1–G3, T1–T2, N1, M0)
Stage IV	Metastasis identified (G1–G3, T1–T2, N0–N1, M1)

Imaging for staging: This is performed once a diagnosis of soft tissue sarcoma has been confirmed on biopsy. A staging CT chest is performed prior to definitive treatment to exclude pulmonary metastases. A CT scan for the abdomen and pelvis may be considered for lower extremity sarcomas. Additional scans may be performed depending on the subtype of the sarcoma—this may be to assess regional nodal basins or because of known metastatic patterns. MRI scanning, if not already performed, may be required to determine anatomical boundaries and whether a tumour is

surgically resectable. Whole body MRI scans or PET-CT scans, although not routinely used, can provide useful information in detecting metastases in some patients. A chest X-ray can be considered sufficient instead of a CT scan for certain low-grade sarcomas due to very low metastatic potential.

24.7 Management of Soft Tissue Sarcomas

The management of STS is primarily surgical. Depending on the grade of tumour, patients may be offered radiotherapy either before (neoadjuvant) or after (adjuvant) surgery to reduce the risk of disease recurrence.

Chemotherapy tends to be reserved for advanced or metastatic disease but is considered as neoadjuvant therapy for certain sub-types such as synovial or Ewing's sarcoma, in combination with surgery and radiotherapy.

24.8 Surgical Management

When planning surgery, patient comorbidities, topographical anatomy and tumour stage and grade must be considered. Detailed surgical planning and reconstruction are made after a full MDT discussion. Patients with inoperable tumours, or with metastatic spread, are considered for palliative radiotherapy, chemotherapy or best supportive care. An important measure of successful sarcoma treatment is the surgical tumour margin. Broadly, there are four types of excision: (1) intra-lesional; (2) marginal; (3) wide local; and (4) radical.

Intra-lesional excision (or 'whoops' operation) is usually as a result of inadequate pre-operative assessment, often in a non-specialist unit where a lesion has been assumed benign. Macroscopic tumour is left in situ, and the prognosis is worse with local recurrence (LR) rates of 80–100%. Sometimes, marginal excision may be required, due to tumour proximity next to critical structures, such as major nerves and blood vessels, potentially leaving microscopic tumour in situ (LR rate 40–60%). There is no difference between patients undergoing unplanned excision and planned excision regarding local recurrence and overall survival. The planned excision group has a higher risk of distant metastasis, whereas there is a high rate of residual cancer in the unplanned excision group [4]. Wide local excision (WLE) involves removing the tumour in its entirety with a surgical margin of 1–3 cm (depending on feasibility) or a clear fascial plane (LR rate $\leq$ 10%). Radical excision includes compartmental excision and amputation. Although gaining greater surgical clearance, both carry higher surgical morbidity and post-operative functional loss (LR rate 0.5%). As with many malignant tumours, prognosis is not significantly improved by radical procedures [5].

Pearls and Pitfalls

Such options may confuse the onlooker. In general, the main priority is excision of tumour with clear histological margins. This includes planning the excision to include any previous cutaneous biopsy sites and meticulous surgery with adequate margins, to avoid contamination of the surgical bed. How radically to excise a tumour will depend on the extent of surgery a patient will physiologically tolerate, their rehabilitation potential, the reconstructive options and the proximity to vital structures which removal will significantly affect function. Pre-operative radiotherapy of high-risk soft-tissue sarcomas allows for good local control rate at the expense of local wound complications, which are, however, manageable with plastic surgical techniques. For this reason, plastic and reconstructive surgeons are in the best position to advise patients in treatment, of which there is likely to be a choice of options.

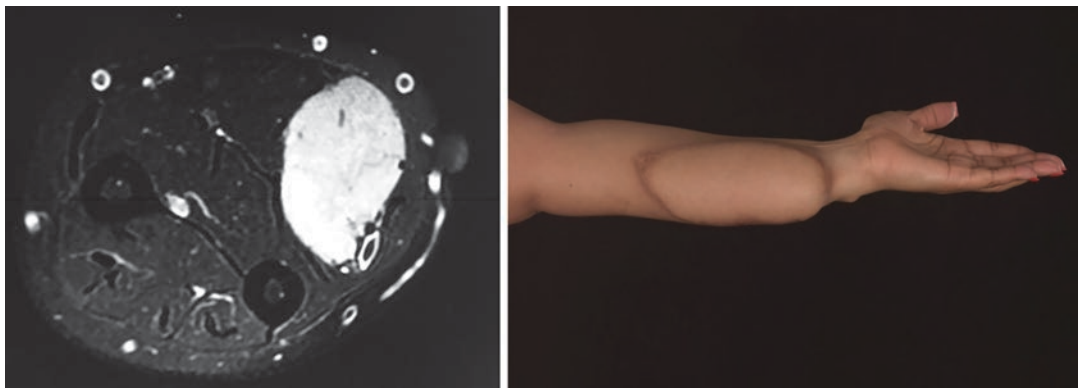
Tips and Tricks

For low-grade tumours, wounds are usually best closed directly or with split skin grafting. For high-grade tumours, soft tissue reconstruction is often indicated to promote healing by primary intention whilst managing the dead space with soft tissue infill and coverage of joints or vital structures. STS excision involving critical structures that would have detrimental effect on limb function may be appropriate for functional restoration. This may involve reconstruction of the skin, bone, vessels, nerves and muscles [6]. Examples include using great saphenous vein graft for femoral vein reconstruction and inter-positional nerve grafts such as cabled sural nerve for nerve reconstruction. Pedicled musculocutaneous flap transfer includes regional flaps such as latissimus dorsi flap to reconstruct flexion at the elbow, following biceps brachii excision. Functional reconstructions can also employ a free flap that has vascularised nerve and musculo-tendinous units within the soft tissue reconstruction, so-called chimeric free flap [7], such as free innervated gracilis myocutaneous flap for anterior compartment lower limb reconstruction. Other techniques such as component separation can be used for abdominal wall reconstruction. For thoracic wall reconstruction following extirpation of sarcoma, a composite reconstruction with mesh and cement is utilized combined with adequate soft tissue cover.

Such cases can be the most challenging of all reconstructive operations. Many patients are elderly and physiologically fragile, and surgical beds are large and have had or will have irradiation. Sarcoma surgeons have to work all around the body and must have good knowledge of likely recipient vessels and a variety of workhorse flaps to be familiar with. Some tumours can grow fast and have prolific blood supply, and it is advisable to enter surgery with a flexible mind and a backup plan.

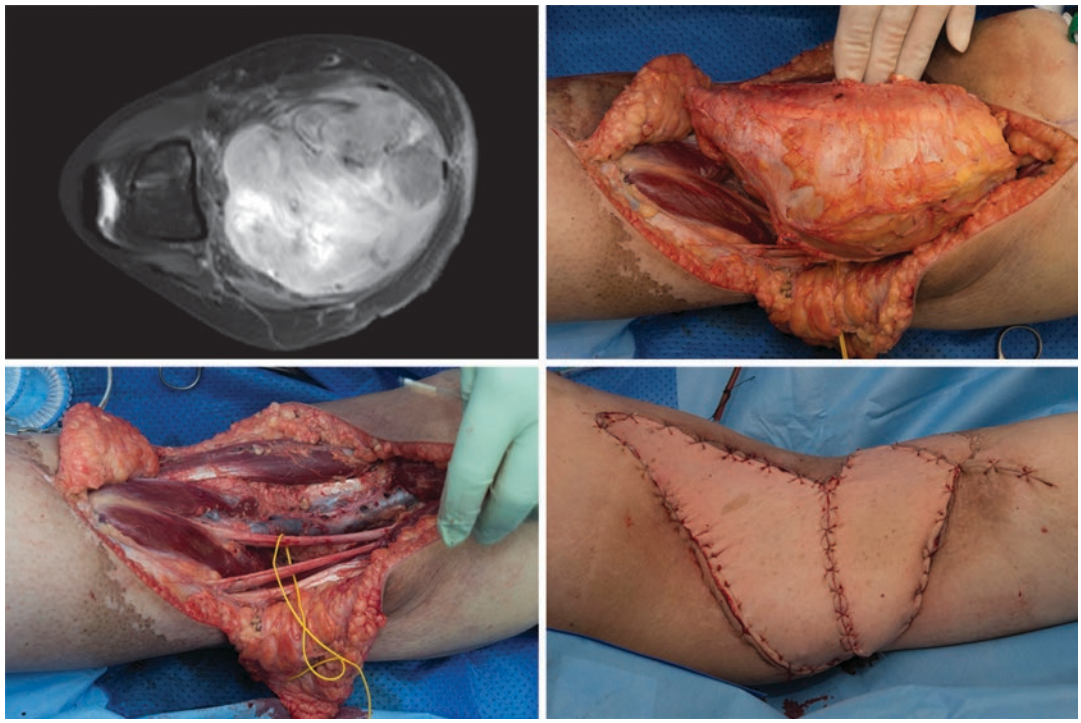
24.8.1 Example 1: Free Flaps

A sarcoma of the distal forearm involving the ulnar artery and nerve (coronal MRI left), reconstructed with flow through ALT free flap and partial nerve grafting (right).



24.8.2 Example 2: Chimeric Free Flaps

A sarcoma of the flexor compartment of the thigh, adjacent to but not involving sciatic nerve (MRI top left, tumour resection top right), reconstructed with chimeric neurotized latissimus flap to restore hamstrings and parascapular/scapular flap for skin cover (defect bottom left, flap in situ bottom right)



24.9 Radiotherapy

Radiotherapy (RT) is considered for all intermediate- and high-grade tumours. Deep low-grade tumours with marginal excision are managed by interval surveillance. Patients who have undergone radical excision do not require RT if their histological margins are clear.

RT in STS is administered via external beam, using intensity-modulated radiation therapy (IMRT), which allows better mapping and targeting of the tumour, reducing the scatter of the radiotherapy to unaffected adjacent tissues. The dose is 60–66 Gy in 1.8–2 Gy fractions. RT is either administered 5 days a week, pre-operatively (neoadjuvant) for 5 weeks or post-operatively (adjuvant) for 6 weeks [8].

The consensus in the UK is still out as to whether patients are best treated with neoadjuvant or adjuvant RT. Some cases however lend themselves to one or the other. For example, a patient with a rapidly enlarging, ulcerating tumour would be best managed with surgery first, compared to a large tumour adjacent to critical structures which is marginally operable best managed with radiotherapy first to reduce the risk of local recurrence. Furthermore, some histological STS sub-types like myxoid liposarcoma are more radiosensitive than others, lending themselves well to neoadjuvant RT [9, 10].

Neoadjuvant RT	Adjuvant RT
Lower dose (50 Gy, with option of 10–16 Gy adjuvant if required)	Higher dose (60–66 Gy)

Neoadjuvant RT	Adjuvant RT
Splinted/obvious tumour bed (less adjacent, healthy tissue damage)	Disrupted/unclear tumour bed (more adjacent, healthy tissue damage)
Increased wound complications	Reduced wound complications
Poor function post-operatively	Relatively better function post-operatively
Psychological delay of surgery for the patient (surgery performed 6 weeks following RT completion)	Physical prompt removal of tumour (RT can commence 4–6 weeks following surgery)

24.10 Chemotherapy

Some STS are particularly chemosensitive, including synovial and Ewing's sarcomas. Most STS however are less chemosensitive which, coupled with a lack of strong evidence to support its use in adults with STS, means chemotherapy does not play a significant role in their primary management. On occasions where a marginal excision is planned, neoadjuvant chemotherapy may be considered by the MDT [11].

Treatment of advanced disseminated disease with palliative chemotherapy is complex and largely depends on whether the patient has symptoms such as pain or dyspnoea from their disease. Response from chemotherapy varies from 10 to 50% and depends on the drugs used, patient selection and histological subtype. Young, physiologically fit patients with no liver metastases tend to respond best [12]. Single agent (doxorubicin 75 mg/m^2, thrice weekly) is used for a maximum of six cycles, due to cardiotoxicity, with a response rate of <20%. Second-line treatment is ifosfamide, with a response rate of around 8% [13, 14]. The combination of both agents has been trialled, but demonstrated no significant difference compared to doxorubicin alone [15].

24.11 Prognosis

Whilst sarcoma survival rates have been steadily improving, it remains one of the cancers with a poorer prognosis. Death is usually secondary to metastasis, predominantly to the lungs, but also to other viscera, bones and brain. Single metastases, if confirmed radiologically, may still be suitable for curative surgery or procedures for symptomatic purposes. Prognosis depends on the following:

- Type and location of the tumour
- The stage and grade of the cancer
- Patient age and comorbidities

In the UK, around 75% current 1-year survival rates are there for intermediate- and high-grade sarcoma patients. Male patients tend to do slightly better than their female equivalents. This survival rate drops down to 53% at 5 years and 45% at 10 years. The more-than-65-year-old cohort conversely has better survival rates than younger patients.

One of the challenging factors to improve prognosis is low public awareness of the disease; sarcomas are not a well-known tumour group with a distinctive pattern of symptoms. With this relatively anonymous collection of symptoms and low index of suspicion in the patient population, presentation is often late, or these tumours are incidentally discovered.

Key Points

In conclusion, sarcomas represent a diverse and challenging group of tumours. Concern should be raised for any patient presenting with a painful, deep, growing mass. Sarcoma assessment generally follows the triple assessment approach of a clinical history and examination, radiological imaging and biopsy and discussion in MDT setting. Plastic surgeons, with their experience of tissue handling and management of difficult wounds, with potential large areas of dead space and exposure to irradiation, their knowledge of reconstructive techniques, understanding of anatomy and effect on function depending on the proximity of vital structures, are in the best position to advise patients of the surgical and reconstructive options in treatment.

Take-Home Message

Sarcomas are rare and have variable growths. Suspicion should be raised by any rapidly enlarging painful mass and should be referred urgently to specialist centres where a MDT after appropriate investigation will decide the best treatment option, likely a combination of surgery and radiotherapy if treatable. Outcome will depend on the type, stage and grade of the tumour.

24.12 Useful Reading

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Part V

Reconstructive Plastic Surgery

Breast Reconstructive Surgery

25

Jaume Masia, Cristhian D. Pomata,
and Patricia Martinez-Jaimez

Background

Breast cancer is the most common cancer in women worldwide [1]. Although the incidence varies widely according to race and age, it is estimated that approximately one in eight women (about 12.4%) will be diagnosed with breast cancer at some point during their lives [2]. Nevertheless, the overall survival rate has improved significantly in recent years and is currently about 80% at 15 years [3].

Surgery is generally the first line of attack in the therapeutic management of breast cancer, but evidence shows that mastectomy has a significant impact on patient self-esteem and body image perception [4–6]. For this reason, breast reconstruction after mastectomy is an integral part of breast cancer treatment as it will improve patients' quality of life [7, 8].

With recent technological advances and greater knowledge of anatomy, reconstructive procedures have been refined, and new techniques have been developed. The many surgical alternatives now available can be divided into those which involve prosthetic devices and those based on patients' own tissue.

Considering that each breast reconstruction technique has specific advantages and disadvantages, the same procedure may not be suitable for all patients. The choice of breast reconstruction technique will therefore depend on many factors, especially the patient's personal preferences and desired outcome.

25.1 General Considerations

The ideal goal of breast reconstruction is to replace the resected breast tissue with something similar to the natural breast in terms of size, shape, and texture. The reconstruction should also be stable over time and achieve symmetry with the contralateral side.

An important consideration to keep in mind during the planning process is the timing between mastectomy and breast reconstruction. Both immediate and delayed breast reconstruction are valid options. However, the decision must be

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made individually in order to guarantee oncological safety and to optimize functional, aesthetic results.

Immediate breast reconstruction is increasingly considered an option in patients undergoing oncologic breast surgery. Although it represents an additional procedure to mastectomy, performing the two procedures in a single operation provides a considerable psychological benefit by avoiding the emotional impact on body image after ablative surgery. Additionally, when the native breast skin envelope and inframammary fold are preserved, the reconstructed breast usually assumes a more natural cosmetic result (Table 25.1).

In contrast, delayed breast reconstruction can be performed months and even years after breast resection. It may be delayed for a number of reasons, including certain comorbidities and major risk factors such as advanced age, smoking, and vascular disease, or in case of doubts about local cancer control (Table 25.2). In the context of radiotherapy treatment, the timing is usually managed according to the protocol at each institution, and this will probably determine the choice of the reconstructive technique.

Taking these considerations into account, when deciding the most appropriate reconstructive technique, the surgeon should assess the type of mastectomy to be performed and the quality of the remaining skin. Whatever the case, an accurate preoperative evaluation of the patient's objectives and expectations plays an essential role when choosing the most adequate reconstructive technique. Therefore, so that surgical strategies and possible outcomes are discussed, and so that the patient's requirements are considered, it is essential that effective communication be established between the patient and the surgeon from the onset.

Table 25.1 Immediate breast Reconstruction

Advantages
• Single operation and one period of hospitalization
• Psychological benefit (avoid breast deformity)
• Better cosmetic results for nipple- or skin-sparing mastectomy
• Lower costs
Disadvantages
• Increased single operating time
• Possible difficulties of coordinating two surgical team when required (oncological surgery and reconstructive surgery teams)
• Possible changes in the reconstructed breast as a consequence of postmastectomy radiotherapy

Table 25.2 Delayed breast reconstruction

Advantages
• Unlimited time to think about reconstructive options
• Avoid the harmful effects of radiaotherapy on the reconstructed breast
Disadvantages
• Skin mastectomy flaps may result to be thin, scarred, contracted, or irradiated
• Requires additional surgery and recovery time
• Psychological effects of breast deformity until the reconstruction
• Additional surgical cost

25.2 Breast Reconstruction with Prosthetic Devices

25.2.1 Direct-to-Implant Reconstruction

Many different materials have been described for breast reconstruction after mastectomy, but the greatest advance with alloplastic materials occurred in the early 1960s when Thomas Cronin and Frank Gerow from the University of Texas, USA, developed silicone gel-filled breast implants [9]. However, complications associated with prosthesis implantation under the remaining thinned skin soon appeared. Cases of malposition, severe capsular contracture, and implant exposure appeared, and removal of the prosthesis was required.

In order to prevent such failures, in the 1970s, the first experiences in submuscular implant-based breast reconstruction after subcutaneous mastectomy were reported [10]. This approach consisted of placing the implant below the pectoralis major muscle and part of the serratus anterior muscle, and it became the chosen reconstructive technique for decades. However, despite the advantage gained by the implant coverage, the anatomical alteration of the muscle

was considerable. The postoperative period was more painful, and breast animation deformity was a displeasing drawback.

An important innovation in implant-based reconstruction took place in early 2000 when the acellular dermal matrix (ADM) was introduced in combination with a dual-plane subpectoral approach [11]. With this combined technique, the upper part of the implant was held under the pectoral muscle, while the lower part was supported by the ADM. However, the early ADMs were not well tolerated as their greater thickness hindered their integration into the skin flap and the dynamic deformity remained unsolved.

In recent decades, refinements in mastectomy techniques have allowed better vascular preservation of skin flaps. The tendency to relocate implants in the pre-pectoral plane has made it possible to avoid animation deformity [12]. Furthermore, the design of thinner ADMs has allowed better integration to the mastectomy skin flaps, making their use increasingly popular. By wrapping the implant with ADM, the implant is fixed in the mastectomy pocket, the inframammary fold can be easily rebuilt, malpositioning is prevented, the incidence of capsular contracture is decreased, and the aesthetic results are improved [13]. These benefits have changed the concept of implant-based breast reconstruction.

Key Point

The use of implants is the simplest approach and the most common method of immediate breast reconstruction in many institutions. It is mainly indicated for patients who undergo a nipple- or skin-sparing mastectomy but lack a suitable donor site for reconstruction with their own tissue and for those who do not want additional scars from the extraction of autologous flaps.

Women with small-to-moderate-sized breasts are good candidates for breast reconstruction with implants. Patients who undergo a bilateral subcutaneous mastectomy are also good candidates for reconstruction because the same volume of implants will be placed in both breasts, achieving more precise and permanent symmetry (Fig. 25.1).

25.2.2 Tissue Expander/Implant-Based Reconstruction

Two-stage breast reconstruction with a tissue expander and implant is another breakthrough from last century. The first clinical experience about the application of this technique was described by Radovan in 1978 [14]. The first stage of this procedure consists of placing the expander under the skin/pectoralis muscle and filling it progressively via transcutaneous injections with saline at regular outpatient visits. Once the desired volume has been reached, the second stage consists of replacing the expander with a permanent implant. The average expansion time can range from 2 to 6 months depending on the characteristics of the skin during expansion and the volume to be reached.

In 1984, a one-stage variant was described by Becker [15]. It consists of the use of a permanent double-lumen expander composed of an internal expandable compartment surrounded by a cohesive silicone gel compartment. Once the expansion is completed, the reservoir or valve can be removed and converted into a conventional breast implant, thus avoiding the need for a second operation to remove the expander and replace it with a permanent prosthesis.

Key Point

The two-stage breast reconstruction remains the technique of choice for many reconstructive surgeons. It is mainly indicated in patients who have insufficient remaining tissue after mastectomy to achieve full coverage of a direct-to-implant breast reconstruction and who do not prefer breast reconstruction with autologous tissue (Fig. 25.2).

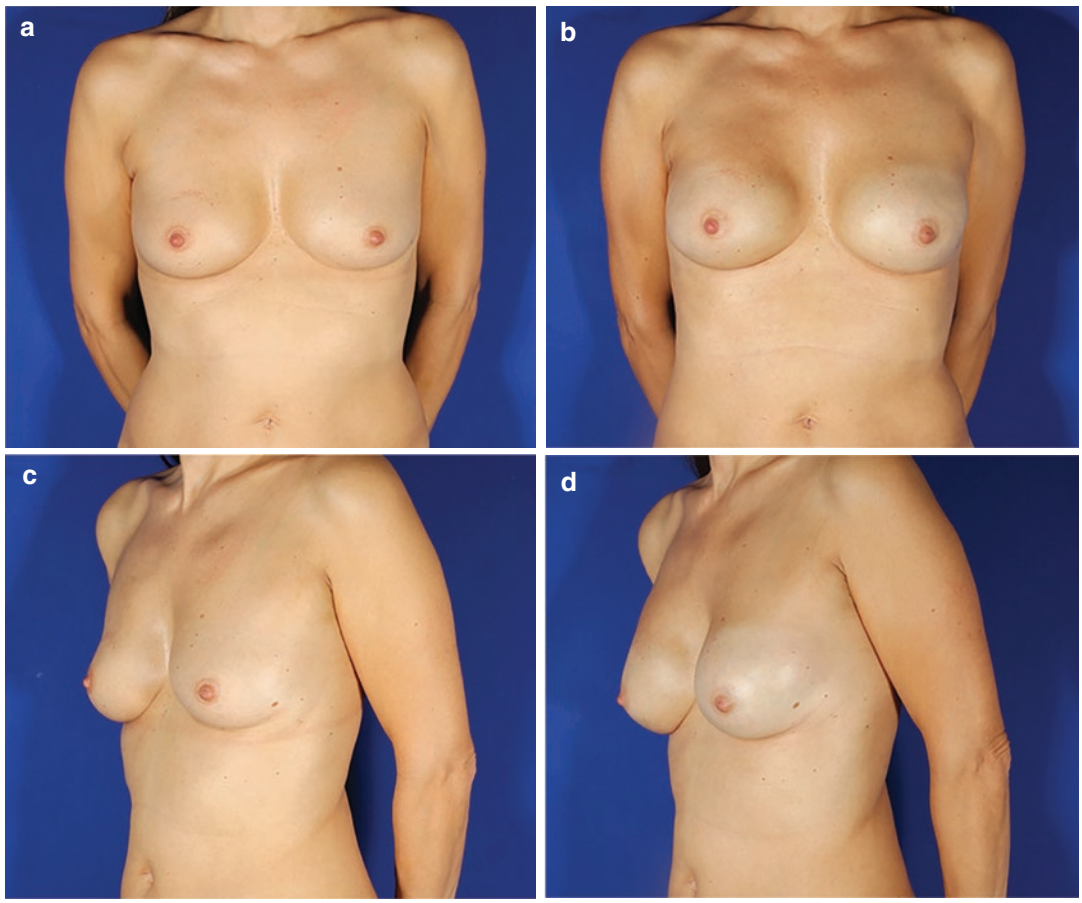

Fig. 25.1 Breast reconstruction with prepectoral implants wrapped in ADM, following bilateral subcutaneous mastectomy. Preoperative (**a**, **c**) and postoperative (**b**, **d**) images

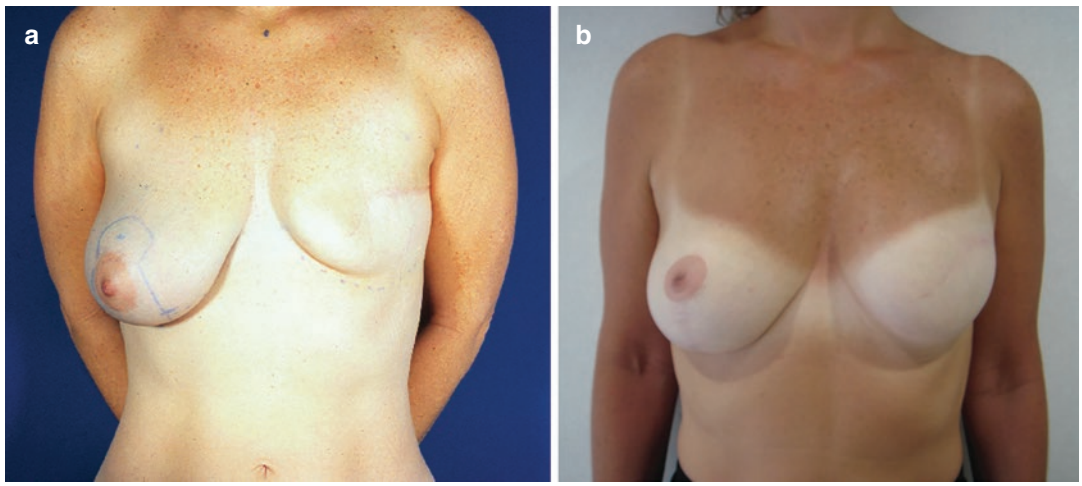

Fig. 25.2 Tissue expander/implant-based reconstruction of the left breast and mastopexy of the right breast. Preoperative (**a**) and postoperative (**b**) images

25.2.2.1 Limitations

Although breast reconstruction with prosthetic devices offers specific advantages—such as the reduced surgical time, the simplicity of the technique, minimal scarring, easier postoperative recovery, and faster return to normal activity—several limitations should be taken into account when using these techniques.

First, implant-related complications, such as capsular contracture, rippling, malposition, and implant rupture, lead to the need for a higher rate of reoperations for adjustment and symmetrization [16]. Permanent monitoring of the implants is therefore needed not only to ensure their integrity and position but also to confirm the absence of fluid accumulation (late seroma) because certain types of breast implants have been associated with anaplastic large cell lymphoma (BIA-ALCL), particularly those with textured surface [17]. In addition, breast implants are foreign objects that gradually deteriorate and will require replacement surgery within 10–15 years.

Second, breast implants are not recommended for patients who have received or will receive radiotherapy because irradiated tissue is weakened, very thin, and less vascularized. These conditions can lead to a higher rate of capsular contracture, malposition, and even skin flap deterioration with subsequent extrusion of the implant, thus producing highly unfavorable aesthetic results [18].

Third, another drawback of breast reconstruction with implants can be observed in patients with large breasts and those with certain ptosis. In such cases it is necessary to perform not only a skin-reducing mastectomy to lift the breast, but also symmetrization surgery of the contralateral breast (Fig. 25.2).

Nevertheless, the most important long-term limitation of implant-based reconstruction is that the breast will not have the same consistency, texture, or temperature as the natural breast, and it will not evolve harmonically over time. Age and gravity cause a loss of skin elasticity which will modify breast shape. As these changes will not occur naturally in implant-based reconstruction, in cases of unilateral reconstructions, the postoperative symmetry achieved between the healthy breast and the reconstruction decreases over time.

Regarding the tissue expander technique, the disadvantages include frequent outpatient visits to gradually fill the expander, discomfort associated with tissue expansion, and the need for an additional procedure to replace the expander with the permanent implant. Again, application of this technique in an irradiated breast is not advisable due to the relatively high rate of early and late complications (Table 25.3).

Table 25.3 Breast reconstruction with prosthetic device

Advantages
• Simple and less invasive technique
• Short surgery and stay in hospital
• Faster recovery and return to normal activity
• Minimal scarring (only in the breast area)
• Symmetrical and stable results in bilateral reconstructions
Disadvantages
• Difficulty in achieving symmetry in unilateral cases
• The implant does not evolve in the same way as the natural opposite breast
• Implants do not change to match variations in body weight
• Poor cosmetical result in irradiated skin
• Poor response to postmastectomy radiotherapy
• Possible unnatural results
• Requires implant maintenance and exchange
• Additional surgery in case of two-stage expander and implant-based reconstruction
• More long-term complications (capsular contracture, malposition, rupture, rippling)

25.3 Breast Reconstruction with Autologous Tissue

In recent decades, breast reconstruction has seen a shift toward the use of the patient's own tissue to recreate a more natural breast. In effect, breast reconstruction with autologous tissue is currently considered by many surgeons the best reconstructive choice that can be offered to patients.

The main advantage of this type of breast reconstruction is that the transferred tissue has a natural appearance that ages naturally over time. In addition, with the absence of alloplastic mate-

Table 25.4 Breast reconstruction with autologous tissues

Advantages
• Use of own tissue
• Easier symmetry in unilateral cases
• Natural appearance and feeling breast that change with the patient over time
• Possibility of recovering breast sensivity
• The breast will gain and lose volume with body weight variations
• Longevity of the reconstruction
• Better tolerance of postmastectomy radiotherapy
Disadvantages
• Technically more demanding
• Additional scar in the donor site
• Longer surgery and hospital stay
• Longer recovery
• More short-term complications (partial or complete flap failure and donor-site morbidity)

rials and their potential complications, the autologous tissue reconstruction can last forever, allowing the patient to completely forget about the distressing event of breast cancer.

Breast reconstruction with autologous tissue, however, is technically more demanding, and operating time, hospitalization, and recovery take longer. Although the success is very high in the hands of experienced microsurgeons, this technique is not exempted from short-term complications that can lead to partial or total flap failure or to morbidity at the donor site, such as wound dehiscence, weakness, hernia or bulge, seroma, and contour deformities (Table 25.4). The tendency to perform unilateral or bilateral mastectomy and immediate reconstruction with autologous tissue has increased progressively. This type of reconstruction is generally recommended for patients who have adequate soft tissue excess at the donor site and do not want to use alloplastic materials for breast reconstruction.

25.3.1 Types of Autologous Reconstruction

Broadly speaking, autologous breast reconstruction can be performed using pedicled flaps or free flaps. Pedicled flaps originate from tissue close to the breast (the thoracodorsal region and abdomen) that is transferred from its natural location to the chest, maintaining the blood supply through its native vascular pedicle. In general, these types of flaps are technically less demanding, with shorter operative times and a lower risk of partial or total flap failure. However, potential loss of donor site function can result when the muscle is included in the pedicle flap.

Alternatively, free flaps can be taken from areas close to or far from the breast. They are disconnected from their native blood supply and reconnected in the chest to the internal mammary or thoracodorsal vessels using microsurgical techniques. The major advance in autologous breast reconstruction has been the development of perforator flaps. These allow the harvesting of more tissue, without sacrificing the underlying muscle and minimizing donor site morbidity. However, the procedure is technically more demanding, with longer operating times, prolonged hospital stays, and the relative risk of partial or total flap failure.

25.3.2 Donor Sites

Excellent results can be obtained with a variety of flaps, from various donor sites (see below). The most commonly used flaps for breast reconstruction are from the abdominal region. These include the transverse rectus abdominis myocutaneous (TRAM) flap, the deep inferior epigastric artery perforator (DIEAP) flap, and the superficial inferior epigastric artery (SIEA) flap. Other widely used flaps are those of the dorsal region, including the latissimus dorsi myocutaneous (LDM) flap, and the thoracodorsal artery perforator (TDAP) flap.

Donor sites that have gained popularity as an alternative to abdominal flaps include the gluteal region with the superior gluteal artery perforator (SGAP) flap, the lumbar region that provides the lumbar artery perforator (LAP) flap, and the thighs that include the transverse or diagonal upper gracilis (TUG, DUG) flaps and the profunda artery perforator (PAP) flap.

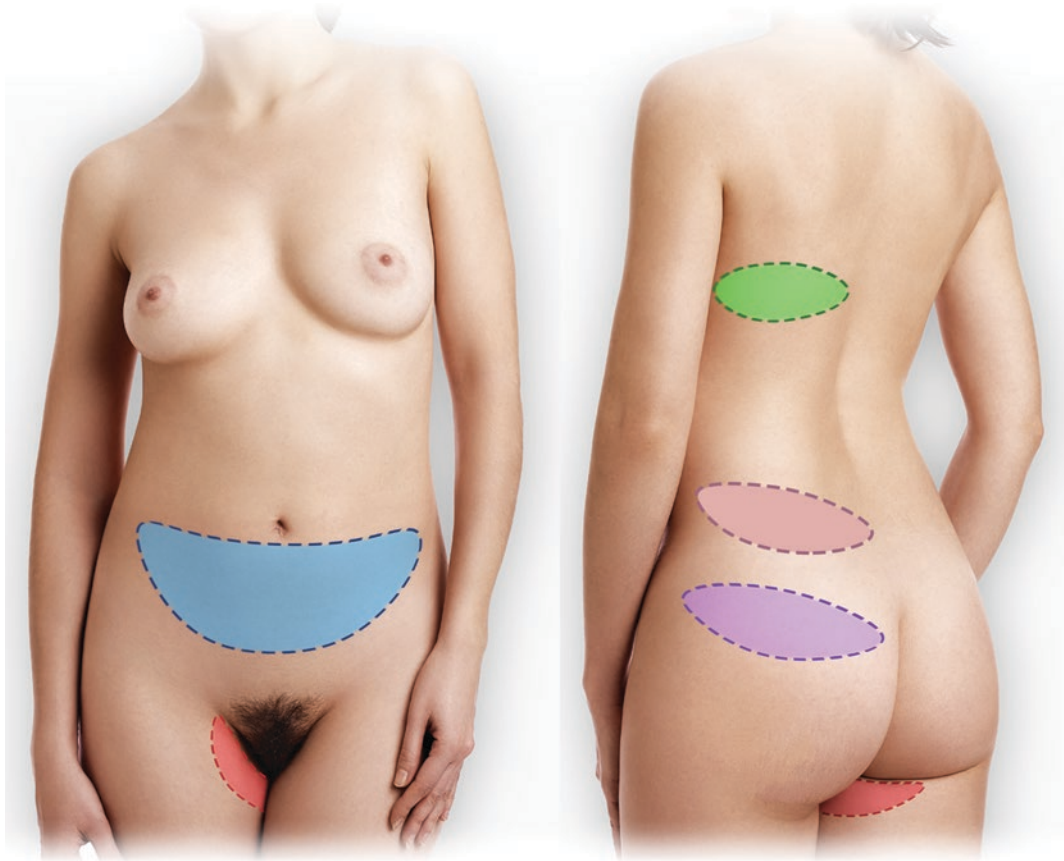

Fig. 25.3 Donor sites for autologous breast reconstruction

Key Point
The selection of the flap will basically depend on the suitability of the donor site, the surgeon's experience, and the patient's preferences (Fig. 25.3).

25.3.2.1 LDM Flap

The use of a pedicled myocutaneous flap from the dorsal region to cover the defects of breast amputation was first published by Iginio Tasini in 1906 [19]. Nevertheless, this technique was excluded for decades until Neven Olivari, in the mid-1970s, once again described the latissimus dorsi flap to cover defects of the anterior thoracic wall and irradiation damage following mastectomy [20], and it became the workhorse flap for autologous breast reconstruction in the following decades.

The technique consists of removing a significant amount of skin and subcutaneous tissue from the thoracodorsal region and part of the latissimus dorsi muscle. The flap is then transferred to the chest through an axillary tunnel. The LDM flap is based on the thoracodorsal vessels that provide a reliable blood supply and do not present significant anatomical variations that prevent its safe anterior transposition [21].

The LDM flap is technically simple to harvest and does not require microsurgery. The skin paddle size should not exceed 10–15 cm width in order to achieve primary closure, and the donor site scar can be hidden under the brassiere. However, the appearance and consistency of the thoracodorsal tissue may differ from that of a normal breast.

An important disadvantage of this flap is the possible limited amount of tissue available to recreate a breast. In addition, the muscle may undergo atrophy. It is therefore generally neces-

sary to combine this technique with the use of breast implants. Regarding muscle transposition, dynamic weakness may occur in the extension and adduction of the shoulder and may hinder the performance of certain sports and even daily activities [22].

Key Point
The result that can be achieved with the LDM flap is frequently satisfactory, but it is currently one of the last options for breast reconstruction.

25.3.2.2 TRAM Flap

The first breast reconstructions with abdominal tissue were performed by Sir Harold Gillies in the 1940s [23]. These procedures consisted of the staged transfer of a tubed abdominal flap, incorporating the umbilicus for the "nipple." Later, in 1977, Drever reported the transfer of a vertically oriented skin-muscle flap of the rectus abdominis, based on the deep superior epigastric vessels, tunneled to the mammary region [24]. In 1979, Robbins described a similar vertically oriented abdominal flap for breast reconstruction [25]. Soon after this, in 1982, Hartrampf et al. [26] reported and popularized the use of a transversely oriented rectus abdominis myocutaneous pedicle flap.

The TRAM flap has a reliable and extensive vascular pedicle which allows a wide arc of rotation to be tunneled through the thoracic-abdominal region and be inserted in the ipsilateral or contralateral mammary region. It even allows the safe transfer of a large amount of tissue with characteristics that are very similar to those of a natural breast, without the need for microsurgery, and within a relatively short operating time.

The most significant comorbidity of this technique is the resulting abdominal-wall weakness. Although there is an aesthetic improvement in the abdominal area, a localized bulge is often observed in the para-infra-umbilical region, corresponding to the muscle defect [27]. Nonetheless, the incidence of abdominal bulges and hernia can be significantly decreased by repair of the anterior rectus with the placement of a polypropylene mesh [28]. Breast reconstruction with a pedicled TRAM flap is therefore not indicated in obese patients or in those considering pregnancy.

Key Point
The TRAM flap is also one of the last options for breast reconstruction due to its considerable comorbidity at the donor site. However, it is still the chosen technique in many parts of the world.

25.3.2.3 DIEAP Flap

In 1979, for the first time, Holmstrom reported the transfer of a free transverse-oriented myocutaneous flap from the abdominal region based on the deep inferior epigastric vessels [29]. Nevertheless, the great advance in autologous breast reconstruction with abdominal tissue occurred with the development of perforator flaps. In 1989, Koshima and Soeda [30] published the use of abdominal flaps based on perforators of the deep inferior epigastric vessels without the rectus abdominal muscle. In 1994, Allen and Treece [31] described its application for breast reconstruction, and together with Blondeel [32], they expanded the use of this technique to a high technical level, after which it quickly gained great popularity worldwide.

The DIEAP flap provides a large amount of well-vascularized skin and subcutaneous tissue and a pedicle of good length and caliber. It offers a natural and permanent result with minimal morbidity at the donor site because the rectus abdominus muscle is not sacrificed; the incidence of hernias and abdominal bulging therefore decreases considerably [33]. This technique also improves the body contour of the abdomen, leaving a well-hidden scar. Compared with the TRAM flap, postoperative pain is minimal, the recovery period is shorter, and the patient returns to normal life more rapidly.

Nevertheless, a few aspects of this technique can be considered disadvantages. Like other perforator flaps, the intervention requires a longer learning curve and considerable experience in microsurgical techniques. Preoperative assessment with computed tomography (CT) angiography is essential go locate the dominant

perforator preoperatively and perform safe surgery. The intervention takes longer than that for the TRAM flap, and the risk for immediate microvascular complications is higher [34].

Key Point

Nowadays, the DIEAP flap is considered the first choice for breast reconstruction with autologous tissue. This flap is especially indicated for unilateral or bilateral breast reconstruction in patients who have excess abdominal tissue and who have not had previous abdominal surgeries in which perforators could have been sacrificed (Fig. 25.4).

25.3.2.4 SIEA Flap

The first description of the use of a pedicled abdominal flap based on superficial epigastric vessels was published by Wood in 1863 [35]. More than a century later, in 1971, it was described as a free flap by Antia and Buch [36]. For breast reconstruction, however, the application of the SIEA free flap was first described by Allen, in 1989 [37], and the first case report published was that by Grotting, in 1991 [38].

The vessels of the superficial epigastric system lie just below the skin and are easily located preoperatively using a Doppler ultrasound. The additional advantage over the DIEAP flap is that the SIEA flap is raised in a suprafascial plane, allowing less complex and relatively faster dis-

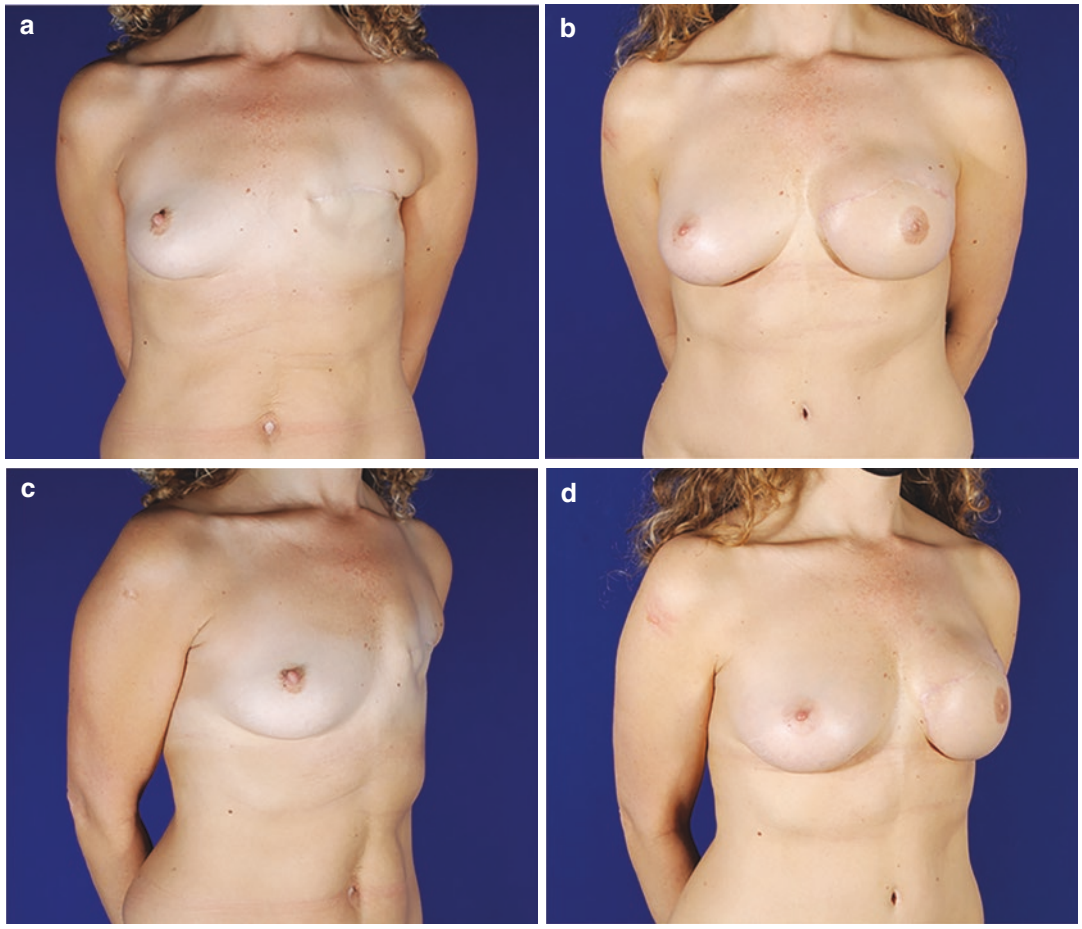

Fig. 25.4 Left breast reconstruction with DIEAP flap and contralateral augmentation mammoplasty. Preoperative (**a**, **c**) and postoperative (**b**, **d**) images

section. Besides, as there is no need to perform a fasciotomy and myotomy, the integrity of the abdominal wall is not altered, thus, morbidity at the donor site is minimal [39].

Nonetheless, the SIEA is anatomically inconstant. It may not therefore be available for use in all possible candidates. Besides, its short pedicle and small arterial caliber make anastomosis with the recipient-site vessels technically more demanding. Another disadvantage is that the cutaneous territory irrigated by the SIEA is mainly limited to the ipsilateral hemiabdomen, so if all the lower abdominal tissue is needed to perform a unilateral breast reconstruction, an extra anastomosis will be necessary to ensure the vascularization of the entire flap.

To perform safe surgery with this flap, intraoperative comparison of vascular dominance of the superficial inferior epigastric system and the deep inferior epigastric system is essential. When perfusion of the superficial system is not adequate, it is advisable to perform a DIEAP flap. Special attention is necessary to identify abdominal scars that may contraindicate the use of this flap, such as the lower transverse abdominal scar (Pfannestiel).

Key Point
The indications for SIEA flap breast reconstruction are practically the same as those for the DIEAP flap, and it is a good option for women with small breasts who undergo bilateral breast reconstruction (Fig. 25.5).

25.3.2.5 SGAP Flap

As early as 1920, Sir Harold Gillies advocated a tube pedicle to transfer a slice of skin and fat from the buttock to create a breast [23]. In 1973, Orticochea published the first report on the transplantation of a myocutaneous flap from the gluteal region, in multiple stages, using the volar aspect of the forearm as a transport medium to reconstruct the breast [40]. Shortly afterward, in 1975, Fujino et al. reported the use of a free myocutaneous flap based on the superior gluteal artery for breast reconstruction [41]. With the advent of perforator flaps, Koshima et al. described the gluteal flap based on perforators of the superior gluteal artery in 1993 [42], and its application for breast reconstruction was reported in 1995 by Allen and Tucker [43].

The adipocutaneous tissue of the upper gluteal area is a suitable option for breast reconstruction due to its consistency, volume, and reliable anatomy. However, harvesting the SGAP flap can be challenging because of the complexity of the intramuscular dissection of the short pedicle (5–7 cm). In this context, CT angiography can be very helpful to preoperatively identify the trajectory of the suitable perforator. Furthermore, in most cases, it is necessary to use arterial and venous grafts to increase the length and match the caliber to the recipient-site vessels. Likewise, during the dissection, special care must be taken to avoid damaging vital anatomic structures that emerge caudally to the piriformis muscle, such as the sciatic nerve, the inferior gluteal artery, the internal pudendal artery, and the posterior femoral cutaneous nerve.

Although the donor site scar can be well hidden by underwear, the contour defect produced in the upper part of the buttock can be significant, requiring secondary refinement with lipofilling at the donor site in almost all cases.

Key Point
The SGAP flap has become a valuable alternative for autologous breast reconstruction when the abdominal tissue is not adequate, especially in bilateral breast reconstructions and in patients considering pregnancy after breast reconstruction (Fig. 25.6).

25.3.2.6 LAP Flap

In 1978, Hill et al. published the anatomical basis of a transverse lumbosacral back flap and its use as a transposition flap based on the intercostal and lumbar perforators [44]. Nonetheless, the first description of the anatomical path and vascular territory of the lumbar artery perforators was published in 1999, by Kato et al. [45]. Later, in 2003, De Weerd et al. [46] reported the use of a free LAP flap for breast reconstruction.

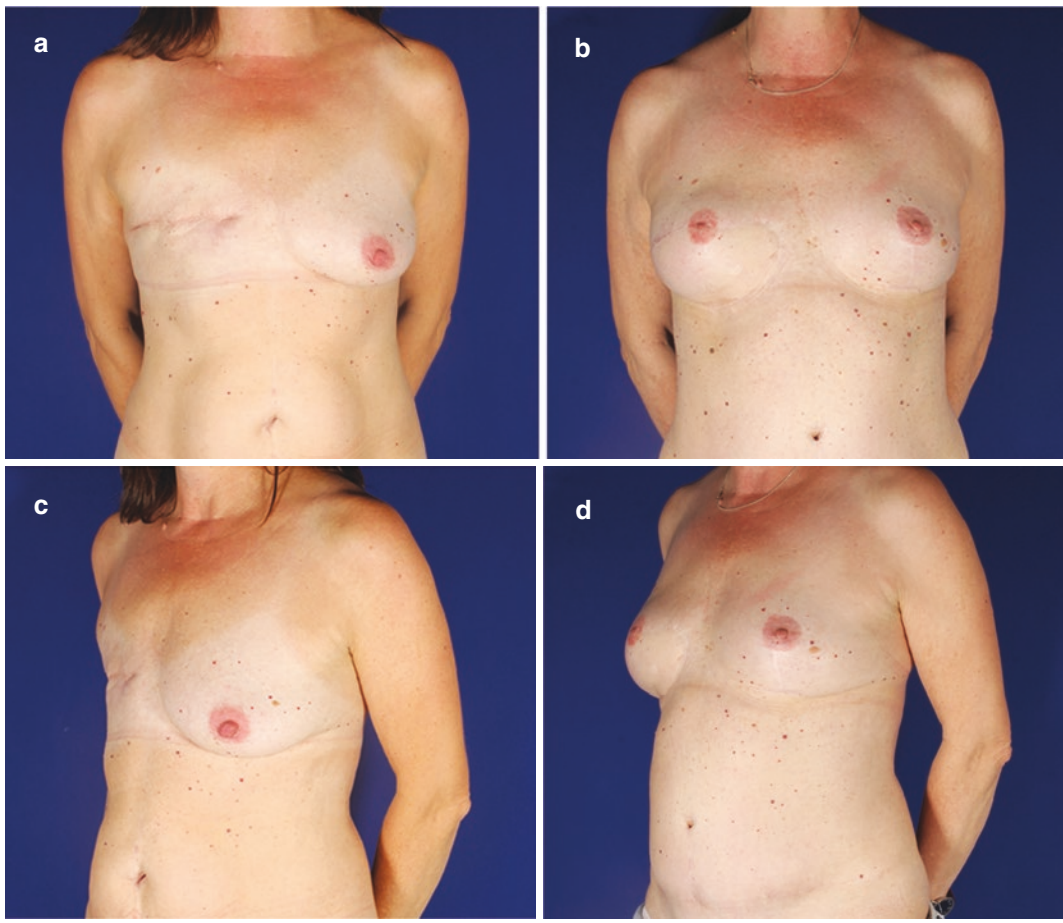

Fig. 25.5 Right breast reconstruction with SIEAP flap and contralateral mastopexy. Preoperative (**a**, **c**) and postoperative (**b**, **d**) images

The donor site area for this flap is essentially the same as that for a traditional buttock lift. The fatty tissue tends to be less sturdy than that of the SGAP flap, making shaping of the new breast easier. Nonetheless, harvesting a LAP flap can be challenging even for experienced microsurgeons in terms of perforator identification and dissection through the thoracolumbar fascia. In addition, the pedicle can be rather short (average 6–7 cm), and there tends to be a size discrepancy between the diameter of the lumbar perforators and the recipient-site vessels, making the use of an interposition arterial and venous graft necessary. To facilitate flap design and harvest, preoperative planning with CT angiography is therefore crucial to assess the location and trajectory of the perforators [47].

Regarding the resulting donor-site scar, sometimes, it may be slightly high, making it difficult to hide with underwear. Besides, a sensory deficit may occur in the upper gluteus due to the section of the cluneal nerve during flap dissection, especially when looking for a sensitive flap, but this rarely bothers the patient. Moreover, unilateral harvesting of the LAP flap may frequently require liposuction of the contralateral lumbar region to symmetrize the contour.

Key Point
The LAP flap is among the most complex flaps in the microsurgeon's armamentarium and is a reliable alternative when abdominal and gluteal areas are not available (Fig. 25.7).

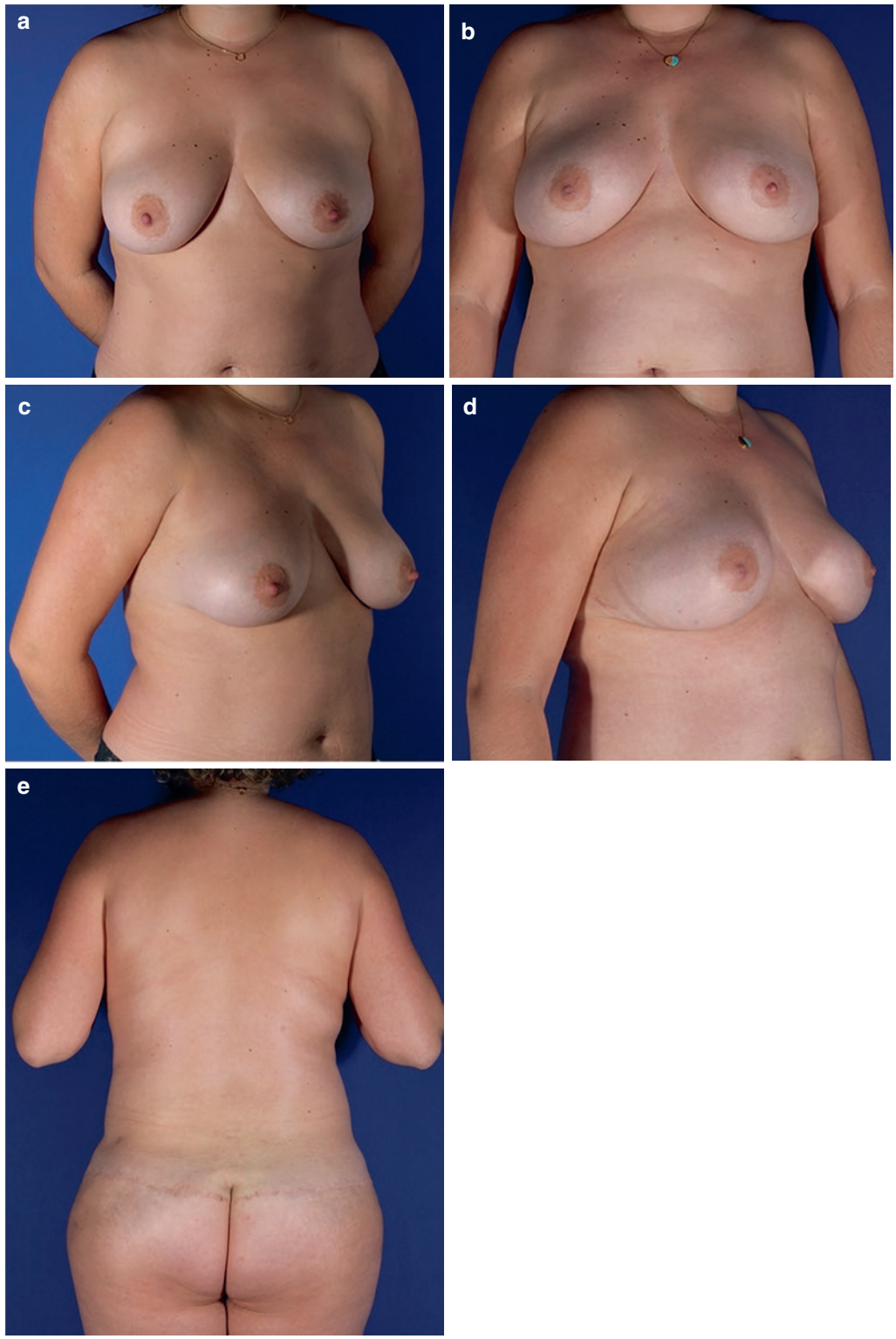

Fig. 25.6 Bilateral breast reconstruction with SGAP flaps following subcutaneous mastectomies. Preoperative (**a**, **c**) and postoperative (**b**, **d**, **e**) images

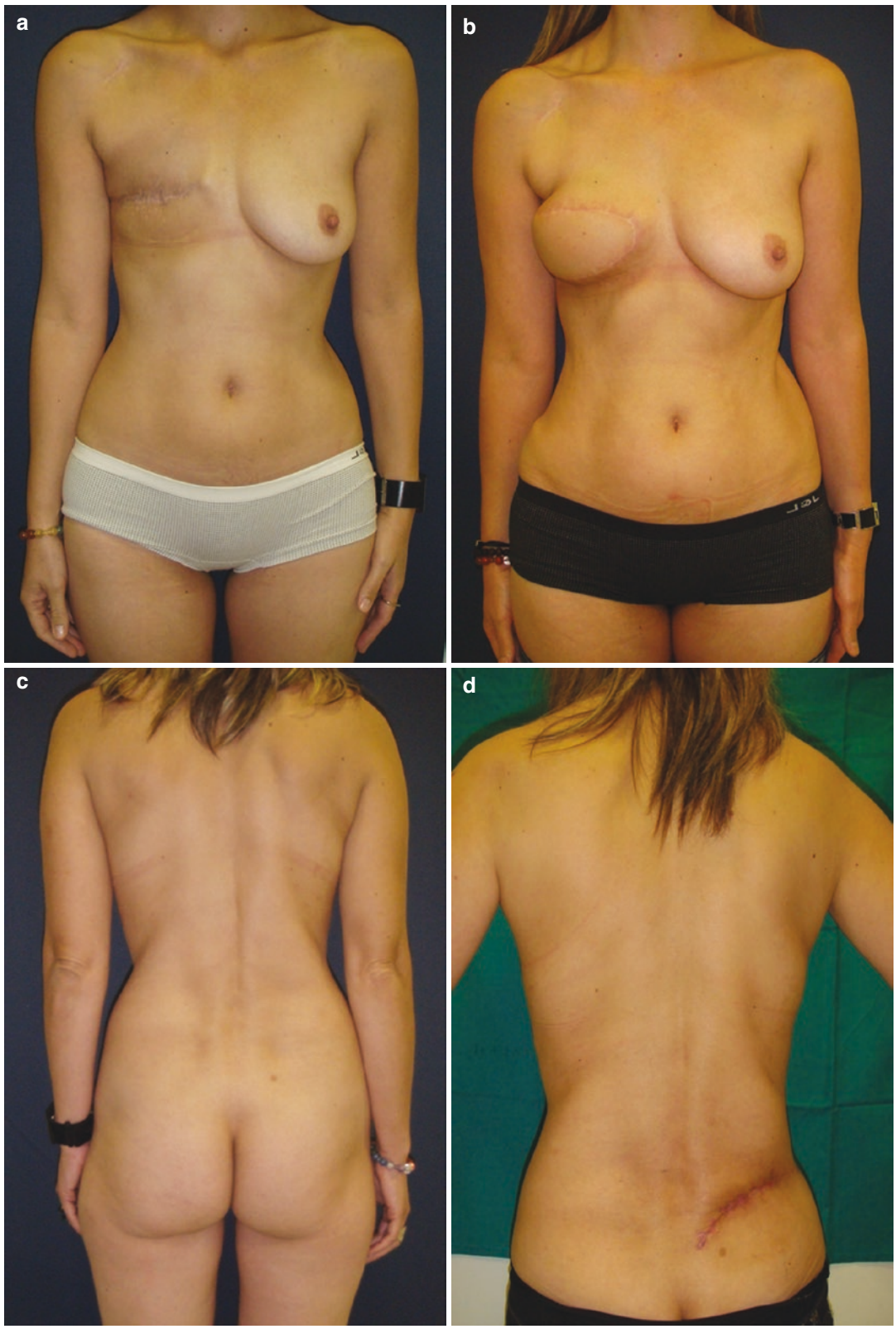

Fig. 25.7 Right breast reconstruction with LAP flap. Preoperative (**a**, **c**) and postoperative (**b**, **d**) images

25.3.2.7 TDAP Flap

The thoracodorsal artery perforator flap is an evolution of the LDM flap. It was developed in the search to individualize the thoracodorsal pedicle and incorporate the smallest amount of muscle in order to reduce morbidity at the donor site. The TDAP flap was first described by Angrigiani et al. in 1995 [48]. Although the use of the TDAP flap as a possible method for breast reconstruction was reported in 1996 [49], the first clinical experience of its application for breast reconstruction was published by Hamdi et al. in 2004 [50]. It soon gained wide acceptance due to its versatility, reliability, and low donor site morbidity.

Although identifying a reliable thoracodorsal perforator could be challenging and the pedicle dissection is time-consuming, the main advantage of the TDAP flap when compared with the LDM flap is the preservation of muscle function and motor nerves of the lateral thoracic area.

Key Point

The TDAP flap is an excellent option for breast reconstruction in patients with small breasts when abdominal tissue is not available (Fig. 25.8). It can be combined with fat grafting into the flap or with the placement of an implant in order to achieve the same size as the contralateral breast. The TDAP flap is also indicated for partial breast reconstruction after a lumpectomy and as a salvage flap in the case of complications from other breast reconstructions techniques (Fig. 25.9) [51].

25.3.2.8 Thigh Flaps

In recent years, the thigh regions have become an excellent alternative for autologous breast reconstruction, especially in women who do not have sufficient tissue in other possible donor sites.

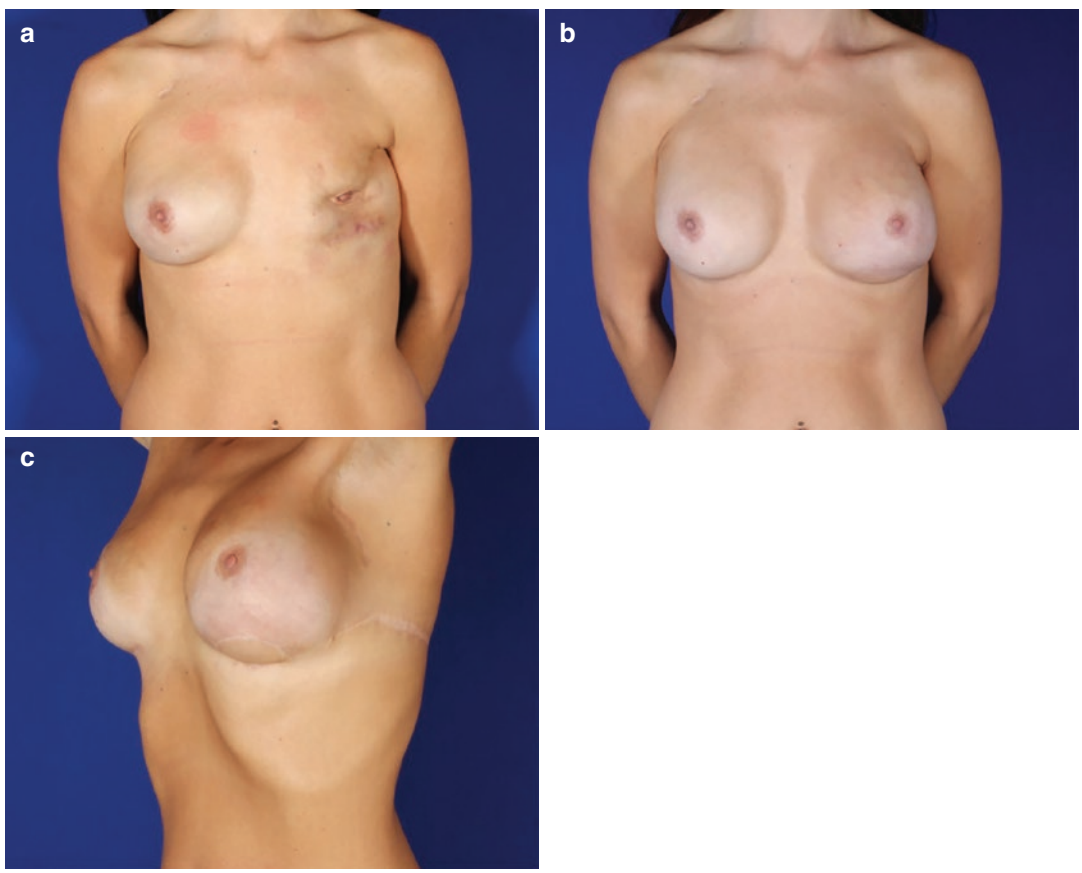

Fig. 25.8 Left breast reconstruction with TDAP flap and implant. Preoperative (**a**) and postoperative (**b**, **c**) images.

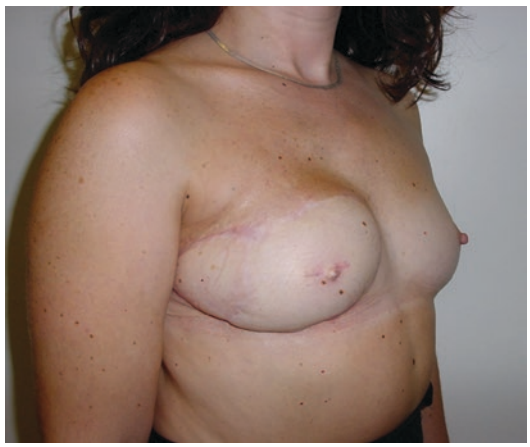

Fig. 25.9 The use of TDAP flap to cover a lateral defect after partial loss of a previous DIEAP flap breast reconstruction

Flaps such as the transverse upper gracilis (TUG) flap and the diagonal upper gracilis (DUG) flap are good options when there is excess tissue in the medial part of the thigh [52, 53]. In contrast, the profunda artery perforator (PAP) flap is a reliable alternative when there is small-to-moderate lipodystrophy in the posterior thigh region [54].

The medial thigh-based flaps have a reliable dominant vascular pedicle, the donor site can usually be closed primarily, and morbidity is minimal. Special care should be taken not to overextend the flap to the anterior part of the thigh in order to avoid damaging the inguinal lymph nodes and causing disruption of the lymphatic drainage of the leg. Nevertheless, the donor site can often result in an unfavorable change in the contour of the thigh and the scar is not well hidden by underwear.

The vascular pedicle of the PAP flap is long compared to the medial thigh-based flaps, and dissection is distant from the lymphatics, reducing the risk of seroma. Wound dehiscence is a potential donor site complication, so the flap should not exceed 7 cm in width to ensure primary closure. Unlike the SGAP flap, the gluteal contour is not affected, and the donor-site scar is well hidden in the sub-gluteal crease, being less visible than the more anterior scar of the medial thigh-based flaps.

Key Point
The thigh-based flaps provide soft and pliable tissue that is suitable for breast reconstruction in patient with small breasts. Besides, they also add the option of bilateral harvesting and simultaneous breast reconstructions.

25.4 Secondary Refinements for the Reconstructed Breast

In general, breast reconstruction with the different techniques offers satisfying aesthetic results. However, in many cases, refinement procedures might be needed to achieve a more natural appearance and better symmetry between breasts (Fig. 25.7b).

Key Point
Contour irregularities, volume discrepancy, asymmetrical infra-mammary fold position, and reconstruction of the nipple-areola complex are the most common indications for secondary procedures for the reconstructed breast.

In cases of unilateral reconstructions, the healthy breast will rarely need revision because mastopexy with augmentation or reduction mammoplasty should always be addressed in the initial surgical intervention.

Secondary procedures should be performed once the healing process after the first stage of breast reconstruction is complete. The optimal time is between 4 and 6 months. When a complementary radiotherapy is performed, secondary procedures can be postponed even longer, until the treatment is completed. However, the timing must be determined specifically in each case.

Fat grafting is probably the most important technique for the refinement of the reconstructed breast. It provides a significant improvement in breast contour and skin quality. In the case of breast reconstruction with autologous tissue, other refinement techniques include liposuction and direct tissue

resection. Each procedure has its specific purpose to shape the reconstructed breast, and a combination of approaches can be safely performed.

Similarly, a well-positioned inframammary fold is a crucial factor in the final appearance of the reconstructed breast. Consequently, during a secondary refinement, it may be necessary to raise or lower this fold to symmetrize it with the contralateral side.

Reconstruction of the nipple-areola complex is usually the final stage of breast reconstruction. This procedure should be performed when the patient is satisfied with the final shape, size, and symmetry of breasts. When the reconstructed breast shape will not change significantly with refinement procedures, the reconstruction of the nipple can be performed in the same procedure. Otherwise, if the refinement of the reconstructed breast will significantly change the size or shape, it is advisable to postpone nipple reconstruction to avoid the risk of wrong positioning.

The challenge of nipple reconstruction is to create a three-dimensional structure from a two-dimensional surface [55]. A number of techniques described for nipple reconstruction are associated with high patient satisfaction, including various local flaps (C.V, star flap, and skate flaps) and nipple-sharing techniques [56]. Regarding areola reconstruction, the most common techniques include skin grafts, tattoos or a combination of these (Figs. 25.4b, d and 25.5b, d).

Most nipple-areola complex reconstructions can be performed in an office setting using local anesthesia. Areolar tattooing is usually done within 3–5 months after nipple reconstruction. In women with implant-based breast reconstruction who have received postmastectomy radiotherapy, surgical reconstruction of the nipple is not advised. In such cases, 3D nipple-areola tattooing is an excellent option [57].

Take-Home Message

Breast reconstruction is an integral part of breast cancer treatment. Currently, as many effective options are available for breast reconstruction, practically, all breast cancer patients are candidates. Therefore, there are no reasons not to replace the resected breast and restore the patient's quality of life after breast cancer. Due to the variable needs of individual patients, the reconstructive surgeon must be able to provide the full range of reconstructive options and resolve any sequelae of mastectomy or previous breast reconstructions. However, effective doctor-patient communication is essential, both to provide all the necessary information and psychological support and to understand patients' expectations so as to achieve the desired result.

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Abdominal Wall Surgery

26

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Background

In their daily working activities, plastic surgeons frequently face issues related to the abdominal wall region.

The abdomen, symbol of both motherhood and eroticism, is one of the most important anatomical subunits of the body. This explains the significant psychological impact related to abdominal wall diseases.

Abdominal wall defects may represent a challenging issue, and plastic surgery involvement in abdominal wall reconstruction becomes necessary especially in complex cases where routine techniques are not adequate or sufficient.

26.1 Introduction

Abdominal wall defects can be either congenital or acquired.

Congenital umbilical and inguinal hernias are usually repaired in infancy or childhood.

On the other hand, most of the acquired defects arise from postpartum changes, traumas, tumors, radiation necrosis, or complications of previous abdominal surgeries, leading to high costs for the healthcare system, related to high rates of recurrence and reoperation. Besides being a cosmetic problem, abdominal wall defects have a strong negative functional impact on patients' quality of life. The majority of these patients also have significant comorbidities like tabagism, diabetes mellitus, chronic obstructive pulmonary disease (COPD), coronary artery disease (CAD), poor nutritional status, immunosuppression, chronic corticosteroid use, and obesity. Such risk factors need to be reduced before surgery, in order to have the greatest chances of success and to reduce the risk of bacterial contamination, infection, and failure of the whole reconstructive process. Diagnosis is made on physical examination and supported by abdominal computed tomography (CT) or magnetic resonance imaging (MRI), which confirms the extent and location of the abdominal wall defect and gives information on the integrity of musculofascial structures involved. A proper integration of clinical and radiological evaluations helps the surgeon to define the best preoperative planning, especially if the patient has undergone previous surgeries. The anterior abdominal wall assists in protection of viscera, postural stabilization, and maintenance of intra-abdominal pressure. The latter function is central to the voluntary control of coughing, micturition, and defecation. Consequently, loss of continuity of abdominal

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wall structures or full-thickness defects may significantly affect these functions. The goals of abdominal wall reconstruction are to treat any abdominal open wounds, providing a complete soft-tissue coverage, to restore and reinforce fascial integrity, to protect abdominal viscera, to restore function, and to prevent hernias according to the "like-with-like" principle of reconstructive surgery [1]. The decision to perform an immediate or a delayed reconstruction must be taken after having considered the patient's comorbidities and clinical condition, the etiology and type of the defect, and the infective status of the wound. If possible, an immediate reconstruction is always preferable, due to the benefits that this kind of approach brings from a psychological and medical point of view. When that is impossible, an adequate abdominal coverage is performed to provide temporary closure; in such conditions, vacuum-assisted closure therapy reduces bacterial colonization and aids in keeping the wound clean by improving vascularization and minimizing wound inflammation.

Acquired abdominal wall defects represent the focus of this chapter.

26.2 Surgical Anatomy

A thorough understanding of the anatomy of the abdominal wall is essential when planning reconstruction. The abdominal wall is defined as the part of the trunk that is bounded laterally by the right and left mid-axillary lines; superiorly by the costoxiphoid margins; and inferiorly by the pubic crest, the inguinal ligaments, and anterior halves of the iliac crests. The anterolateral abdominal wall is made up of several layers, which from the outside to the inside are represented by the skin, subcutaneous tissue of variable thickness with its fasciae, three fascia layers and five paired symmetrical muscles, transversalis fascia, and parietal peritoneum.

26.2.1 Anatomy of the Integument

The skin envelope is related to body habitus and is certainly more prone to undergo drastic changes due to massive weight gain and/or loss, pregnancies, physical activity, age, abdominal surgeries, or genetic conformation. The skin is mobile compared to the musculoaponeurotic plane below.

On the abdominal wall, the minimum skin tension lines, or Langer lines, are oriented in a horizontal or oblique direction, thus defining the best direction for surgical incisions. Between these lines, which can be real skin folds, we can identify the suprapubic fold (site of Pfannenstiel incision) and the infraumbilical fold, which unites the two anterosuperior iliac spines, approximately in the middle of the navel-pubis line.

The quality of the skin differs depending on the subunits of the abdomen: the subcutaneous tissue below the umbilicus is more represented, giving this region a softer and more relaxed texture, compared to the supra-umbilical region. In men, the adipose plane tends to thicken subumbilically and laterally at the hip level.

In women, fat distribution is commonly located at the sub-umbilical level and in the periumbilical region. This distribution determines the so-called "round abdomen" appearance. It is important to check the quality of the skin, the presence and the distribution of abdominal scars, and the existence of stretch marks. The abdomen is divided into four quadrants and nine regions; in the region above the umbilicus, the Camper fascia and Scarpa fascia are usually adherent to each other and form a single layer. They split below the umbilicus, forming:

- Camper fascia, a thick fibrofatty tissue layer that extends from the xiphoid process and the lateral costal margins to the inguinal ligament bilaterally, and it continues inferiorly past the inguinal ligament as the subcutaneous fat of the thigh. It lies deep in the skin, but superficial to the Scarpa's fascia, and it is composed by a three-dimensional architecture of fibrous septae, which provides support for the adipose tissue.
- Scarpa fascia is a thin and more membranous layer, loosely connected to the aponeurosis of the obliquus externus abdominis by areolar tissue, but closely adhered in the middle line to the linea alba and to the symphysis pubis, and is prolonged on to the dorsum of the penis, forming the fundiform ligament [2].

26.2.2 Anatomy of the Myofascial System

The muscles of the abdominal wall can be divided into two groups: the anterolateral muscles and the posterior muscles.

The former is composed by five paired muscles:

- Rectus abdominis
- Pyramidalis
- External oblique
- Internal oblique
- Transversus abdominis

All of them have corresponding layers of investing fascia (Fig. 26.1).

Rectus abdominis and pyramidalis muscles are located anteriorly; each rectus joins the midline to form the linea alba, an important landmark during abdominal surgery: wider in its upper part, it undergoes alterations following the increase in intra-abdominal volume in case of pregnancy, obesity, or ascites. Rectus muscles running vertically from the xiphoid process and costal cartilages of V–VI–VII ribs to the pubic symphysis. Their lateral borders create a surface known as the linea semilunaris. There are also three tendon inscriptions that form three transversal grooves, interrupting the muscle fibers.

The pyramidalis muscles are not functional and are found in 80% of the population. It is a triangular-shaped muscle with its base on the pubic bone.

External oblique is configured as the largest and most superficial muscle in the abdominal wall, which originates from the cartilage of the lower VII ribs and runs obliquely from superior/lateral to inferior/medial and inserts on to the iliac crest and pubic tubercle.

Internal oblique lies deep in the external oblique; smaller and thinner, it originates from the inguinal ligament, iliac crest, and lumbodorsal fascia; its fibers course perpendicular to the external oblique from inferior/lateral to superior/medial and inserts to the cartilage of the lower five ribs. At this inferior portion, it joins the aponeurosis of the transversus abdominis muscle to create the conjoined tendon.

Transverus abdominis is the deepest of the three anterolateral wall muscles with transversely running fibers and originates from the lower six costal cartilages, lumbar vertebrae, iliac crests, and iliopsoas fascia and inserts into the conjoint tendon, xiphoid process, linea alba, and pubic crest [3].

Tranversalis fascia is the thin aponeurotic membrane of the anterolateral abdominal wall which lies between the inner surface of the transversus abdominis muscle and peritoneum. It forms part of the general layer of fascia lining the abdominal wall and is directly continuous with the iliac and pelvic fasciae.

The parietal peritoneum is a continuous membrane which is made up of simple squamous epithelial cells called mesothelium.

The three fascial components of the lateral abdominal wall (the external oblique, internal oblique, and transverse abdominis) come together medially to form the anterior and posterior rectus sheath; each aponeurosis is bilaminar. Above the arcuate line, the anterior rectus sheath is composed of both leaves of the aponeurosis of external oblique and the anterior leaf of the aponeurosis of internal oblique fused together. The posterior rectus sheath is composed of the posterior leaf of the aponeurosis of internal oblique and both leaves of the aponeurosis of transversus abdominis. At the midline, fibers from each layer decussate to the opposite side of the sheath forming the so-called linea alba. Below the arcuate line, the three aponeurotic layers form the anterior rectus sheath [4]. Also, this is the point where the inferior epigastric vessels perforate the rectus abdominis to vascularize the skin.

The posterior abdominal wall is essential for postural stability, as well as lower limb movements, and acts as a barrier for the retroperitoneal organs. The muscles that form the posterior abdominal wall are:

- Quadratus lumborum
- Psoas major
- Psoas minor
- Iliacus

Key Points

The rectus muscle presents an anterior and posterior sheet for most of its length: the anterior sheet is formed by the aponeuroses of the external oblique and the anterior leaf of the aponeurosis of internal oblique, whereas the posterior is formed by the posterior leaf of the internal oblique and the aponeuroses of the transversus abdominis. Midway between the umbilicus and the pubic symphysis, all the aponeuroses move to the anterior sheet. At this point, the posterior sheet becomes thinner leaving the rectus abdominis in direct contact with the transversalis fascia. This demarcation point is called the arcuate line.

26.2.3 Anatomy of Vessels, Nerves, and Lymphatics

The vascular supply to the abdomen can be subdivided into three zones (Huger's zones I, II, and III) based upon regional anatomy as described by Huger (Fig. 26.2) [5]. The first zone corresponds to the middle part of the abdomen and is vascularized by the perforating branches of the superior epigastric artery and inferior epigastric artery, which anastomose within the rectus muscle fascia. The second zone corresponds to the hypogastrium and is nourished by the superficial circumflex artery, the superficial epigastric artery, and some perforating branches from the proximal segment of the inferior epigastric artery. The third zone includes the lateral areas of the abdomen and is supplied by the perforating branches

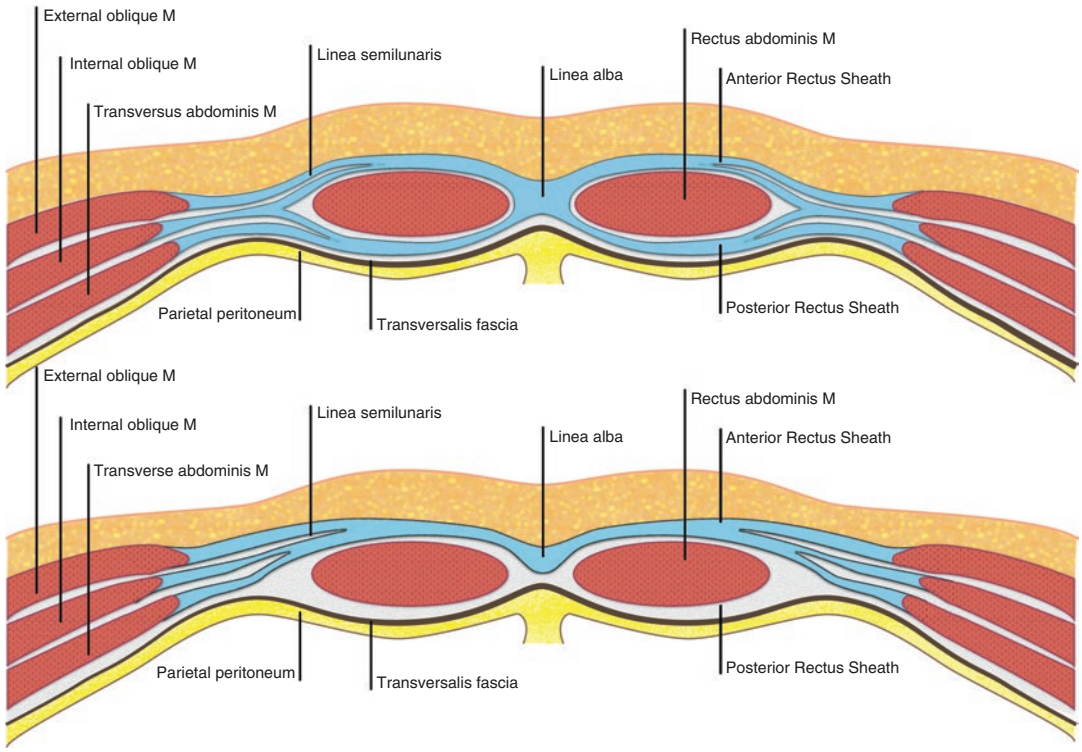

Fig. 26.1 Myofascial abdominal wall anatomy. Difference between above and below arcuate line. (Illustration by Federico Di Crescenzo)

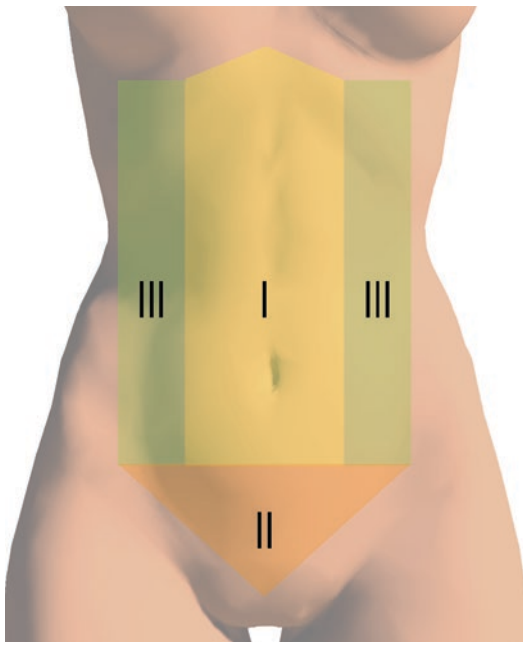

Fig. 26.2 Vascular zones of the abdominal wall (Huger's zones). (Illustration by Federico Di Crescenzo)

from the diaphragmatic, intercostal, and lumbar arteries. The third zone is responsible for the vascularization of the lateral cutaneous flaps advanced caudally during abdominoplasty procedures; when such branches are spared, there is no increased risk of marginal skin necrosis [6].

The venous drainage of the abdominal wall superior to the umbilicus is via the internal mammary, intercostal, and long thoracic veins: these veins ultimately drain into the superior vena cava. Inferior to the umbilicus, the venous drainage is via the superficial epigastric, circumflex iliac, and pudendal veins, eventually draining to the groin in the saphenofemoral junction and, ultimately, to the inferior vena cava.

The lymphatic vessels of the abdominal wall are organized according to two systems, one superficial and the other one deep. The superficial one is in the soft tissue above the deep muscular fascia, and it accompanies the subcutaneous blood vessels below the dermis. Vessels from the infra-umbilical skin run with the superficial epigastric vessels and drain into the superficial inguinal nodes; the supra-umbilical region is drained by axillary and parasternal nodes. The deep lymphatic system is associated with the abdominal wall musculature: these vessels parallel the deeper arteries; lymphatics in the upper part of the abdominal wall run with the superior epigastric vessels to parasternal nodes, while those in the lower abdominal wall run with the deep circumflex iliac and inferior epigastric arteries to external iliac nodes.

Sensory and motor innervation to the muscles comes from the intercostal and subcostal nerves, from T7 to L1, for the rectus abdominis muscle, as well as from the iliohypogastric nerve for the external oblique muscle or the ilioinguinal nerve for the internal oblique muscle. The iliohypogastric nerves provide sensation to the anterior abdominal wall in the suprapubic region.

Key Points

Vascularization of the abdominal wall must always be kept in mind when approaching both reconstructive and aesthetic surgery procedures to minimize complications. In patients with previous abdominal scars and associated comorbidities, wide undermining should be avoided, and as many perforators as possible should be spared.

26.3 Classification of the Abdominal Wall Defects

Abdominal wall defects can be classified in congenital or acquired based on their pathogenesis and may be asymptomatic or symptomatic (Tab1). Such defects may produce a wide variety of clinical issues ranging from minor cosmetic impairment to major destructive conditions (Table 26.1).

26.3.1 Congenital Defects

Congenital defects are due to an incomplete closure of the abdominal wall during embryogenesis, including omphalocele, umbilical hernia, gastroschisis, and bladder exstrophy; nowadays,

Table 26.1 Classification of abdominal wall defects

Abdominal wall defects		
	Acquired	
Congenital	Partial defects	Full-thickness defects
Gastroschisis	Diastasis recti	Traumatic defects
Omphalocele	Hernias (umbilical, lateral, inguinal)	Oncological resection
Bladder exstrophy	Postoperative or incisional hernia	
Umbilical hernia		

they are usually diagnosed in the context of a routine ultrasound during pregnancy.

26.3.1.1 Omphalocele

Omphalocele is the protrusion of the abdominal viscera through a median defect in the abdominal wall at the base of the navel. The prevalence of omphalocele is approximately 2–3 cases per 10,000 births [7]. The herniated contents are covered by a membranous sac contiguous with umbilical cord and can become necrotic after birth. The size of the defect can be small, up to 5 cm, also called "minor," or more than 5 cm, called "major," and the sac may contain bowel loops, small or large intestine, stomach, bladder, ovary, or liver. In infants with omphalocele, the incidence of other congenital anomalies, such as bowel atresia, chromosomal abnormalities, and cardiac and renal anomalies, is very high.

26.3.1.2 Gastroschisis

Gastroschisis is the protrusion of abdominal wall contents through a defect in the abdominal wall that is not in the midline, but usually to the right of the umbilicus, with no covering membrane or sac. The incidence of gastroschisis is about 0.5–4.5 cases per 10,000 living births [8–10]. The cause of this defect is still unknown. This condition is not generally associated with other major congenital or chromosomal anomalies. Gastroschisis is often classified into simple (isolated defect) and complex (associated with bowel-related complications: intestinal atresia, perforation, stenosis, or volvulus) [8, 10].

26.3.1.3 Bladder Exstrophy

Bladder exstrophy represents a failure of the anterior bladder wall to close normally, due to a lack of muscular or connective tissue. The reported incidence is 0.25–0.5 in 10,000 births and is more common in males at a ratio of 2:1 [9]. The disease can be diagnosed by a prenatal ultrasound, which highlights the absence or non-visualization of the bladder, which is open to the abdominal wall. Other findings include external genitalia malformation, represented by a small penis with anteriorly displaced scrotum. Also, in females, besides a widening of the iliac crests, a bifid clitoris and uterine and vaginal anomalies can be identified [11]. Differential diagnosis must be with an empty bladder: in this case, the scan can be repeated in 15-min intervals.

26.3.1.4 Umbilical Hernia

The umbilical hernia in the baby results from an incomplete closure of the fascia of the umbilical ring at the time of reintegration in the abdominal cavity of the intestinal loop; therefore, intraabdominal contents may protrude. The skin coverage is not missing. The incidence is very high at birth: it is estimated at 10–30% of all white children at birth, decreasing to 2–10% at 1 year of age, with boys and girls affected equally, but it tends to close spontaneously in the first 2 years of life, after separation of the umbilical cord. Umbilical hernia is more common in black infants than in whites. It is usually asymptomatic [12].

26.3.2 Acquired Defects

The acquired defects can be divided into:

1. Partial abdominal defects
2. Full-thickness defects

26.3.2.1 Partial Defects

Diastasis Recti

Diastasis recti is not a true abdominal wall fascial defect, but a common condition characterized by the separation of the two rectus abdominis

muscles along the linea alba, resulting in abdominal protrusion that is often associated with a negative body image, musculoskeletal pain, and occasionally urogynecological symptoms. This separation results in a gap, defined as inter-recti distance (Fig. 26.3). The condition may appear in newborns, in men, or in patients with prior abdominal surgery, but it is more commonly found in women; during pregnancies, the geometry of the abdominal muscles changes, and uterine growth leads to an elongation of the abdominal muscles and a change in the angle of the muscles' attachment. This leads to a stretching and flaccidity of the linea alba which may result in the enlargement of the distance between the medial borders of the muscles, with subsequent loss of their straightforward course. Most studies have agreed that the minimum inter-recti distance to designate a diastasis is 22 mm [13]. The diagnosis of diastasis recti is based on the patient's history and physical examination, confirmed by ultrasonographic study, computer tomography (CT), or magnetic resonance imaging (RMI). An umbilical hernia is often associated with diastasis recti due to the progressive laxity of the midline fascia.

Hernia

A hernia is defined as a bowel coming out of the cavity that normally contains it, through an orifice or area of weakness. According to the European Hernia Society, we can classify abdominal wall hernia in medial and lateral. Medial hernias include umbilical and epigastric hernias, whereas lateral hernias involve Spigelian and lumbar hernias [14]. For the development of a hernia, two conditions must occur: a predisposing condition, due to malformations, congenital weakness, or a thinning of the abdominal wall caused by pregnancy, old age, or constitutional thinness, and a triggering condition, caused by an increase in intra-abdominal pressure related to coughing, obesity, or overexertion.

An *umbilical hernia* is a ventral hernia located at or near the umbilicus. The European Hernia Society classification for abdominal wall hernias defines the umbilical hernia as a hernia located from 3 cm above to 3 cm below the umbilicus. It

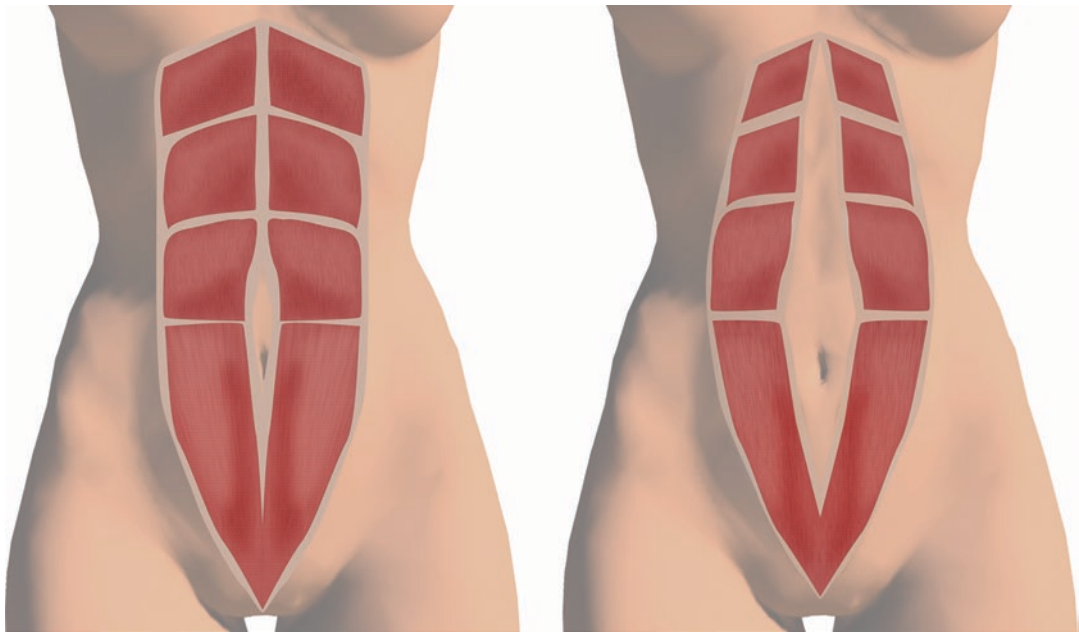

Fig. 26.3 On the left, normal anatomy of the rectus abdominis muscles and the linea alba. On the right, diastasis recti with increase of the inter-recti distance. (Illustration by Federico Di Crescenzo)

is the second most common type of hernia in adults following inguinal hernia. It accounts for 6–14% of all abdominal wall hernias in adults [15]. Unlike in children, the adult umbilical hernia has no tendency to spontaneous regression and must always be operated, considering the high risk of incarceration related to it. Narrow-neck hernias are at greater risk for incarceration and strangulation of bowel, whereas large-neck hernias are less likely to cause bowel trauma. The navel is the scar located in the center of the xiphopubic line and consists of a fibrous ring covered by the pre-peritoneal tissue and by the peritoneum; this represents a locus minoris resistentiae. In adulthood, it measures 2–3 mm, but it can be wider in predisposed patients. Abdominal distension is a risk factor for umbilical hernias; this is the reason why they are more frequently found in multipares, in cirrhotic patients, and in the obese. Diagnosis is clinical and is easier in normal-weight or underweight patients when an umbilical bulging appears during the Valsalva maneuver. Umbilical hernias are generally asymptomatic, becoming symptomatic in case of strangulation or incarceration. When diagnosis is doubtful or when it is indicated to study the accompanying diastasis, ultrasound or CT exams are useful.

Epigastric hernia occurs when an area of weakness in the abdominal wall allows pre-peritoneal fat to push through; these kinds of hernias are typically small. They occur in the area between the navel and the breastbone. These hernias typically do not cause symptoms, but the patients may experience pain in the upper abdomen. It is important for the surgeon to know that some patients develop more than one epigastric hernia at a time.

Lateral hernias include Spigelian hernias, which might appear on the semilunar line at the level of the external margin of the rectus abdominis muscle; this line extends from the anterior margin of the IX costal cartilage to the pubis. They are usually found below the umbilical level due to dehiscence of the transversus aponeurosis and internal oblique muscle which appear to be weaker in the vicinity of the semilunaris line.

Lumbar hernias come out through one or both areas of least resistance in the posterolateral supra-iliac region: the superficial lumbar Petit's triangle and the quadrilateral area of Grynfeltt. Petit, in 1738, described one of the first cases of complicated lumbar hernia which appeared in a triangle bounded by the iliac crest, the external oblique muscle, and the latissimus dorsi muscle (named from him the Petit's triangle). On the other hand, the space described in 1866 by Grynfeltt is bordered by latissimus dorsi muscle at the level of the XII rib, the posterior margin of internal oblique muscle, and the serratus muscle. The area of greatest weakness is represented by the aponeurosis of the transverse muscle, due to the passage of three muscular nerve pedicles. Such "costo-iliac" hernias can vary between 2 and 20 cm in diameter. Other abdominal wall hernias are represented by inguinal and crural hernias.

Inguinal hernia can be classified as:

- External or indirect oblique hernias, also called "lateral hernias"; they are the most frequent, involving peritoneal sac, which is externalized through the lateral inguinal dimple, lateral to the epigastric vessels. Usually, the sac is intra-funicular and corresponds to the persistence of the peritoneo-vaginal duct. It develops like a "glove finger" inside the fibro-cremasteric sheath and follows the way of the funiculus.
- Direct hernias, also called "medial": they exteriorize from the dimple medial inguinal, medial to the epigastric vessels. Usually, the sac is wider than long and spheroidal and corresponds to a prolonged relaxation of the transversalis fascia a level of the medial inguinal dimple. Sometimes the sack externalizes through a limited orifice and takes a diverticular aspect.
- Internal oblique hernias are located at the level of the internal inguinal dimple, medial to the umbilical artery, and are externalized at the inner corner of the inguinal duct. They are exceptional.

Crural hernias, also called "femoral," are rarer than inguinal and more frequent in females. Crural hernias do externalize through the sheath

of the femoral vessels, which extends the transversalis fascia to the thigh. This sheath is normally narrow around the femoral vessels, except at the level of the medial aspect of the femoral vein. It is at this level that common crural hernias develop. The sack pushes through the crural ring, below the crural arch, medial to the femoral vein.

Postoperative or Incisional Hernia

Incisional hernia is defined as the herniation below the cutaneous plane of abdominal viscera, through a previous laparotomy incision, representing a rather frequent complication of abdominal surgery. In most cases, it appears in the first year after surgery, representing a complication, and it is often a source of long-term morbidity. Based on anatomical and clinical criteria, incisional hernias can be distinguished in median and lateral hernias. The median ones, originating at the linea alba, are the most frequent, representing a 75–90% of the total; among the lateral hernias, less frequent than the median (10–25% of total), the subcostal and inguino-iliac ones are the most common, in most of the cases located, respectively, in the right hypochondrium, as consequence of biliary surgery, and right iliac fossa, following surgery for appendicular peritonitis or for gynecological pathologies [16]. Depending on the size of the hernia gate, they can also be categorized as follows: small hernias (<5 cm), intermediate hernias (5–10 cm), large hernias (>10 cm), and giant hernias (>20 cm). Incisional hernia is an evolutionary disease, and when it reaches a considerable size, it alters the physiological balance between abdominal muscle activity, abdominal pressure, and diaphragm activity causing the so-called laparocele disease with important muscular, respiratory, cardiocirculatory, and visceral alterations. More than the endoabdominal pressure is the lateral traction carried out on the linea alba by the contraction of the lateral muscles of the abdomen that contributes to an increase of the fascial gap. This explains the natural trend of most ventral hernias to progressively increase in dimensions, unless scarring sclerosis acts to consolidate the hernial port when it is still small. In mobile hernias, synchronous with the acts of breathing, the viscera are rhythmically pushed through the hernial gate out of the abdominal cavity, and the activity of the diaphragm is seriously compromised; the movements of the abdominal wall become irregular during the phases of breathing with subsequent worsening of the respiratory function. It is useful for surgical planning to perform instrumental examinations like a CT scan to investigate defect depth (full or partial thickness), the presence of both rectus abdominis muscles, and horizontal diameter between the rectus abdominis and perforators' anatomy.

26.3.2.2 Full-Thickness Defects

Traumatic Defects

Acquired or full-thickness defects generally result from different conditions like previous surgery, trauma, infections, and tumor resections. Massive abdominal wall defect is a challenge to any reconstructive surgeon. Defects due to any trauma are very difficult to manage due to associated injuries, infection, and non-availability of local tissues for reconstruction. Traumatic rupture of the abdominal wall is most commonly supraumbilical and is related to a concurrent intra-abdominal injury. Plastic surgery is usually called not for the management of acute penetrating abdominal injury but for the repair of subsequent loss of domain. Reconstructive surgeons may also be called to evaluate wounds that have been left temporarily open.

Oncological Defects

History of abdominal neoplasm may complicate the reconstructive course: chemotherapy may impede wound healing, and radiotherapy causes extensive tissue injury and may contribute to abdominal wall defects. Acute radiation injury poses several challenges: difficulty in distinguishing anatomical planes, extensive soft-tissue fibrosis, reduced tissue pliability, and prolonged healing time. The injury to a wound bed is manifested by stasis or occlusion of the small vessels and decreased tensile strength.

26.4 Surgical Treatment

A lack of abdominal wall integrity is often a cause of frustration for patients, having a huge impact on quality of life, social relationships, and physio-psychological well-being.

Plastic surgeons are called to restore proper abdominal wall structure and function when it is diminished or absent. It is very common that patients consulting plastic surgeons have already made multiple attempts at surgical closure of their abdominal wounds with no success.

Risk factors for failure of primary hernia repair include obesity, surgical-site infection, hernia size, hernia repair technique, patient demographics, smoking history, chronic respiratory disease, prolonged wound healing, and mesh failure. Obesity is also an independent risk factor for postoperative complications. Surgeons must bring the patient to surgery in the best possible conditions and must reduce all related risk factors before planning an operation, except for emergency situations [17]. In line with that, nutritional evaluation and counseling for obese patients are paramount, and weight loss surgery should be considered; smoking cessation is mandatory, and diabetes and cardiac and pulmonary status should be assessed and optimized.

Depending on the clinical situation and on the type of defect, a decision should be made on whether it is advisable to proceed with immediate or staged repair.

Immediate reconstruction is commonly preferred because it is more cost-effective and less time-consuming in stable patients; on the other hand, major surgery should be postponed in case of significant distension, inflammation, infection of the wound bed, or planned staged reconstruction.

26.4.1 Repair of Congenital Defects

In case of congenital defects repair postpartum, fetuses with *gastroschisis* will benefit from intravenous fluid resuscitation and wrapped herniated loops in warm saline as there is an increased risk for water and heat losses by evaporation. A surgical option for gastroschisis includes repositioning of the herniated bowel into the abdominal cavity, with closure of the abdominal wall like in primary reduction and repair. In such cases, there is a high risk of respiratory complications. The surgical procedure can also be postponed if the patient is unstable. In cases of complex gastroschisis, the repair is usually delayed, as anastomosis is impossible, having an inherent risk of infectious and cholestasis complications.

In cases of *omphalocele* with a small abdominal wall defect, primary closure is the preferred therapeutic procedure, while in cases of a larger defect, multiple surgeries may be required to repair it. Various agents such as povidone-iodine, sulfadiazine, neomycin, silver-impregnated dressings, neomycin, polymyxin, and bacitracin ointments have been reported to help with the formation of an eschar of the amnion sac. There are different surgical techniques for the cure of omphalocele that include serial reductions or closing the defect gradually after replacing the sac with a mesh.

Bladder exstrophy is detected with prenatal US, and the prognosis is quite favorable. The postnatal management includes early surgical procedure to close the anterior wall defect within the first 3 days after birth. If the surgical repair is performed later, there is a higher risk of urinary incontinence or uterine prolapse, infertility, and increased risk of bladder adenocarcinoma. Besides bladder closure, pediatric surgeons must also repair the epispadias simultaneously, or in a staged intervention, in order to offer an acceptable appearance and function of the external genitalia.

Repair of the *umbilical hernia* in infants is usually postponed due to a low rate of complications; furthermore, most umbilical defects will be corrected spontaneously within 2 years. The size of the hernial ring provides a useful indicator for spontaneous closure. Expectant management of asymptomatic umbilical hernias until the age of 4–5 is both a safe and standard procedure in many pediatric hospitals. Surgery is indicated for complications of the hernia which include incarceration, strangulation, or rupture. Fascial defects

with diameters less than 1.0 cm almost always heal spontaneously before 6 years of age and therefore rarely need surgical treatment. Fascial defects greater than 1.5 cm rarely heal spontaneously before age 6; such large defects should be surgically corrected prior to age 6 to prevent embarrassment in school [18]. Umbilical hernia repair is a day case surgery performed under general anesthesia; a semicircular periumbilical incision is usually made on the left margin of the umbilical ring allowing to proceed with a dissection of the peritoneal sac at the deep face of the skin of the navel. The aponeurotic margins of the umbilical ring are then identified and carefully prepared, bringing them closer together with transverse stitches with non-absorbable suture. Umbilicoplasty may be performed, especially for those with a large umbilical hernia, to improve cosmetic results.

26.4.2 Repair of Acquired Defects

Acquired defects of the abdominal wall are categorized in partial defects, which involve the loss of either the skin and subcutaneous tissue or the myofascial tissue, and complete defects, involving the full-thickness loss of both superficial and musculofascial layers.

26.4.2.1 Repair of Partial Defects

Partial defects involving the *skin and subcutaneous tissues*, if smaller than 5 cm in size, are usually closed primarily; defects between 5 and 15 cm in size are closed either with local flaps (random flaps, perforator flaps) or a split tissue skin graft or can also be managed with a vacuum-assisted closure device. For defects greater than 15 cm in size, options include pedicled or free fasciocutaneous flaps or, alternatively, the use of random flaps, whose use can be optimized with tissue expansion processes, which aid in tissue advancement and donor site closure. Expansion of both sides of a defect improves the process of reconstruction. The disadvantage of this technique is that it is a staged and lengthy procedure, and there is also a possibility of exposure and infection of the tissue expander. The advantage is that reconstruction can be performed with well-vascularized, innervated, autologous tissue.

Partial *myofascial defects* are closed primarily whenever possible; the plication of the anterior and/or posterior rectus sheath is the most frequent procedure performed by plastic surgeons to correct deformities of the musculoaponeurotic layer involving the midline.

Diastasis Repair

The most common partial myofascial defect of the abdominal wall is rectus diastasis, which usually needs surgical repair with different techniques, either through an open or laparoscopic/endoscopic procedure.

Open approach is performed during conventional abdominoplasty or mini abdominoplasty procedure, depending on the patient's body shape and skin laxity: conventional abdominoplasty is generally more suitable when there is redundant skin excess and involves the transposition of the umbilicus which is detached from the skin but remains connected to its stalk; mini abdominoplasty is usually performed in young women, when the abdominal skin tissue is elastic and involves a complete detachment of the navel from its pedicle, which remains adherent to the surrounding skin. This procedure does not involve the excision of abundant skin and subcutaneous tissue. The concept of abdominoplasty surgery has remained constant over the years. The purpose is to improve the contour of the abdominal wall by means of rectus abdominis fascia plication and removal of excess skin and fat from the lower abdominal region. These benefits are achieved using a low-lying suprapubic incision that can be hidden under the bikini line; anterior rectus sheath plication extends from the xiphoid appendix down to the suprapubic area. Plication of the anterior rectus sheath is performed with a one- or two-layer synthetic, monofilament, non-absorbable polypropylene suture. It is not uncommon that some patients present persistent musculoaponeurotic flaccidity after correction of the diastasis. Therefore, when there is laxity in the flank and hypogastric area after plication of the anterior rectus sheath, plication of the external oblique aponeurosis is an interesting

adjunctive procedure that can be used to improve overall tension of the musculoaponeurotic layer and to valorize the fine contour of the abdomen in thinner patients (Fig. 26.4).

In case of severe laxity, the use of a resorbable or no resorbable mesh can be considered; this might be placed over the anterior or posterior rectus sheath and anchored interrupted by using an absorbable suture. Obtaining a complete coverage of the mesh with the anterior rectus sheath layer is advisable to avoid complications.

Hernia Repair

The treatment of all umbilical hernias in adults must be surgical, considering the risk of strangulation. It is performed under general anesthesia that allows dissection in optimal conditions on a curarized patient. There are different techniques available: simple closure, closure with local plasty, or prosthetic reinforcement by conventional or laparoscopic approach. The indication for a specific technique depends on the size of the hernia, skin conditions, and the surgeon's preference. Elliptical semi-circle skin incision is performed on the left side of the navel, which can be slightly prolonged on the midline above or below, and then the surgeon proceeds with sack isolation, disconnection from skin adhesions, and repositioning of its content into the abdominal cavity. When the tension is high after hernia correction, small fascial releasing incisions (1–1, 50 mm on each side) are suggested. To avoid hernia recurrence, a wall reinforcement with a prosthetic material is often necessary. This must be inserted deeply to limit the risk of infection, often between the peritoneum and posterior aponeurosis of the rectus sheath; a cleavage plane is generally present between peritoneum and muscle sheath. The laparoscopic approach is also performed under general anesthesia, with an empty bladder. The patient is placed in a supine position. The operation starts with the creation of the pneumoperitoneum. The trocar with optics is inserted lateral to the navel or in the suprapubic region. Two more 5 mm operating trocars are placed laterally; after exploring the peritoneal cavity, the sac is freed from its adhesions, using scissors and hook coagulator. If a prosthesis is

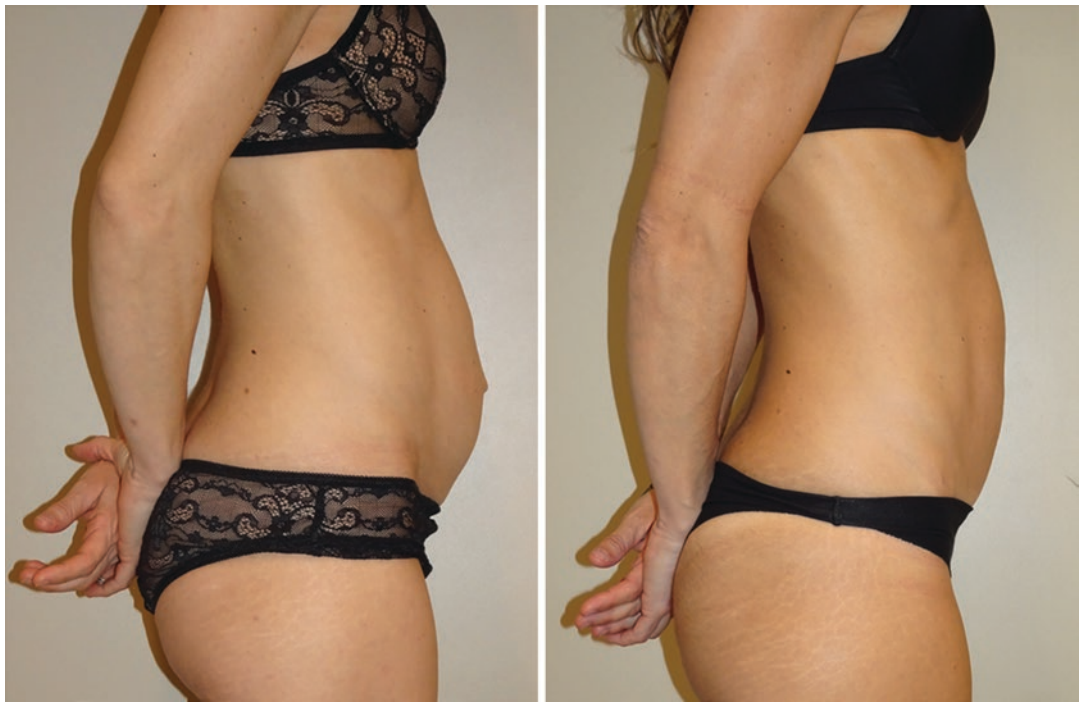

Fig. 26.4 Pre- and post-correction of a rectus diastasis and umbilical hernia with conventional abdominoplasty

needed to be inserted, it is shaped and introduced in the abdominal cavity both through the optic trocar and through an additional 10 mm trocar.

Postoperative or Incisional Hernia Repair

Ventral hernias are one of the most common abdominal wall defects faced by reconstructive surgeons, known for the high relapse rate and surgical complications. It is important to note that, despite advances in hernia repair techniques and technologies, recurrence following standard ventral herniorrhaphy remains unacceptably high. Evidence from the trial conducted by Luijendijk suggests that nearly one quarter of ventral hernias repaired with synthetic mesh recur within 3 years; this rate reaches 50% for primary repair alone. In addition, the risk of hernia recurrence increases with each additional operation: the length of time between reoperations was progressively shorter after each additional hernia repair [19]. Postoperative complications and recurrence are the two main issues in ventral hernia repair; infection is a common and significant postoperative occurrence that increases the risk of hernia recurrence. Use of prosthetic repair material is highly recommended in order to reinforce the repair of all incisional ventral hernias, whether the midline fascia can be re-approximated or not. Very small defects may be closed primarily along with reinforcing prosthetic repair material, potentially using a retrorectus repair. Most defects too large for primary repair can be closed with the component separation technique and reinforced with prosthetic repair material. In 1990, Ramirez published his work on local tissue transfer for the repair of ventral hernias [20]. Component separation technique involves suprafascial lateral dissection to the midaxillary line, followed by a fasciotomy through the external oblique aponeurosis and then lateral dissection in the plane between the external and internal oblique muscles up to the midaxillary line. This avoids damage to the neurovascular structures supplying the muscles, which travel in the plane between the internal oblique and the transversus abdominis. These maneuvers allow medial advancement of 3–5 cm in the epigastrium, 7–10 cm at the waistline/umbilical region, and 1–3 cm in the suprapubic area for a single side; therefore, a bilateral component separation can allow for closure of a 20-cm-wide fascial defect. Component separation creates a dynamic repair by using incisions that create fascial release to bring the rectus muscles together at the midline, thereby recreating an innervated, functional abdominal wall. When component separation is not feasible or is insufficient to completely reduce the defect, surgeons may consider bridging the defect with prosthetic repair material (Fig. 26.5).

Tips and Tricks

Important things to consider for better outcomes in abdominal wall surgery:

- According to the multidisciplinary approach, a good anesthesiologist-surgeon relationship is critical to achieve the best possible results; it is important to avoid cough, nausea, vomiting, and abdominal contractions postoperatively.
- Wearing compression garments after surgery will improve the patient's recovery and will reduce the rate of postoperative seromas.
- When dermolipectomy is performed, tension-free sutures with layered abdominal closure are suggested, which transfer the tension to the superficial fascia system and not on the distal skin flaps, in order to reduce skin flap necrosis and hypertrophic scars.
- Get out of bed: moving around and walking in the days following surgery help in faster recovery while reducing thromboembolic complications.

Synthetic mesh is currently the most common repair material used for reinforcement of ventral hernias; however, despite significant advantages such as reduced recurrence rates, ease of use, and comparatively low cost, permanent synthetic mesh has certain drawbacks. These disadvantages include increased risk of visceral adhesions to the

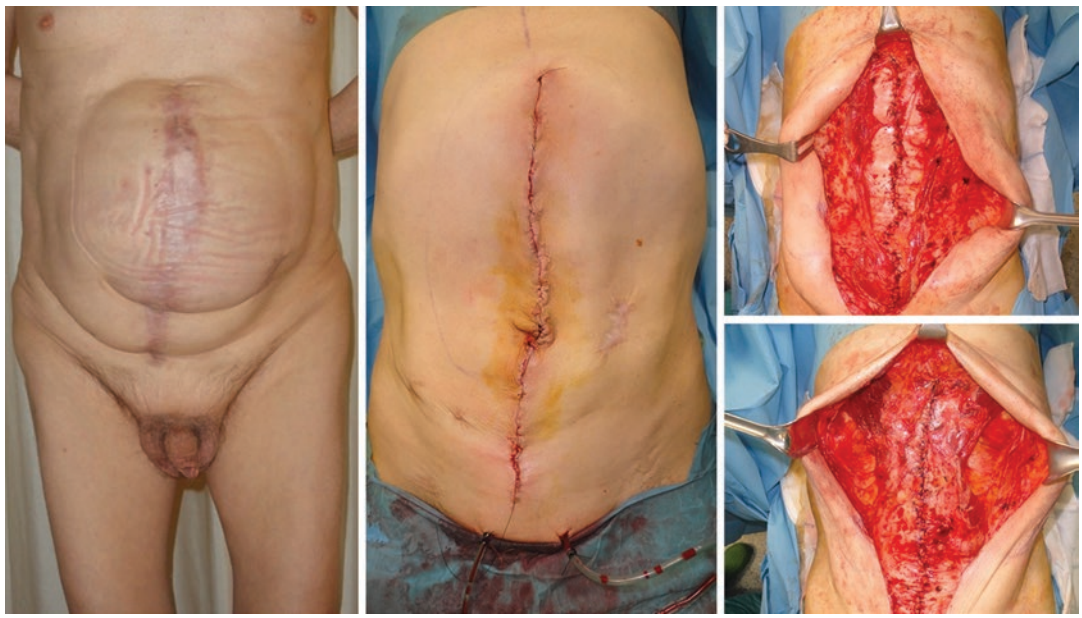

Fig. 26.5 Recurrent incisional hernia operated with a combination of mesh placement and component separation technique (Ramirez), which allowed bilateral advancement of the muscular layers with complete coverage of the mesh

repair site, erosion into the bowel leading to formation of enterocutaneous fistulae and/or bowel obstruction, extrusion of the repair material, and infection. Following removal of an infected prosthesis, the surgeon is left with a contaminated field and a hernia deficit larger than the original that still requires repair material. Surgeons must consider the use of biologic repair materials in place of permanent synthetic mesh, because of their ability to support revascularization: these materials are more resistant to infection and do not require removal when exposed or infected; furthermore, the ability of certain biologic prostheses to support revascularization may contribute to clearance of a contaminated field. Biologic repair materials have been successfully used to repair large contaminated and/or irradiated abdominal wall defects in patients with cancer when placed directly over the bowel. The choice between synthetic and biologic repair material for many surgeons is often based on several considerations including cost, choice of technique, technical expertise, and the risk for postoperative complications. In open incisional hernia repair, prosthetic repair material may be placed to reinforce a primary repair or to bridge a remaining defect if reapproximating of the fascial edges is not possible. There are several techniques that have been described, according to the location of the prosthesis: this can be sutured superficial to the primary repair of fascial edges *(onlay*), within the myofascial layers (*sublay*), or beneath the fascia and exposed to intraperitoneal contents (*underlay*). Overlay placement, therefore, may be preferred for types of synthetic mesh that are associated with formation of bowel adhesions to minimize the risk that the mesh may erode into the abdominal compartment and become exposed to the viscera. Bridging may not generally be recommended except in cases where component separation is not feasible or is insufficient to bring the fascial edges together. There are also theoretical advantages to the placement of repair material as an underlay: when the material is placed deep into the abdominal musculature, increases in intra-abdominal pressure press the repair material into the defect and against the native tissue, rather than away from the defect. This technique also seems to have a lower recurrence rate.

Although recurrence rates following reinforced laparoscopic hernia repair are comparable

to those of open repair with reinforcement, there are several documented advantages of the laparoscopic approach, including smaller incisions, lower risk for complications, shorter hospital stay, and patient preference. However, seromas may be more common following laparoscopic hernia repair, due to the use of drains in the open approach, which are not generally placed in laparoscopic repairs. In addition, the limitations of laparoscopic repair include the inability to restore functional abdominal wall anatomy, to manage skin redundancy and the hernia sac.

Key Point

Ventral hernias are one of the most common abdominal wall defects faced by reconstructive surgeons.

Repair of giant incisional hernias can bring to an increase of intra-abdominal pressure and, sometimes, to abdominal compartment syndrome. Patient optimization is crucial for the success of the intervention.

Given the high risk of recurrences, the use of a prosthesis is mandatory and must be placed preferably between the muscular plane and the posterior rectus sheath. In our experience, biologic mesh is the first choice, given the lower infection rate.

26.4.2.2 Repair of Full-Thickness Defects

Traumatic Defects Repair

Traumatic accidents or, more commonly, oncological resection (soft tissue sarcoma) may result in large full thickness of the abdominal wall. In trauma patients, especially with loss of domain, delayed reconstructions are preferred. In such cases, every effort should be made to achieve primary fascial closure after adequate debridement of any poor-quality, attenuated, scarred, damaged, or nonviable musculofascial tissue. In this case, the wound is closed with a temporary cover and subsequently re-explored. A skin graft may be applied as a temporary measure until reconstruction can be performed. Vacuum-assisted closure devices are used in such cases; using this adjunctive tool, a sterile foam dressing is placed in the wound cavity with an evacuation tube which exits the wound to create an airtight seal, and sub-atmospheric pressure is applied to the foam dressing; this procedure ensures a complete sealing from the environment, a better vascularization of the wound bed, a decrease of bacterial colonization, an improvement of granulation tissue while reducing the size of the defect, and increased flap survival. Unstable or trauma patients with full-thickness defects require reconstruction of the different layers to restore muscular function and replace skin and fascial gaps. In such patients, a staged approach is preferred using a temporary vacuum-assisted closure device and, if needed and possible, a planned tissue expansion procedure. Tissue expansion can provide autogenous tissue to close skin and subcutaneous defects larger than 15 cm in size after initially achieving temporary closure. Reconstruction requires expansion on both sides of the defect. Despite being a lengthy, staged procedure, it provides well-vascularized innervated autologous tissue for reconstruction. Expansion is achieved between external and internal oblique or between internal oblique and transverses abdominis muscles. Tissue expansion also restores abdominal domain thus allowing easy reduction of visceral contents of the ventral hernia and prevents postoperative respiratory discomfort [21].

Oncological Defects Repair

Similar full-thickness defects are encountered after oncological resection of soft tissue sarcomas or skin metastasis from other cancer invading the abdominal wall. In such cases, immediate reconstruction is needed to provide urgent coverage of exposed viscera. We should support the use of mesh as a fascial repair in all oncologic cases. For moderate-size defects involving the lower abdominal wall and the inguinal region, local and/or locoregional pedicled flaps are used with success: in particular the gold standard coverage is provided by the use of tensor fascia lata flap and anterolateral

thigh flap with combination of fascia lata and muscle (vastus lateralis, rectus femoris) harvesting. In this scenario, the thigh donor site is ideal to provide an abundant source of vascularized fascia to perform fascial reconstruction; vascularized fascia lata was historically the mainstay for reconstructing contaminated fascial defects of the abdominal wall. In cases of prior radiation therapy, prior surgery, or excessive skin resection, vascularization may not be reliable, and a pedicled regional or free flap from the contralateral abdomen, thigh, or posterior trunk may be considered. Also, perforator flaps can be used with a similar purpose of skin resurfacing (deep inferior epigastric artery perforator flap, superficial circumflex iliac perforator flap), in combination with the use of a mesh; perforators are identified using a hand-held Doppler, and the flap is then meticulously raised ensuring no injuries to perforators under loupe magnification. For defects of significant size, especially extending in the upper abdominal quadrants, microsurgical transfer of free flaps from distant donor sites (anterolateral thigh flap, latissimus dorsi flap) is preferred to cover the exposed viscera and restore function: this is a more advanced technique, associated with long operating times, technically demanding and more prone to complications (Fig. 26.6). The procedure can be performed in a nonfunctional (if one or both rectus abdominis muscles are intact and functional) or functional way (if the motor function of the anterior abdominal wall is impaired) [17]. In such cases, the latissimus dorsi transfer is frequently indicated. The alternative in such extensive cases is abdominal wall transplantation. Composite allotransplantation of the abdominal wall involves harvesting full-thickness abdominal wall with the iliac or inferior epigastric vessels from a donor. Candidates for this reconstructive option should have exhausted all other options.

Key Point

It is advisable to perform an immediate reconstruction after oncological resection, when the wound is clean and local tissues are available and allow a proper reconstruction.

In traumatic defects, delayed reconstruction represents the best course of action; a temporary vacuum-assisted closure device is employed during stabilization of the patient in order to decrease the bacterial colonization, to define the real extent of the loss of substance, and to improve tissue vascularization.

An interdisciplinary approach plays a key role especially in full-thickness defects.

Take-Home Messages

- The abdominal wall is a functional unit: a comprehensive knowledge of the vascular and neural architecture is mandatory to successfully approach abdominal reconstruction.
- Elective defects such as rectus diastasis are frequently encountered and approached with a combined functional/aesthetic procedure: abdominoplasty/mini-abdominoplasty.
- Ventral hernia repair should be addressed with a combination of autologous and synthetic approaches to reduce complications.
- Component separation technique is the approach of choice for significant myofascial defects, especially in comorbid and obese patients.
- Oncological cases should be referred to microsurgical units with expertise in flap transplantation.

Pearls and Pitfalls

- Accurate planning of dermolipectomy patterns combined with rectus diastasis plication offers the best functional and aesthetic results.
- Reduce risk factors before surgery like tabagism, diabetes mellitus, chronic

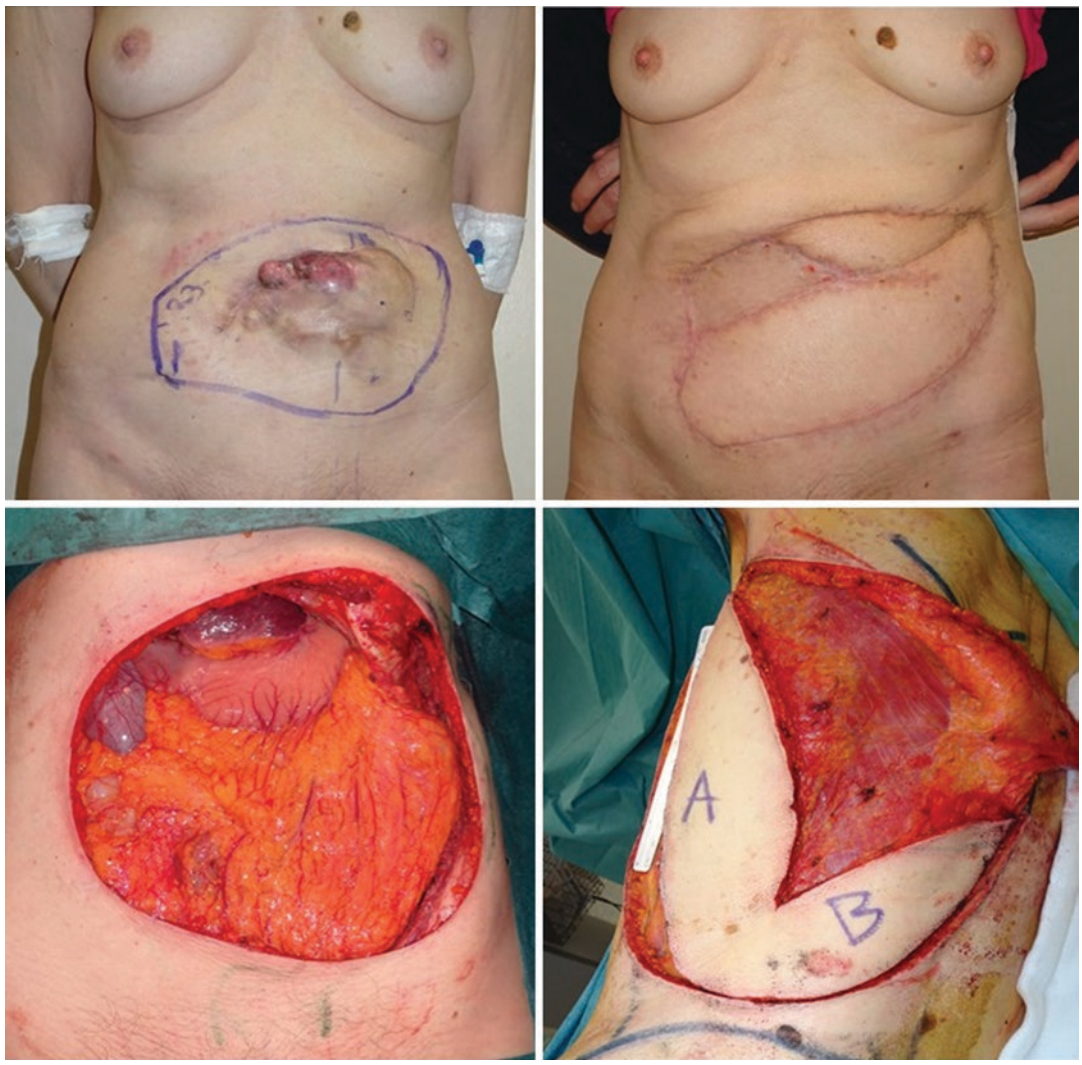

Fig. 26.6 Microsurgical abdominal wall reconstruction with a KISS LD free flap after wide resection of dermatofibrosarcoma protuberans

obstructive pulmonary disease (COPD), coronary artery disease (CAD), poor nutritional status, immunosuppression, and obesity in order to have the greatest chances of success.

- The use of prosthetics material is highly recommended in case of postoperative hernias, due to the high recurrence rate.
- The use of biologic meshes should be preferred to reduce the risk of bacterial contamination.

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Lymphedema: Diagnosis and Treatment

27

Peter C. Neligan

Background

Lymphedema refers to swelling of a limb secondary to malfunction of the lymphatic system from either congenital or acquired causes. Recent developments in the treatment of lymphedema have changed our approach to management of these patients. New imaging modalities have provided a better understanding of the problem and how it can be treated.

Key Points

An understanding of the lymphatic system is important in approaching treatment.

Careful clinical examination helps establish the diagnosis and evaluate treatment progress.

Imaging is an important part of the workup to identify the problem and help in treatment choice.

Conservative treatment remains an important part of management.

Surgical options are excision and reconstructive.

The commonest type of excisional treatment is liposuction.

Lymphaticovenous bypass (LVB) and vascularized lymph node transplant (VLNT) are the commonest reconstructive procedures.

Prophylactic LVB is a good approach in patients having lymphadenectomy.

27.1 Introduction

We produce approximately 3 L of lymph each day from the circulatory system. This fluid passes through the integument and is collected by lymphatic channels. It takes with it cells, bacteria, and proteins, essentially anything that is free in the integument, and transports them to the regional lymph nodes for the immune system to deal with. The lymph system has been called the sewage system of the body. Lymphedema is often thought of as a plumbing problem since, when the system backs up, regardless of whether the cause is congenital or acquired, fluid builds up in the tissues. However, it is far more than that. Lymph vessels have walls containing smooth muscle as well as a valvular system. Nitric oxide (NO) is implicated in the pumping

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action of lymphatic vessels [1]. If we look at experimentally induced lymphedema in animals, whether by tail surgery, popliteal node excision, or toxic injection, several things are consistently seen in clinical lymphedema. These include fibro-adipose deposition, attenuated and eventually absent lymph vessel pumping, and decreased dendritic cell trafficking which decreases collateral vessel formation. So in lymphedema, we see a lack of collateral vessel formation compared, for example, with what we see in venous obstruction. The other consistent finding is inflammatory cell infiltration [2]. This has led to the investigation of the efficacy of anti-inflammatories in the treatment of lymphedema. There is both animal and human evidence to show that this deserves further investigation [3, 4]. All of these things need to be kept in mind in dealing with these patients.

27.2 Types of Lymphedema

Lymphedema can result from any abnormality or injury to the lymphatic system. Lymphedema may be primary or secondary. Traditionally primary lymphedema has been described relative to the time of presentation. Milroy's disease, or type 1 primary lymphedema, presents at or shortly after birth. It is related to a VEGF3 receptor mutation. Type 2 primary lymphedema has two iterations. Lymphedema praecox presents in the late teen years, while lymphedema tarda presents in patients in their 30 s [5, 6].

Acquired or secondary lymphedema is a huge worldwide problem. Filariasis is by far the commonest cause of acquired lymphedema. It is a mosquito-borne condition in which the insect bites an infected individual and transfers the nematode to another individual. The larvae mature in the lymphatic system, destroying the lymphatics [7]. This condition is endemic in many parts of the world. It is estimated that 70 m people worldwide have filariasis and 120 m are at risk.

There are many causes of secondary lymphedema. Essentially anything that blocks normal flow in the lymphatic system will cause lymphedema. Morbid obesity has been associated with lower extremity lymphedema [8]. Lymphedema may be reversible if the patient loses weight. However, the commonest cause of lymphedema we see is secondary to surgical procedures, often combined with radiation. There is a lymphedema incidence of approximately 25% following axillary node dissection and radiation. The incidence in the lower extremity following groin dissection and radiation is even higher. For this reason, we are now able to prophylactically reconstruct the lymphatics at the time of node dissection in these patients [9].

27.3 Patient Assessment

When presented with a patient with limb swelling, the diagnosis has firstly to be established since there are many causes of limb swelling. Assuming that lymphedema has been verified as the cause of the swelling, we then have to assess the patient in order to choose the most appropriate treatment. History is important. It helps differentiate between primary and secondary lymphedema. We also want to know the duration of the condition, any history of infection, and most importantly what treatment the patient has had and how they responded to that treatment. On physical examination, we want to ascertain whether or not the patient has any pitting. Pitting edema is diagnosed by firmly pressing on the swollen body part for a minute. If the imprint of the thumb is easily seen on release of the pressure, the patient has pitting edema. We tend to see pitting in early lymphedema, while later in the disease, there seems to be less pitting and a greater fibrofatty element to the swelling. It is established both clinically and experimentally that there is fibrofatty deposition in lymphedema [10, 11]. We want to determine if there are any trophic skin changes as this can increase the risk of infection, and, of course, we want to determine whether there is any sign if infection at the time of our examination. We also want to perform some basic tests, and while none of these is a pathognomonic of lymphedema, taken together, they are

useful particularly as an ongoing assessment tool to measure the patient's response to treatment.

27.4 Limb Circumference and Volume

To be of any use, we need to standardize how these measurements are made so they can be reproduceable. Limb volume is of more use than limb circumference measurements and can be measured in a number of ways. Volume can be calculated from limb circumference measurements, and Brõrson has published how this can be done [12]. Volume has traditionally been measured by water displacement. Perometry can also be used to measure volume [13, 14]. One final tool that can be used to assess the lymphedematous patient is bio-impedance spectroscopy. This measures the time taken for a small electrical current to pass through the tissues and is based on the principle that the resistance to the passage of a current through the tissues (impedance) is inversely proportional to the amount of fluid in the tissues [15].

27.5 Imaging

Having assessed the patient, the next step is to image the lymphatics. This is necessary in order to visualize where the patient's problem is and what can be done about it. There are several imaging modalities available, and each has a place.

Lymphoscintigraphy: This involves the injection of a filtered sulfur colloid, technetium-99, into the web spaces of the hands or feet. It has been the gold standard test for diagnosing lymphedema. It gives good information on the state of the lymphatic system. It documents the lymphedema and gives good information lymphatic function. The transport index of the technetium, i.e., the time taken for the marker to travel to the regional nodes, can be measured [16]. The downside with this technique is that the images are fuzzy and it doesn't give anatomic information on the lymphatic channels (Fig. 27.1). It does have an application however in reverse lymphatic mapping. This is a technique that allows identification of limb draining lymph nodes that must be avoided when harvesting lymph nodes for vascularized lymph node transfer [17].

MR Lymphangiography: This technique not only documents the lymphatics with high-quality images, but it also gives good information about the rest of limb. This can uncover unexpected findings that may be causing limb swelling. An example is shown in Fig. 27.2. One of the difficulties with MR is telling lymphatics apart from veins. Because of that, we introduced

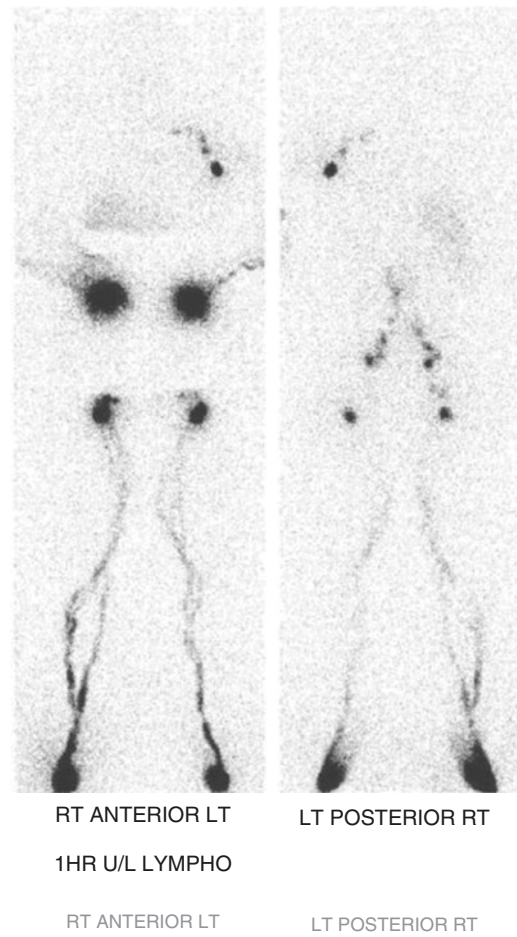


Fig. 27.1 This is a lymphoscintigram of a patient post mastectomy and axillary dissection. The injection sites of technetium are seen in both hands. Lymph node uptake is seen in the left axilla but not in the right, indicating lymphedema in the right arm

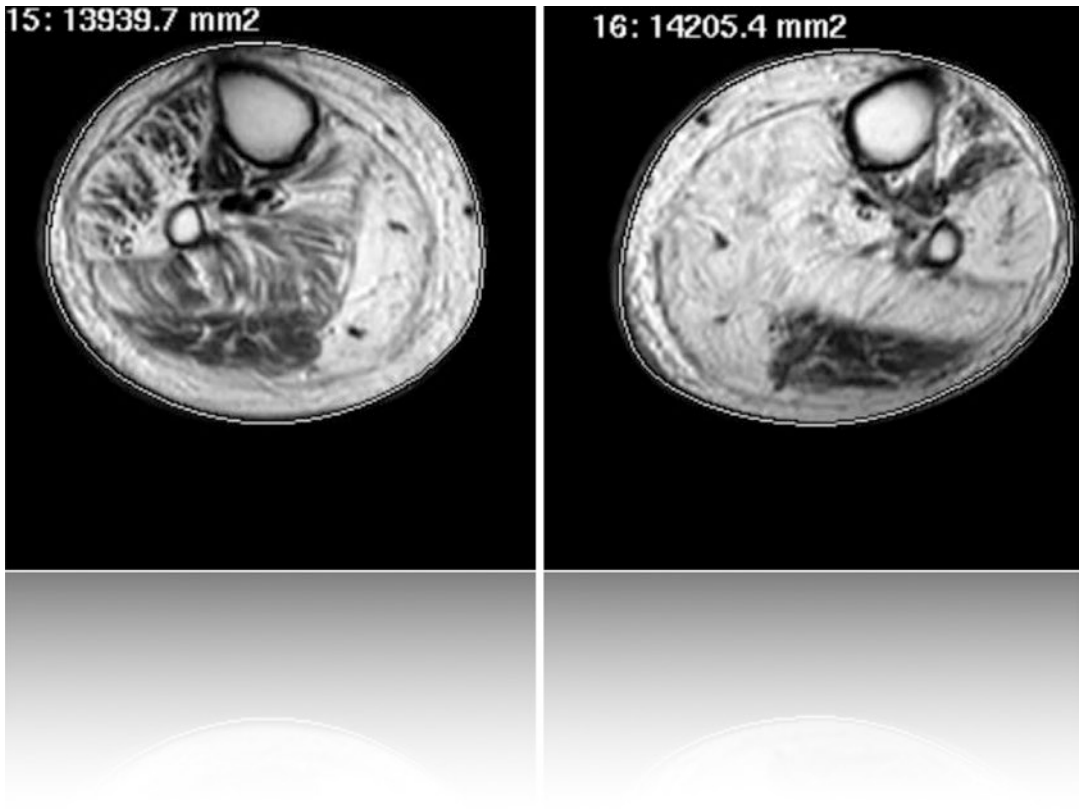


Fig. 27.2 This patient presented with bilateral lower extremity swelling, but MRI showed complete fatty degeneration of his musculature which was the real cause of his limb swelling

a dual-agent technique [18, 19]. This involves an intradermal injection of gadolinium and an intravenous injection of Feraheme which suppresses the venous signal allowing better visualization of the lymphatics. One important part of the MR examination is to look at the axillary veins in upper limb secondary lymphedema and the pelvic veins in lower extremity secondary lymphedema. This is because some of these patients show evidence of compression of the axillary or pelvic veins from a combination of surgery and radiation, and excising the scar from around these veins often improves their symptomatology.

Fluorescent lymphangiography: This involves the use of indocyanine green (ICG). This is a fluorescent dye that is activated by a laser light source and visualized with a near infrared camera. This allows visualization of the superficial lymphatics. Koshima and his group have described the different patterns that we see in lymphedema and correlated these patterns with what we see clinically [20, 21] (Fig. 27.3). The disadvantage of ICG is that only the superficial lymphatics can be visualized. However, it is an invaluable tool.

Most recently, ultrahigh frequency ultrasound has been introduced as a tool [22]. This has opened up new horizons in the surgical management of lymphedema as lymphatic channels can now be clearly seen within areas of dermal backflow and targeted for lymphaticovenous bypass (LVB). In the past, we have avoided areas of dermal backflow for LVB because of the difficulty of visualizing lymphatic channels with other imaging techniques. It has the added advantage of also visualizing veins so that planning of the LVB is simplified [23]. Most recently, the use of microscope integrated laser tomography has been described [24].

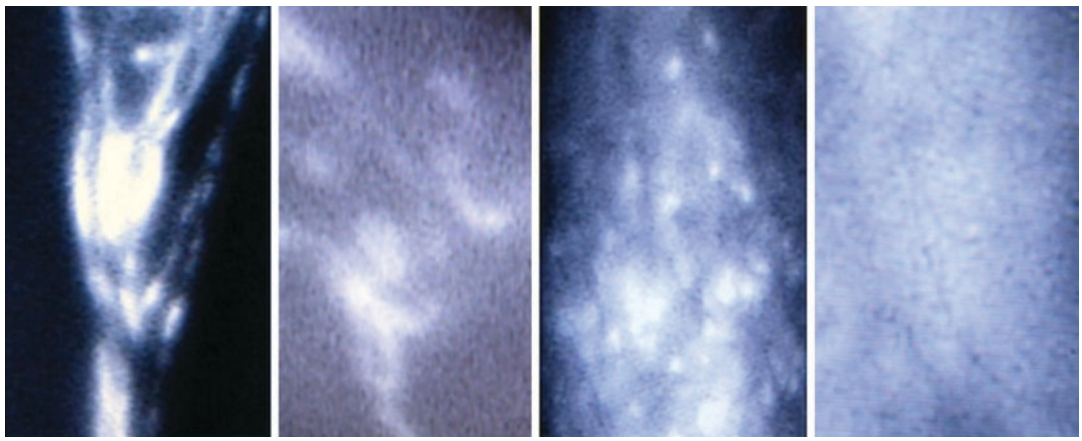


Fig. 27.3 This shows the different patterns seen with fluorescent lymphangiography, linear, splash, stardust, and diffuse. These correspond to decreasing diameter of the lymphatics associated with increased sclerosis

Tips and Tricks

Careful physical examination is important.

Pitting edema is elicited by pressing firmly with the thumb on the swollen area for 1 min.

Lymphoscintigraphy is the first-line imaging investigation to establish the diagnosis.

Fluorescent lymphangiography with ICG is a vital tool intraoperatively as well as pre- and postoperatively.

Optimize the patient's condition preoperatively with conservative treatment.

27.6 Management of Lymphedema

27.6.1 Conservative Management

Conservative management is called decongestant therapy. It involves a combination of elevation, compression, and massage. Manual lymphatic drainage is a type of massage designed to maximize lymphatic drainage in patients with extremity lymphedema. Various types of compression garment are available. Most of these are custom measured and designed for each patient. These are generally worn during the day, and many patients also wear night garments. Sequential pumps are also available. This type of therapy doesn't do anything to treat the lymphedema, though it does control the sequelae (swelling). Regardless, it remains an important part of therapy.

27.6.2 Surgical Management

There are essentially two types of surgical treatment, excisional [25] and reconstructive. Excisional treatments consist of direct excision. This applies to folds or festoons of localized lymphedema, most commonly in the lower extremities and most commonly associated with morbid obesity (Fig. 27.4). These folds generally don't resolve, even with weight loss, and often impede mobility and make weight loss a far greater challenge. These patients need to be warned that they are likely to encounter for wound healing problems, but despite this, patients are generally relieved to be rid of these large folds.

The Charles procedure, attributed to Sir Henry Havelock Charles but never apparently done by him, involves excision of the lymphedematous tissue down to the deep fascia and grafting of the deep fascia. This is reserved for extreme cases who are not candidates for any other type of treatment [26].

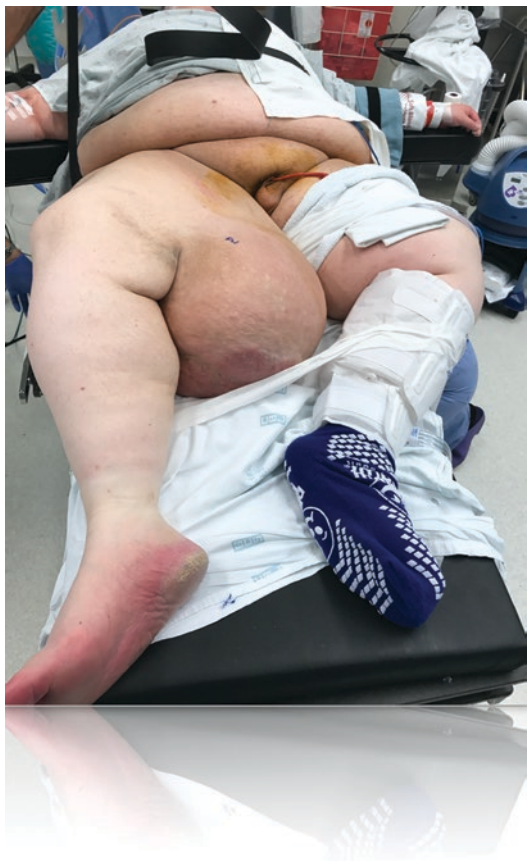


Fig. 27.4 This patient is morbidly obese and has a fold or festoon of localized lymphedema in his thigh. This will not go away even if she loses weight, and its size and weight impede her mobility. The only solution is excision

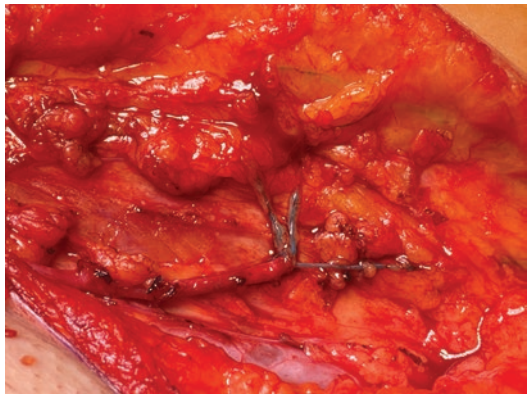


Fig. 27.5 Several blue lymphatics have been telescoped into a vein in the axilla to re-establish lymphatic flow from the limb following axillary dissection

Liposuction however is the most common type of excisional procedure in lymphedema. As a stand-alone procedure, it removes the fatty element associated with lymphedema but doesn't treat the lymphedema. It does reduce limb volume very effectively. However, the patient needs to wear compression 24/7 for life. Used as an adjunct to the reconstructive procedures which address the fluid element of the condition, liposuction works very well, and the patient may not need to wear lifelong compression [27, 28].

There are currently two kinds of reconstructive procedure, lymphaticovenous bypass (LVB) and vascularized lymph node transplant (VLNT). The former involves anastomosis between lymphatic channels and veins with the goal to drain the lymphatic system into the circulatory system. This may be done prophylactically in patients undergoing axillary or groin lymph node dissection. The technique was described by Boccardo and involves identifying lymphatic channels in the groin or axilla and then inserting them into a vein at the end of the dissection [9] (Fig. 27.5). As a therapeutic option, LVB is performed usually at several sites in the arm or leg. Imaging is vital for successful LVB. ICG is used intraoperatively to map the lymphatics so that a decision can be made as to where the optimal sites of incision should be. These lymphatics are very superficial, being just subdermal (Fig. 27.6). For this reason, the complete operation is done under the microscope.

VLNT involves transferring lymph nodes, along with their vascular supply, from one part of the body to the lymphedematous area. The lymph nodes are then re-vascularized at the recipient site (Fig. 27.7). This paper will not describe the details of how that is done; rather, we will concentrate on how the decision is made to offer the appropriate operation to the most suitable patient.

All of the elements we have discussed to date are important. First, the diagnosis has to be confirmed. Then the lymphatics have to be examined in detail. In practice, this translates to an MRI or other imaging for all patients (Table 27.1). Those who, for some reason, cannot have an MRI are examined with ICG. Patients who have no visible lymphatic channels are divided into those who

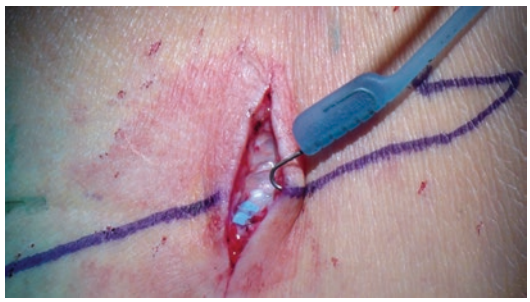


Fig. 27.6 This shows a completed LVB showing how superficial these lymphatics are. They are subdermal and measure between 0.3 and 0.8 mm in diameter. For this reason, they are repaired under an operating microscope

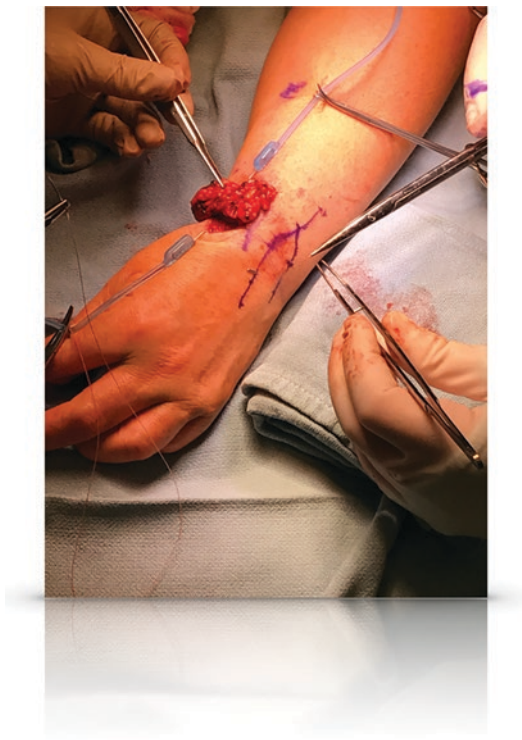


Fig. 27.7 These are supraclavicular nodes harvested with the transverse cervical vessels. They are being transferred to the wrist and will be anastomosed end to side to the radial artery

have had previous surgery, such as a lymph node dissection, and those who have not had any surgery. The latter represent patients with primary lymphedema. In both of these categories, an excisional procedure is offered, usually with liposuction. However, if there are areas of dermal backflow, VLNT to that area is also an option. On the other hand, if lymphatic channels are seen, LVB can be offered. Again, these patients are divided into those who have had previous surgery and those who have not. VLNT may also be offered to those patients who have had a lymph node dissection, and again, if areas of dermal backflow are identified, these may be targeted for VLNT. In the future, it is possible that with the adoption of newer imaging techniques, such as ultrahigh-frequency ultrasound, this treatment algorithm may change. Our approach is to add liposuction to the treatment regimen about a year after successful reconstructive procedure since these procedures address the fluid element of the swelling but do nothing to reduce the fibrofatty element of the swelling seen in chronic lymphedema.

Prophylactic lymphatic reconstruction is also available. This involves re-establishing lymphatic flow from a limb in patients having axillary or groin node dissection [9].

Pearls and Pitfalls

Isosulfan blue (Lymphazurin) is extremely helpful in identifying and staining the lymphatics.

Over-injection of Lymphazurin can stain all the tissues blue and may actually take it harder to find lymphatics.

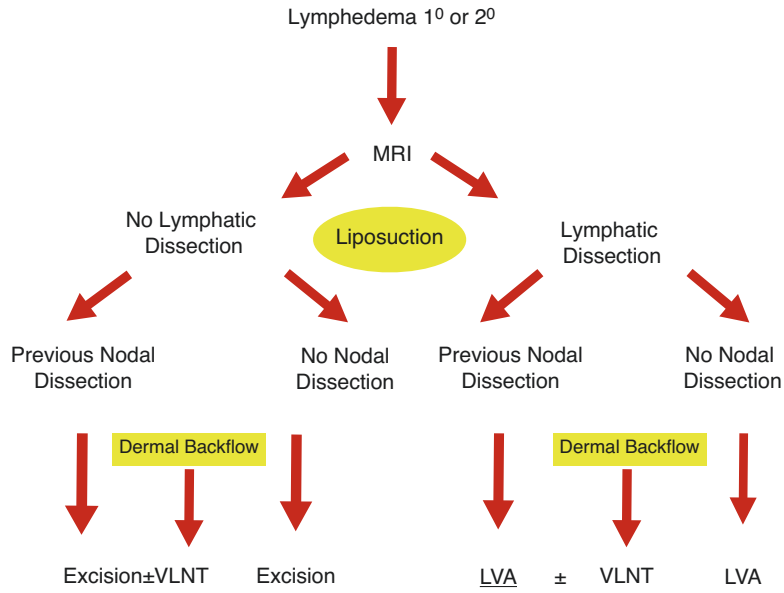
Because of the size and thinness of the lymphatic channels, it is sometimes helpful to stent the lymphatic with a fine nylon suture while completing the anastomosis. However, some people find this to create more difficulty than it helps.

Appropriate instruments, sutures, and microscope are vital for the success of lymphatic surgery.

27.7 Results

Prophylactic lymphatic reconstruction does have a place. Results have shown a reduction in the occurrence of lymphedema from approximately 25% to between 5 and 10% in patients who have undergone an axillary resection [29, 30]. LVB is also success-

Table 27.1 Current algorithm for management of lymphedema



ful and can reverse lymphedema completely in a small number of patients, though usually it does not cure lymphedema; rather, it improves it and prevents progression. The same is true of VLNT [31].

Take-Home Messages

- Lymphedema is a complex condition, and we have several options for treatment.
- Choosing the most appropriate treatment is vital to successful outcome.
- It is important to weigh all the evidence before making that choice.
- There is no one test that can be used, and many patients require multiple investigations.
- Evidence is gathered by looking at all the information.
- Setting appropriate expectations for the patient is important.

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Nerve Surgery

28

Alberto Bolletta and Emanuele Cigna

Background

The ability to repair injuries of the peripheral nervous system in order to restore sensitivity and motor function is an essential aspect of reconstructive microsurgery today.

In recent years, the increased understanding of nerve anatomy and pathophysiology has offered new insights, both in terms of comprehending nerve degeneration and regeneration processes and developing new strategies for treatment. Technological improvements have also had a significant impact on this field. The use of high-resolution microscopes and thinner suturing materials, together with a better understanding of nerve regeneration, has facilitated the development of more precise approaches to different types of injuries and enhanced outcomes. The purpose of this chapter is to provide a detailed description of nerve anatomy and present current trends in surgical techniques for the treatment of nerve injuries.

28.1 Introduction

The basic principles of nerve reconstruction are largely based on the understanding of peripheral nerve anatomy and physiology both from a macroscopic and microscopic point of view. In particular, the comprehension of fascicular arrangements in specific nerves, together with the understanding of nerve physiology in terms of neurodegeneration and regeneration, has enhanced results of reconstructive techniques.

28.2 Nerve Anatomy

The peripheral nervous system conveys signals between the spinal cord and the rest of the body, and it can be classified according to the function of its fibers. The *afferent* arm consists of sensory neurons that transfer information from peripheral receptors to the central nervous system. The *efferent* arm is composed of neurons transmitting information from the central nervous system to the effector organ.

The *somatic nervous system* comprises efferent neurons responsible for the conscious and voluntary control of skeletal muscles. In contrast, the *autonomic (or visceral) nervous system* controls the visceral functions of the body, including the regulation of organs, glands, and vessels involved in maintaining the homeostasis of the body.

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Peripheral nerves, composed of various combinations of motor, sensory, and autonomic neurons, can be classified into pure sensory, pure motor, or mixed nerves, based on the different components.

From a microscopic perspective, peripheral nerves are composed of unmyelinated or myelinated axons and Schwann cells. These latter cells play a vital role in maintaining and regenerating the axons of the neurons in the peripheral nervous system. They derive from the neural crest and can be either myelinating or non-myelinating, affecting the degree of conduction velocity. Myelinated axons are enveloped in multilaminated sheets of myelin provided by a single Schwann cell, whereas numerous unmyelinated axons are surrounded by a single Schwann cell-derived membrane.

Nerve fibers constituting peripheral nerves can be classified according to fiber diameter and the degree of conduction velocity (Table 28.1).

- Group A fibers, which present a thick myelin sheath, are the largest in diameter. As they are characterized by high conduction rates, they are involved in somatic muscle contraction, proprioception, and fast pain sensation.
- Group B fibers transmit impulses at moderate speeds since they are lightly myelinated. They are preganglionic autonomic fibers.
- Group C fibers are unmyelinated and present low conduction rates. They are involved in slow pain sensation, thermoreceptors, and postganglionic sympathetic transmission.

The figure represents the cross-sectional anatomy of a peripheral nerve (Fig. 28.1).

The epineurium is the connective tissue layer that both encircles and runs between nerve fascicles. The primary function of the epineurium is to protect and nourish the nerve fascicles. The outer layers of the epineurium form a sheath, termed

Table 28.1 Classification of nerve fibers

Erlanger-Gasser	Lloyd-Hunt	Modality	Myelination	Function	Diameter (μm)	Conduction velocity (m/s)
A α		Motor	Yes	Muscle contraction	12–20	70–120
	Ia	Sensory	Yes	Proprioception (length)		
	Ib	Sensory	Yes	Proprioception (tension)		
A β	II	Sensory	Yes	Proprioception Touch: vibration, stretch Pressure Joint movement	5–12	30–70
A γ		Motor	Yes	Skeletal muscle tone	3–6	15–30
A δ	III	Sensory	Yes	Fast pain, cold temperature	2–5	12–30
B		Autonomic	Yes	Preganglionic sympathetic	<3	3–15
C		Autonomic	No	Postganglionic sympathetic	0.4–1.2	0.5–2
	IV	Sensory	No	Slow pain, cold and warm temperature, crude touch	0.3–1.3	0.7–2.3

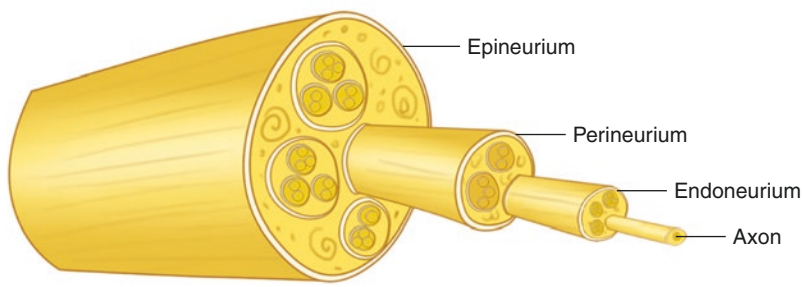

Fig. 28.1 Structure of the peripheral nerve

the external epineurium. Several fascicles lie within and through the epineurium, each surrounded by a perineurial sheath, which is the major contributor to the tensile strength of the nerve. The innermost loose collagenous matrix within the fascicles is the endoneurium. Individual axons are surrounded by the endoneurium and are protected and nourished by this layer [1].

Over the past 20 years, the use of intraoperative direct stimulation has allowed researchers to describe the consistent internal topography of the various nerves in terms of motor and sensory components. According to these findings, in the proximal aspect of the extremity, there is considerable plexus formation between the fascicles within the nerves, but this decreases in the distal extremity. Knowledge of the internal topography of the peripheral nerves is mandatory to achieve proper alignment of fascicles during nerve repair in order to improve results by enhancing the specificity of function-related re-innervation.

Key Points

The connective tissue, essential for nerve fascicles protection and homeostasis, is organized into different layers: the epineurium, the perineurium, and the endoneurium.

Knowledge of nerve internal topography is very important to enhance outcomes of nerve repair.

28.3 Nerve Injury Classification

Peripheral nerve injuries represent a challenge for both patients and surgeons, as they cause a wide range of symptoms, from mild and transitory distress to long-lasting impairment (Fig. 28.2).

The management of nerve injury is guided by Seddon's and Sunderland's classification systems [2, 3] (Table 28.2).

According to *Seddon's classification*, nerve injuries are classified into three categories based on the presence of demyelination and the extent of damage to the axons and the connective tissues of the nerve.

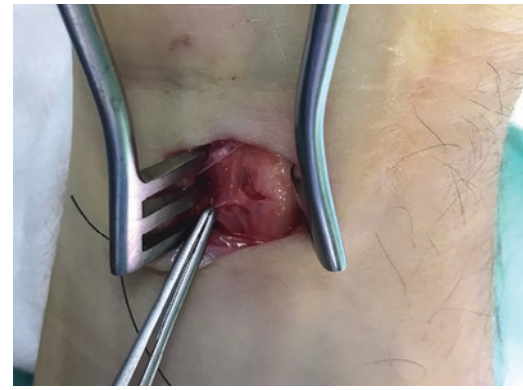

Fig. 28.2 Nerve injury of the median nerve caused by glass fragments

Table 28.2 Seddon and Sunderland classification of nerve injury

Seddon	Sunderland	Pathophysiologic features of injury
Neurapraxia	Grade I	Focal segmental demyelination
Axonotmesis	Grade II	Axon damaged with intact endoneurium
	Grade III	Axon and endoneurium damaged with intact perineurium
	Grade IV	Axon, endoneurium, and perineurium damaged with intact epineurium
Neurotmesis	Grade V	Complete nerve transection
	Grade VI (Mackinnon and Dellon)	Mixed levels of injury along the nerve

Neurapraxia is the mildest form of nerve injury. It consists of an ischemic injury characterized by segmental demyelination without interruption of axonal or connective tissue continuity. Even though the axons are not injured, a localized conduction block is produced. Mechanical stress is a typical cause of this injury, often after compression or mild entrapment. As the axons are not damaged, no peripheral Wallerian degeneration occurs, and nerve regeneration is not required. Remyelination and evidence of recovery are expected in up to 12 weeks.

Table 28.3 Nerve recovery according to classification of nerve injury

Seddon	Sunderland	Spontaneous recovery	Surgery required
Neurapraxia	Grade I	Quick	No
Axonotmesis	Grade II	Slow	No
	Grade III	Slow/partial	No/decompression
	Grade IV	No	Yes
Neurotmesis	Grade V	No	Yes
	Grade VI	Depends on case	Depends on case

Axonotmesis is a more severe form of injury involving direct damage to the axons together with focal demyelination while maintaining continuity of the connective tissues. Axonal damage can be caused by a prolonged increase in perineural pressure. In this case, the segment of the axon located distal to the injury level undergoes Wallerian degeneration. In the meantime, proximally, the nerve fibers regenerate at a rate of approximately 2.5 cm per month. The progress of regeneration can be followed by the advancing Tinel sign.

Neurotmesis occurs when nerve continuity is interrupted both in terms of axons and all connective tissue elements. Surgical repair is necessary for this type of nerve injury.

Sunderland later expanded Seddon's classification by distinguishing the extent of damage affecting the connective tissues.

According to *Sunderland's classification*, **Grade I** and **Grade V** correspond to Seddon's neuropraxia and neurotmesis, respectively. In contrast, axonotmesis is divided into Grades II–IV according to increasing amount of connective tissue damage.

In **Grade II**, axon damage is observed with no damage affecting the connective tissue.

Grade I and **II** injuries, due to the mild level of damage, are usually managed conservatively with favorable outcomes, as demonstrated by clinical experience. A **Grade III** injury involves damage to the endoneurium that prevents the regeneration of some injured axons. Management of these injuries involves surgical decompression if the injury is localized in an area of entrapment. In such cases, the outcome is better than that obtained with a surgical repair or the use of a graft. In **Grade IV–V**, damage to the perineurium is present, with no potential for spontaneous recovery, as the entire population of regenerating axons is blocked. For this reason, a nerve graft repair is indicated in such injuries. A **Grade VI** lesion was later introduced by Mackinnon and Dellon to denote combinations of two or more injury patterns along the course of the damaged nerve. This scenario represents the most challenging situation as it requires differentially treating the various nerve fascicles based on their degree of injury. In particular, it is necessary to identify and differentiate the fascicles that are normal or have the potential to recover from the fourth- and fifth-grade component of the injury pattern that requires reconstruction.

Key Point (Table 28.3)

28.4 Nerve Regeneration

After an injury causing axonal transection, the proximal axon undergoes traumatic degeneration. In most cases, the area of degeneration of the proximal axon is located within the zone of injury, or it extends proximally to the next node of Ranvier. The axon distal to the site of the injury undergoes Wallerian degeneration, during which myelin starts to deteriorate, and the axon becomes disorganized. Myelin and axonal debris are phagocytized by Schwann cells.

After Wallerian degeneration, the basal lamina of Schwann cells persists, as these cells create a supportive environment for axon regeneration. A specialized motile apparatus is formed at the tip of the regenerating axon, the *growth cone*, which releases protease to dissolve the matrix and clear its way to the target organ.

Neurotrophic factors, such as the *nerve growth factor*, aid in neurite survival, extension, and maturation. These macromolecules are present in denervated motor and sensory receptors, as well as in Schwann cells. The nerve growth factor guides axon regeneration and affects growth-cone morphology. Other factors involved in nerve regeneration are the neurite-promoting factors that promote neurite growth, like *fibronectin* as well as *laminin*, which accelerates axonal regeneration across a gap. *Fibrinogen*, a matrix-forming precursor, is an essential substrate for cell migration in nerve regeneration. Other factors involved are fibroblast growth factors, insulin and insulin-like growth factor, electrical stimulation, and hormones such as thyroid hormone, estrogen, and testosterone [1].

28.5 Nerve Reconstruction

28.5.1 Timing

When dealing with nerve injuries, the timing of nerve repair depends on many factors, including not only the general condition of the patient, comorbidities, and associated injuries but also the etiology and degree of injury.

Nerve repair performed within the first 72 h after injury is considered a primary repair. In contrast, a repair performed up to 1 week after injury is classified as delayed primary repair. Secondary repair is a procedure performed more than 1 week following injury. Because nerve repair is not considered an emergency procedure, it can be delayed a few hours in order to be performed by a qualified surgeon during daytime hours.

When a nerve transection is suspected after a penetrating injury from a sharp object, early surgical exploration and reconstruction are recommended, as it is still possible to stimulate the distal stump of the nerve in the first 72 h, facilitating nerve alignment. After this time frame, the surgeon must rely on knowledge of nerve topography for nerve repair. When the nerve is completely transected, the best outcomes can be achieved when repair is performed within the first 3 weeks after the injury, but good results can be obtained with repairs performed in the first 6 months after the injury.

On the other hand, in cases of blunt injuries, it is wise to monitor the patient for signs of spontaneous recovery and delay surgical treatment. Electrodiagnostic studies can be performed, as they will show signs of recovery before clinical evidence of returning muscle function. Nerve recovery should proceed at a steady pace of approximately 1 mm/day; hence, the recovery time is strictly dependent on the injury level.

When patients show no signs of recovery on electrodiagnostic studies or clinical examination within 3–4 months after the injury, surgical exploration and repair should be considered.

Muscle tissue is sensitive to denervation. If not reinnervated within approximately 12 months, fat tissue replacement, atrophy, and muscle fibrosis will occur, leaving motor recovery unlikely.

For this reason, it is essential that motor axons reach the muscle end-plate within 1 year after injury, and functional recovery is inversely proportional to the time of muscle denervation.

Regarding sensory nerves, the repair can be attempted any time after the injury, though improved outcomes are achieved in earlier nerve repairs facilitated by correct nerve alignment [4].

Key Point
Primary repair is performed within the first 72 h, delayed primary repair between 72 h and 1 week, and secondary repair more than 1 week after injury.

28.5.2 General Principles

The main aim of nerve repair surgery is to design the best possible connection between the proximal and distal stump to allow nerve regeneration. This outcome is possible, thanks to meticulous microsurgical techniques performed under adequate magnification and with the use of microsurgical instruments and sutures.

First, nerve stumps must be regularized through sharp neurotomy, which can be performed using the Victor Meyer neurotomy apparatus or a number 11 scalpel blade.

The injured segments of the nerve can be mobilized in order to suture in a tension-free manner, facilitating repair. Small gaps can be overcome by further neurolysis, and the nerve stump can be transposed to gain length for direct suture (e.g., in the case of the ulnar nerve at the elbow).

When a tension-free repair is not feasible, an interposition nerve graft is preferable and should be positioned with the limb in a neutral position.

Whenever the internal topography of the nerve is divided into motor, sensory, or regional components, an effort should be made to correctly align the fascicles to match the sensory and motor modalities to optimize the specificity of nerve regeneration. For this reason, a thorough knowledge of intraneural anatomy is required. The use of intraoperative nerve stimulation can be helpful, together with the detection and alignment of epineural vessels. It is important to remember that surgical results are enhanced by postoperative motor and sensory reeducation.

28.5.3 Techniques

Different techniques have been described for the surgical treatment of nerve injuries. Several factors must be taken into consideration before choosing the most suitable approach, including the type of nerve damage and the situation where a loss of substance causes a gap.

28.5.4 Sutures

Over the years, different techniques for neurorrhaphy aimed at enhancing results have been described. In the clinical setting, each of these different techniques and their modifications will find specific indication [5] (Fig. 28.3).

28.5.4.1 End-to-End Sutures

Epineurial Suture

The epineurial suture is the oldest neurorrhaphy technique, consisting of the juxtaposition of the nerve stumps with epineurial sutures. After fascicles orientation, the epineurial suture starts with two laterally placed 8-0 or 9-0 nylon sutures.

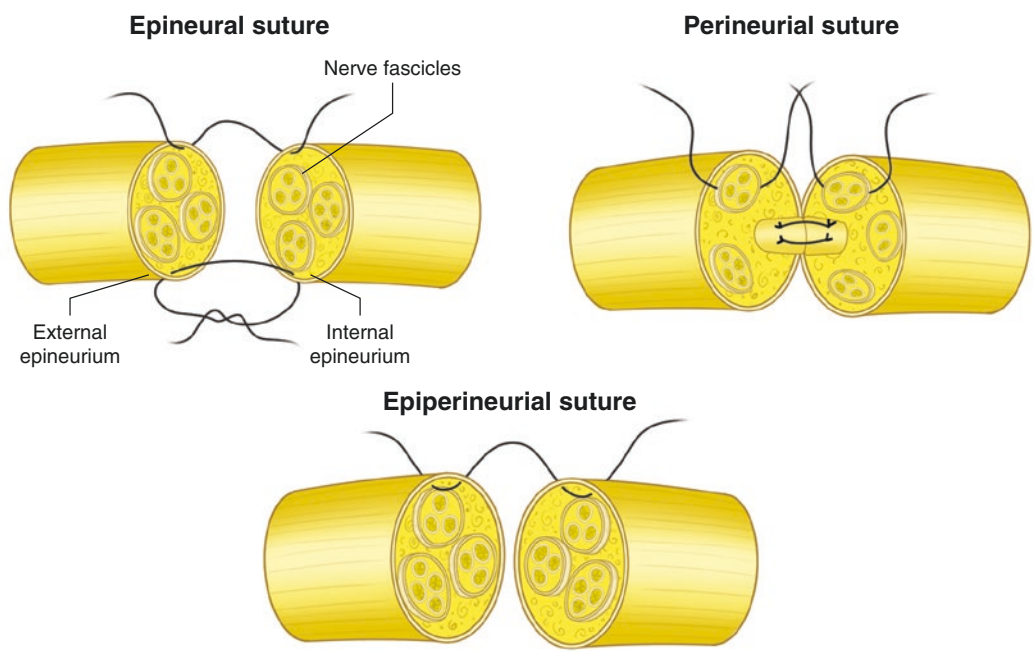

Fig. 28.3 Different nerve suturing techniques

The needle is passed through the epineurium and the internal epineurium and tries to align the fascicles of both nerve stumps, without tying the sutures too tightly, as this would cause the fascicles to twist within the epineurium. Two or three interrupted sutures are added between the first two sutures on the anterior aspect. The nerve is then rotated by pulling the lateral sutures so that the posterior epineurium can be approximated and sutured. The advantage of this technique is that it requires minimal manipulation of nerve stumps, but it can be lacking in terms of precise fascicle approximation. This technique is usually chosen for suturing nerves during primary repair or for nerve transfer. It finds its indication in proximal lesions, where considerable plexus formation is found between the fascicles.

Perineurial Suture

For a perineurial suture, the epineurium is removed from both ends of the nerve stump, and fascicles are meticulously dissected with microsurgery scissors. After orienting and matching each fascicle between both stumps, each single fascicle is sutured with 10-0 nylon. The needle is passed through the perineurium, close to its edge, and the repair is completed by placing three or four sutures. This technique ensures a high level of accuracy in the juxtaposition of the nerve stumps, but it requires greater manipulation of the nerve fascicles. There is also a risk of inaccurate fascicle matching, compromising the outcome. In distal repair, this approach can enhance outcomes due to its accuracy.

Epiperineurial Combined Suture

The epiperineurial combined suture technique allows for a more accurate adaptation of the peripheral fascicles within the epineurium by combining the advantages of both previously mentioned techniques. The 8-0 or 9-0 nylon sutures are passed through the epineurium and perineurium of peripheral fascicles with the same pass of the needle and then tied. In this approach, suturing is performed in a circumferential order, as this allows adapting the remaining fascicles more accurately.

28.5.4.2 End-to-Side Sutures

End-to-side repair is being increasingly used by many authors, representing an alternative when a conventional end-to-end suture cannot be accomplished. This technique involves suturing the end of a recipient nerve to the side of a donor nerve. An epineurial window is created on the side of the donor nerve; usually, two or three 8-0 or 9-0 sutures are enough to approximate the nerve stump. In order for this repairing technique to work, sensory branches must be connected to sensory nerves and motor branches to motor nerves, which can be challenging in certain cases. Moreover, while collateral sprouting spontaneously occurs in sensory nerves, in motor neurons, a proximal axonotmetic injury must be performed on the donor nerve to obtain regenerative sprouting [6].

Pearls and Pitfalls

The epineurial suture causes minimal manipulation of nerve stumps, but does not allow precise fascicle approximation. The perineurial suture is highly accurate but requires fascicle manipulation. The epiperineurial combined suture presents the advantages of both abovementioned techniques.

28.5.5 Nerve Grafts

28.5.5.1 Autograft

In cases where a nerve gap exists and it is not possible to perform a direct suture, such as injuries involving loss of substance or nerve stump retraction and neuroma formation, a nerve graft is considered the gold standard procedure (Fig. 28.4). Usually, nerve grafting is not performed immediately but is delayed for approximately 3 weeks after the trauma in order to determine the extent of the injury. Nevertheless, early nerve grafting can be performed when early soft tissue coverage is required, or when a secondary procedure is expected to be particularly difficult. In this case, the proximal and distal nerve stumps should be accurately trimmed to

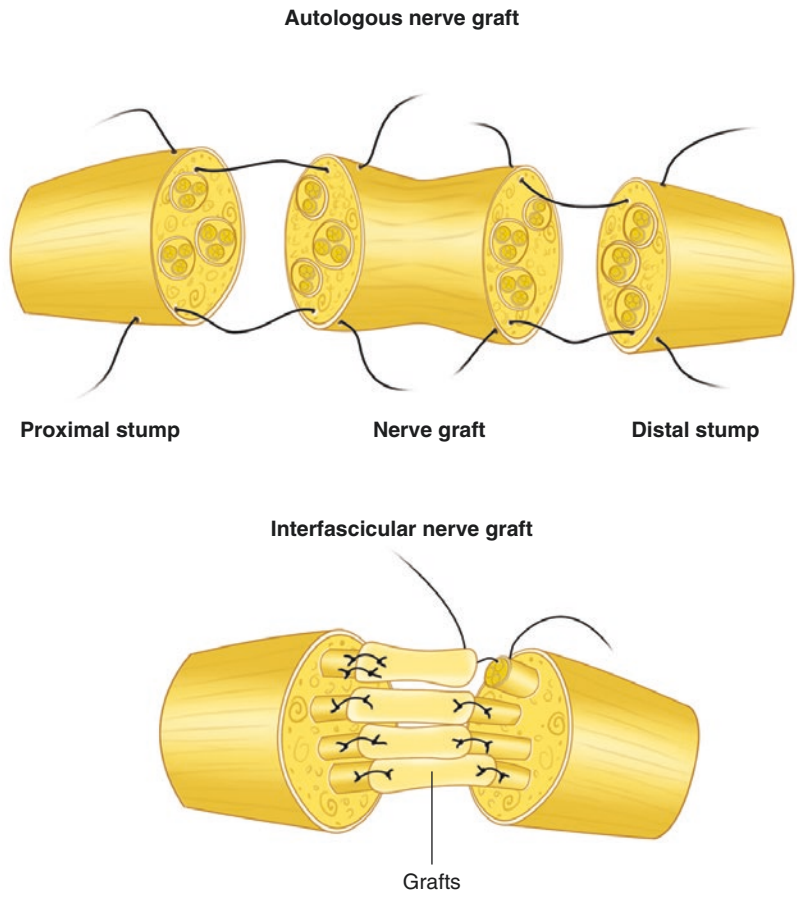

Fig. 28.4 Different nerve grafting techniques

ensure that the repair sites are located outside the zone of injury.

An autograft provides an immunologically inert scaffold with Schwann cells that facilitate axonal regeneration [7]. The most reliable nerve grafts are those ≤6 cm and with a small caliber, as they are easily revascularized, but various degrees of success have also been reported with longer grafts.

Nerve autografts necessarily cause additional scarring and donor site morbidity with the potential for painful neuromas formation. The most used donor nerves for autograft are the sural nerve, the saphenous nerve, the medial antebrachial cutaneous nerve, and the superficial branch of the radial nerve (Fig. 28.5).

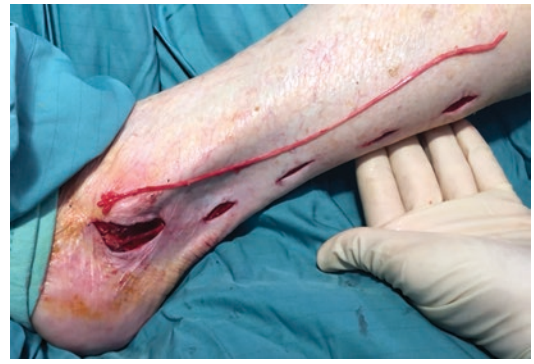

Fig. 28.5 Harvest of sural nerve graft

After harvest, nerve grafts are interposed, using the fascicular pattern of the proximal stump as a guide.

When there is a significant difference in size between the recipient nerve and the graft, each individual fascicle can be dissected and separated to match the size of the recipient nerve. The nerve graft reconstruction should align motor fascicles with motor fascicles and sensory fascicles with sensory fascicles.

In the case of a short nerve gap, it may be possible to use cable grafts to directly connect proximal to distal fascicles. This approach is less achievable in extensive nerve injuries or proximal injuries due to intraneural plexus formation.

Key Point
The nerve graft is considered the gold standard procedure in cases where a nerve gap does not allow direct suture. The nerve graft facilitates axonal regeneration and should align motor fascicles with motor fascicles and sensory fascicles with sensory fascicles.

28.5.5.2 Allograft

Since autologous nerve donor sites are limited, cadaver- or donor-related nerve allografts represent another potential option for nerve reconstruction. This technique provides a temporary scaffold to allow axonal regeneration. The major drawback is that nerve allografts require temporary systemic immunosuppression, increasing vulnerability to opportunistic infections. An alternative to nerve allograft for short gaps in noncritical sensory nerves is the decellularized allograft. These are obtained by processing the donor allograft, making it acellular and nonimmunogenic [7].

28.5.5.3 Vascularized Nerve Grafts

Free vascularized nerve grafts were introduced to improve the outcomes of nerve grafting. The use of a free vascularized graft is recommended for gaps larger than 6 cm or concomitant soft tissue loss with poor vascular supply to the area. Moreover, free vascularized grafts are indicated for large-diameter nerves in which vascularization is critical to prevent central necrosis (Fig. 28.6).

After performing vascular anastomoses, the proximal end of the graft is sutured to the recipient nerve. The nerve graft is then folded and divided, paying attention to avoid injuring the vascular network. The divided graft is then anastomosed to the recipient nerve [8].

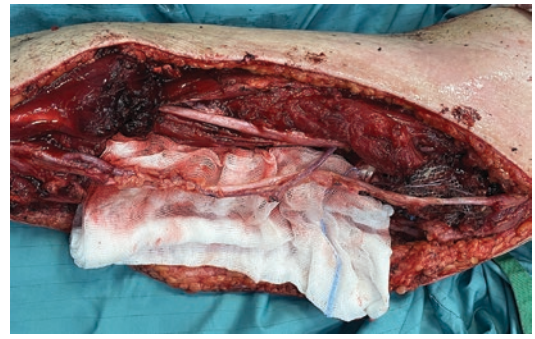

Fig. 28.6 Vascularized nerve graft for ulnar nerve reconstruction

28.5.6 Nerve Conduits

A nerve conduit is a tube used to guide nerve regeneration toward its target. An ideal nerve conduit presents low antigenicity, high availability, and biodegradability. The use of different biological options has been described, including vein, artery, and collagen; more recently, a number of synthetic conduits have also been developed.

Their use is limited to small-diameter, noncritical sensory nerve defects of less than 3 cm or, in the case of large-diameter nerves, for a gap of less than 0.5 cm. In order to enhance regeneration, inserting a piece of nerve graft material into the conduit has been suggested, thus providing trophic factors [9, 10] (Fig. 28.7).

28.5.7 Nerve Transfer

Nerve transfers consist of sacrificing a healthy nerve or nerve branch and suturing it to the distal stump of the injured nerve. The use of nerve transfers is indicated when a proximal stump is not available for primary repair or nerve grafting. This situation is frequent in very proximal peripheral nerve injuries and in cases of root avulsions or severe scarring. In some cases,

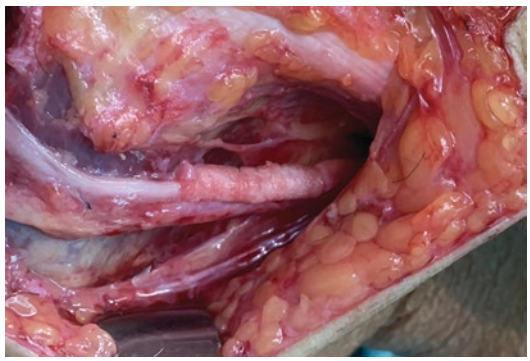

Fig. 28.7 Synthetic nerve conduit

nerve transfers can be preferred to grafting if the injury is located in such a proximal position that the transfer ensures a better outcome in terms of motor end-plate reinnervation compared to the graft. Thanks to the detailed knowledge of intraneural topography, it is possible to determine the most suitable expendable donor nerve. In the case of motor reinnervation, it is preferable that the donor nerve originally innervates a synergistic muscle and presents a large number of motor axons located close to motor end-plates, reducing the time needed to reinnervate the target muscle. Sensory nerve transfers require an expendable donor sensory nerve with noncritical sensory distribution and located near the sensory end organs. Common applications of nerve transfers include the restoration of joint flexion, abduction, and intrinsic hand function.

28.5.7.1 Direct Neurotization

When the distal nerve at the contact point with the muscle is avulsed, direct muscular neurotization can represent a good reconstructive option. Under magnification, on the distal aspect of the nerve, the epineurium is removed, and the nerve is divided into artificial fascicles. A corresponding number of slits are prepared in the muscle, and the artificial fascicles of the nerve are introduced and sutured into the slits. The epineurium of the nerve is then sutured to the epimysium of the muscle to prevent detachment.

28.6 Other Techniques of Functional Restoration

28.6.1 Tendon Transfer

The aim of tendon transfers is to provide a temporary or permanent substitute to restore function in the case of peripheral nerve injuries. The technique requires the release of a proximal or terminal tendon insertion and its reinsertion to restore a lost or deficient action. In particular, tendon transfers are used to restore function, recover a specific motion across a joint, or support function during the recovery of a peripheral nerve injury. The procedure allows for the application of an active motor unit across a passively mobile joint. However, it may be ineffective if scar tissue impedes tendon gliding or there is residual joint stiffness. The donor tendon must have sufficient strength to perform its intended function, and its excursion must be similar to that of the tendon it is replacing. Moreover, it must be expendable, not causing functional impairment after the transfer.

Regarding the coaptation style, if tendon transfers are performed in early stages, end-to-side is preferable because the regeneration of the nerve will allow improvement in function. Otherwise, when there is no chance of nerve recovery, either end-to-end or end-to-side transfers can be used. The surgeon's decision depends on different factors, including the length and caliber of tendon available, the site, and tensioning of the transfer. The rehabilitation process after tendon transfers requires a period of immobilization followed by physiotherapy to learn how to use the transfer [11].

28.6.2 Functional Muscle Transfer

Patients who are not candidates for a nerve or tendon transfer can be considered for a functional muscle transfer.

This procedure requires transecting and transferring both the origin and the insertion of a musculotendinous unit in a different setting, for

example, across a joint, in order to restore its function. Muscle transfer can be performed using a muscle from a different body area, which needs to be transferred as a free flap, thereby performing a distal revascularization and nerve repair.

A key element in approaching this procedure is understanding muscle physiology. Since skeletal muscle properties highly rely on the restoration of the length-tension relationship, it is important to set the muscle resting tension appropriately in order to maximize muscle contraction forces.

The ideal muscle for a transfer should be powerful and long enough to accomplish the desired function, but it must also present enough tendon and fascia to support origin and insertion attachments. Regarding the neurovascular anatomy of the transplanted muscle, it should have a dominant vascular pedicle with a single motor nervous supply. Moreover, the ideal donor site should cause limited functional loss.

Numerous muscles meet these criteria and are therefore used in clinical practice for functional muscle transfers, including the gracilis, latissimus dorsi, tensor fascia latae, rectus femoris, medial gastrocnemius, serratus anterior, and pectoralis major and minor [12].

Key Point
Tendon transfers and free functional muscle transfers allow function restoration when nerve regeneration is not achievable.

28.7 Facial Nerve Reconstruction

The facial nerve is composed of motor, sensory, and parasympathetic fibers. Its major functions include motor supply to facial muscles, parasympathetic secretomotor supply to salivary and lacrimal glands, taste sensation from the anterior two-thirds of the tongue, and cutaneous sensations from the external auditory meatus.

Regarding its course, the facial nerve exits the skull at the stylomastoid foramen and enters the parotid gland at the midpoint of the line connecting the superior aspect of the tragus to the angle of the jaw. The nerve initially divides into two major trunks, which then further divide into five major branches: temporal, zygomatic, buccal, marginal mandibular, and cervical. As they travel distally to the muscles they innervate, the branches of the facial nerve become more vulnerable.

Facial nerve palsy is a condition in which the function of the facial nerve is partially or completely lost. It can be congenital or acquired. Bell's palsy is a frequent form of acute idiopathic facial paralysis, accounting for 85% of all cases of facial paralysis. It is unilateral and, in most patients, has a spontaneous resolution, although some patients may experience lasting motor deficits. In other cases, a specific cause, such as infection, trauma, or metabolic disorders, can be identified. Iatrogenic injury to the facial nerve is possible during procedures such as parotidectomy, skull base surgery, and facelift.

As previously described, neuropraxia is the mildest form of nerve injury and, in most cases, resolves within 3–6 months. Electrophysiologic studies performed in the early stages after injury can help distinguish neuropraxia from other forms of nerve injury. In these cases, watchful waiting for 6 months is recommended before considering surgical treatment [13].

28.7.1 Treatment of Facial Nerve Injury

After severe forms of facial nerve injury and subsequent paralysis, further treatment is indicated, and different approaches may be used to improve patient appearance.

The use of *dynamic reanimation techniques* aims at directly repairing the facial nerve or restoring dynamic movement, whereas *static treatment techniques* do not restore dynamic movement but still improve patient deficits and appearance. In clinical practice, a combination of these techniques is often used in a multimodal approach [14].

28.7.1.1 Facial Nerve Repair

Primary strategies for facial nerve repair include end-to-end repair, nerve grafting, and nerve transfer.

End-to-end repair is performed by directly suturing the severed ends of a nerve in a tension-free manner. This technique is indicated if the nerve is severed during a surgical procedure. In this case, it should be performed immediately or within 72 h.

Nerve grafting is appropriate if the nerve injury results in a substantial gap between the two ends of the nerve. When multiple branches of the facial nerve are damaged, it is possible to perform multiple separate grafts (Fig. 28.8). Alternatively, biological or synthetic conduits can be used in these cases.

In *nerve transfer approaches*, the nerves most frequently used are the hypoglossal nerve and the masseteric nerve. The hypoglossal nerve is commonly used for immediate reconstruction of the proximal facial nerve during tumor extirpation [15]. Masseteric nerve transfer is characterized by easy dissection, low donor site morbidity, and fast onset of movement (approximately 6 months after surgery). The contralateral facial nerve is also used for motor reinnervation, a technique that requires nerve grafts to be passed across the face and attached to branches of the injured facial nerve (*cross-face*). This approach offers the most natural results as it allows for spontaneous mimetic motion and emotional expression. Since the technique requires a significant amount of time for axons to reach the target, atrophy of the denervated muscles is a risk. For this reason, a temporary anastomosis can be created, with motor nerves (hypoglossal or masseteric nerves) providing a motor input while reinnervation from the contralateral facial nerve is achieved (*baby-sitter procedure*).

In terms of outcomes, early repair is consistently related to better results than late repair. The same applies to nerve grafts or nerve transfer procedures performed within 6 months after injury [16].

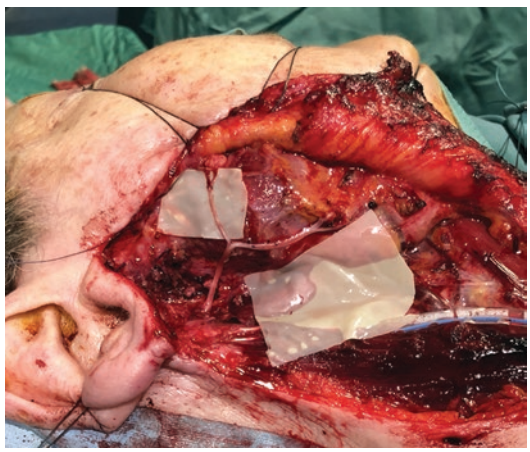

Fig. 28.8 Split nerve graft used to repair nerve gaps of multiple facial nerve branches

Tips and Tricks

End-to-end suture repair should be performed immediately or within 72 h.

Multiple separate *nerve grafts* can be used to treat nerve gaps of multiple facial nerve branches.

The hypoglossal and masseteric nerves are commonly used as donor nerves for facial reanimation.

The *cross-face* technique involves positioning a nerve graft to connect the injured facial nerve to the contralateral nerve.

28.7.1.2 Muscle Transfer for Reanimation

Dynamic facial reanimation in patients affected by long-standing facial paralysis may be achieved using regional or free muscle transfer, as in these patients, facial muscles would not provide useful function after reinnervation.

The temporalis muscle may be transferred to the upper half of the lower lip, allowing for elevation of the oral commissure. This option is indicated in patients who want an immediate solution with a short recovery time. Free muscle transfer involves transplanting a muscle segment, which is then reinnervated using an ipsilateral motor nerve (masseteric nerve) or the contralateral facial nerve via a cross-face graft. The muscles most frequently used for this purpose are the gracilis, the latissimus dorsi, and the pectoralis

minor. The gracilis muscle is the most commonly used as it presents numerous advantages, such as fusiform shape, powerful contraction, and low donor site morbidity [17].

28.7.1.3 Static Reconstruction

When facial reanimation is contraindicated or not achievable, such as in elderly patients with comorbidities, several static techniques can be used. The aim of these procedures is to correct functional disability and restore facial symmetry at rest. Brow lift, upper eyelid loading, and tarsorrhaphy may be used to address visual issues and protect the cornea. Other static procedures, including facial muscle plication, facial sling suspension, and neuromodulator injectables, are used to restore symmetry and reduce drooling [18].

28.8 Peripheral Nerve Reconstruction

28.8.1 Brachial Plexus and Upper Limb

While brachial plexus injuries are often devastating, with life-altering consequences, injuries affecting the major nerves of the upper limb result in a variety of different conditions, mainly dependent on the nerve damage and the level of injury.

Immediate surgical treatment is performed when, according to the type of injury, physical examination, and electrodiagnostic and imaging studies, spontaneous recovery is not possible. Otherwise, a delayed procedure can be considered within 6–12 months in the absence of clinical and electrodiagnostic evidence of recovery.

For example, immediate exploration and primary repair are indicated in sharp open injuries with acute nerve deficits. In these cases, whenever possible, a direct end-to-end suture of nerve stumps is advisable if achievable in a tension-free manner. In the case of a blunt open injury with nerve rupture, the stumps of the nerve should be accurately tagged and a delayed repair performed 3–4 weeks later to allow the zone of injury to demarcate and ensure a safer and more effective repair. When a nerve gap is found, it can be addressed with the abovementioned techniques, such as nerve grafts or conduits. In addition, a nerve transfer can be performed to accelerate recovery in high-level injuries by decreasing the distance between the site of the nerve repair and the motor end-plate. Indications for nerve transfers in the treatment of upper extremity nerve reconstruction are many and include proximal brachial plexus injuries, in which grafting is not possible, but also proximal nerve injuries requiring long distances for reinnervation of distal targets. Additional indications include severely scarred regions, patients with delayed presentation, and segmental nerve loss related to major trauma. Other reconstructive options are represented by tendon transfers and free functional muscle transfers. While tendon transfer relies on the presence of functioning muscles, a free functional muscle transfer can be performed if there is a viable donor nerve and an adequate recipient vessel.

Pan-plexus injuries present the greatest variability in reconstructive approaches. The minimal surgical goal would be for shoulder stability and elbow flexion, though newer techniques may be able to offer some recovery of rudimentary grasp. In these complex cases, reconstructive options largely depend on the number of remaining viable spinal nerves [19–21].

28.8.2 Lower Limb

Nerve lesions of the lower limb are less frequently discussed, even though they are relatively common in orthopedic practice. Injuries related to traction or stretching of the nerves are common in work or road accident traumas, as well as those due to skeletal fractures. Furthermore, lower extremity nerve injuries are also related to knee sprain or hip dislocation. Even though most traumatic and iatrogenic nerve injuries of the lower limb are in continuity, they frequently involve axonotmesis and should not be assumed to be simple neuropraxias. For this reason, a thorough history and

physical examination, together with serial electrodiagnostic studies and advanced imaging, should be used to assess nerve injury in these cases. Outcomes of nerve recovery in the lower limb vary widely, even between operative and nonoperative treatments. Moreover, while the recovery of the femoral and tibial nerve is often satisfactory, for the sciatic and common peroneal nerve around the knee, outcomes are disappointing. In fact, operative repair of the femoral and tibial nerve has shown superior results compared to the sciatic and common peroneal nerve, in which neurolysis is related to better prognosis than repair or grafting. In general, as previously mentioned for the upper limb, sharp lacerations require early surgical exploration. However, when severe nerve contusion is involved, a delay of several weeks is suggested to allow demarcation of the area of injury. In the case of stretch injuries or blunt trauma, observation is suggested, together with serial physical examination and electrodiagnostic and imaging studies. When no signs of recovery are observed after 2–5 months, nerve exploration is necessary, and nerve damage can be addressed with neurolysis, repair, or grafting, according to the situation [22, 23].

28.9 Assessment of Peripheral Nerve Function

Evaluation of peripheral nerve function after injury and outcome assessment following treatment remains a complex process for therapists and surgeons. A combination of tests is required to aid clinical diagnosis, assess surgical repair, and track rehabilitation progress.

During clinical evaluation, the Hoffman-Tinel sign, more commonly known as the Tinel sign, is a simple yet valuable tool. It is defined as the "pins and needle feeling" provoked by tapping on a nerve, with resulting paresthesia in the corresponding distal distribution of an injured peripheral nerve. The Tinel sign is commonly used as an indication of peripheral nerve compression or regeneration.

Many different measurement instruments can be used in peripheral nerve evaluation, including sensory and motor tests, pain and discomfort assessments, neurophysiological examination, and imaging.

Sensory tests are employed to evaluate sensory acuity. The *Semmes-Weinstein monofilament test* is used to assess the perception of cutaneous pressure threshold, reflecting reinnervation of peripheral targets. The *two-point discrimination test* is an established assessment tool for innervation density, aiming at determining the smallest distance between two points that still results in the perception of two distinct stimuli. Other functional sensory tests include vibration and temperature perception, shape and texture identification, and thickness discrimination.

Evaluation of motor function is based on qualitative, semi-quantitative, and quantitative examinations.

Qualitative evaluation is performed by observing muscle volume and tone. *Manual muscle testing* is a semi-quantitative evaluation used to assess motor innervation by way of a muscle strength grading system. Quantitative examinations involve using dynamometers that measure muscle strength (e.g., hand-held dynamometer).

In contrast, the evaluation of pain is always based on self-report by patients. Moreover, assessing the impact of pain on the quality of life is essential.

Neurophysiological examinations include electroneurography (ENG) and electromyography (EMG). These studies, used to evaluate the electrical activity of nerves and muscles, provide valuable information on the location and pathophysiology of peripheral nerve lesions.

Recent developments in the field of peripheral nerve imaging have extended the capabilities of imaging modalities to assist in the diagnosis and treatment of patients with peripheral nerve injuries. Methods such as MRI and ultrasound are capable of assessing nerve structure and function following injury and relating the state of the nerve to electrophysiological analysis [24].

Key Point
Different measurement instruments are used to assess peripheral nerve status and plan surgical treatment: sensory and motor tests, pain and discomfort assessment tests, neurophysiological examination, US, and MRI.

28.10 Bionic Reconstruction and Future Perspectives

Functional reconstruction of highly specialized body areas is essential in restoring body function and integrity, but it can also interfere in the loop of neural circuits, reducing neural pain. It appears that, in the near future, when surgical attempts at nerve repair or reconstruction fail to restore function, complex mechatronic replacement could represent a valuable option. The challenge in bionic replacement is to achieve ultra-specialized connections with the patient's nervous system to ensure natural, intuitive control of the prostheses. In specialized centers for bionic reconstruction, experts in clinical research together with experienced surgeons and a rehabilitation team are currently working to improve results in clinical use of these new technologies in order to enhance their availability for patients in need [25].

Take-Home Messages
- The management of nerve injury is guided by **Seddon's and Sunderland's classification systems**.
- **Grade I** and **II** injuries are usually managed conservatively. **Grade III** injury involves damage to the endoneurium and requires neurolysis or surgical decompression. In **Grade IV–V** injuries, damage to the perineurium is present, with no potential for spontaneous recovery. A **Grade VI** injury represents the most challenging situation.
- The injured segments of the nerve can be mobilized in order to repair with **direct suture** in a tension-free manner. When there is a gap, an interposition **nerve graft** is preferable.
- **Tendon transfers** and **free functional muscle transfers** allow function restoration when nerve regeneration is not achievable.
- Assessment of peripheral nerve status is performed with **sensory** and **motor tests**, **pain** and discomfort assessment tests, **neurophysiological examination**, **US,** and **MRI**.

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Further Reading

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Gender-Affirming Surgery

29

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Introduction

The population of transgender and gender-nonconforming (TGNC) individuals in the United States is currently estimated around 390 per 100,000 adults [1]. However, this number is believed to be quite an underestimate due to inaccuracies of census surveys (i.e., recording birth gender, inconsistent identification with the term "transgender," and correlating sexual orientation to gender identity) [1]. TGNC individuals are estimated to represent 0.4–1.3% of people worldwide [2]. Due to increased advocacy efforts, an increasing number of insurers have considered gender-affirming surgery (GAS) an important part of medically necessary treatment to alleviate gender dysphoria, which is defined as the distress caused by a discrepancy between a person's gender identity and that person's sex assigned at birth (and the associated gender role and/or primary and secondary sex characteristics) [1, 3, 4]. Although not all TGNC individuals experience gender dysphoria, those who do may require medical and surgical interventions for gender affirmation including endocrine therapy, psychological treatment, physical therapy, and GAS.

The goal of GAS is to give the transgender individual the physical appearance and functional abilities of the gender with which they identify. Although gender is not a binary phenomenon, gender-affirming surgical techniques are typically categorized as transmasculine (female-to-male or masculinizing) and transfeminine (male-to-female or feminizing). However, gender non-conforming individuals, whose gender identity falls outside the binary categories of male and female, may also need these surgeries. The American Society of Plastic Surgeons (ASPS) reported 3,256 GAS (1,759 male-to-female and 1,497 female-to-male procedures) were performed in the United States in 2016, which represents a 20% increase compared to the previous year [3].

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29.1 Terminology

Based on the Standards of Care for the Health of Transsexual, Transgender, and Gender-Nonconforming People (SOC), Version 7, provided by the World Professional Association for Transgender Health (WPATH), treatment options for gender dysphoria include psychotherapy, changes in gender expression and role, hormonal or endocrine therapy, and gender-affirming surgery (GAS). A multidisciplinary approach including various treatment options is paramount for the comprehensive management of gender dysphoria in TGNC individuals. In this chapter, we provide an overview of gender-affirming surgical procedures (Table 29.1).

Table 29.1 Gender-affirming surgeries

	Masculinization surgery	Feminization surgery
Face	Facial masculinization Liposuction Lipofilling Voice modification surgery	Facial feminization Thyroid chondroplasty Hairline reconstruction Voice modification surgery
Chest	Subcutaneous mastectomy Chest-wall contouring Pectoral implants	Augmentation mammoplasty Lipofilling
Genitalia	Hysterectomy Salpingo-oophorectomy Vaginectomy Clitoral release Metoidioplasty ± urethral lengthening Phalloplasty ± urethral lengthening Scrotoplasty Testicular prosthesis placement Penile prosthesis placement	Orchiectomy Penectomy Vaginoplasty + clitorolabiaplasty Vulvoplasty + clitorolabiaplasty Gluteal augmentation Waist lipoplasty

Key Point

Key definitions based on the WPATH Standards of Care for the Health of Transsexual, Transgender, and Gender-Nonconforming People, 7th version:

- Cisgender: adjective to describe individuals whose sense of personal identity and gender correspond with their sex assigned at birth.
- Gender: range of psychological and cultural characteristics associated with biological sex. It is a sociological and psychological concept, not a biological term.
- Gender dysphoria: distress that is caused by a discrepancy between a person's gender identity and that person's sex assigned at birth (and the associated gender role and/or primary and secondary sex characteristics).
- Gender identity: a person's intrinsic sense of being male, female, or an alternative gender.
- Gender-nonconforming: adjective to describe individuals whose gender identity, role, or expression differs from what is normative for their assigned sex in a given culture and historical period.
- Gender role or expression: characteristics in personality, appearance, and behavior that in a given culture and historical period are designated as masculine or feminine (i.e., more typical of the male or female social role).
- Sex: sex is assigned at birth as male or female, usually based on the appearance of the external genitalia. When the external genitalia are ambiguous, other components of sex (internal genitalia,

chromosomal and hormonal sex) are considered in order to assign sex.
- Transgender: adjective to describe a diverse group of individuals who cross or transcend culturally defined categories of gender.

29.2 Eligibility Criteria

Certain requirements should be met before surgical treatment, which vary depending on the type of surgical procedure. The SOC recommends several prerequisites prior to any type of gender-affirming procedure. When required, a referral letter should include the following: (A) patient's general identifying characteristics; (B) results of the patient's psychosocial assessment, including diagnoses; (C) duration of the physician-patient relationship, including the type of evaluation and therapy or counselling to date; (D) explanation that surgery criteria have been met and a brief description of the clinical rationale for supporting the patient's request for surgery; (E) a statement about the fact that informed consent has been obtained from the patient; and (F) a statement that the mental health professional is available for coordination of care and welcomes to be contacted to establish this [5].

In order to start hormone therapy, patients must have persistent and well-documented gender dysphoria, capacity to make fully informed decisions and to consent for treatment, and be of legal age in a given country. If significant medical or mental health comorbidities are present, they must be well controlled [5]. It is important to be aware that hormonal therapy has risk associations depending on the treatment. The major risk associations are venous thromboembolic disease and polycythemia for feminizing hormones and masculinizing hormones, respectively [5].

If the patients fulfil all the requirements established by the SOC, they are candidates for gender-affirming surgical procedures (Table 29.2).

Table 29.2 Eligibility criteria based on the Standard of Care of the World Professional Association for Transgender Health

	Referral letter[a]	Hormonal treatment	Social transition
Facial surgery	NS	NS	NS
Chest surgery			
Mastectomy	1	No	No
Augmentation mammoplasty	1	No[c]	No
Genital surgery			
Hysterectomy/salpingo-oophorectomy or orchiectomy	2	1 yr	No
Metoidioplasty	2	1 yr	1 yr
Phalloplasty or vaginoplasty	2	1 yr[b]	1 yr
Other surgical procedures	No	No	No

NS criteria not stated, *yr* year

[a]Referral letter must be from a mental health professional. If two letters are required, they must be from two different professionals

[b]Only if hormone therapy criteria are made, and no contraindications are present

[c]Although not an explicit criterion, it is recommended that transfeminine patients undergo feminizing hormone therapy (minimum 12 months) prior to gender-affirming augmentation mammoplasty

29.3 Gender-Affirming Surgery in Transmasculine Individuals

Approximately, 42–54% transmasculine individuals in the United States have undergone any type of GAS [6, 7]. Gender-affirming surgical techniques for patients on the transmasculine spectrum can be subdivided into three categories: facial masculinization, chest reconstruction (colloquially known as top surgery), and genital surgery (colloquially known as bottom surgery).

Key Points

- Cis-masculine and cis-female facial bone characteristics and soft tissue distribution differ significantly.
- The goal of facial masculinization is to achieve facial male characteristics that align better with the patients' internal gender identity.
- Multiple procedures can accomplish facial masculinization such as implants, osteotomies with bone grafts, autologous rib cartilages, rhinoplasties, and liposuction.

29.3.1 Facial Masculinization

Facial masculinization surgery is rarely performed since the anabolic and androgenic properties of testosterone replacement therapy can lead to growth of facial hair. Nevertheless, facial bones and facial soft tissue distribution differ significantly between transgender and cisgender individuals. Cis-masculine facial features include the following [8–10]:

- M-shaped hairline
- Significant frontal bossing due to large frontal sinus and thick supraorbital ridges
- Straighter eyebrows that tend to sit at the level of the superior orbital rim (transmasculine eyebrows are arched and sit above the superior orbital rim, approximately 1 cm)
- Flatter forehead
- Acute angle between the frontal area of the forehead and nose (transmasculine individuals have an obtuse angle)
- More pronounced temporal ridge
- Wider, taller, and more prominent chin
- Prominent and wider mandible angle with lipping of the bone due to the masseter muscle attachments

In order to achieve facial masculine characteristics, implants, osteotomies with bone grafts, rhinoplasty, liposuction, or autologous rib cartilages to simulate the thyroid cartilage can be used [10, 11].

29.3.2 Gender-Affirming Mastectomy

Gender-affirming mastectomy consists of subcutaneous mastectomies that intend to achieve an aesthetically pleasant masculine chest that aligns better with the individual's gender identity in order to reduce chest dysphoria [12, 13]. The main objectives of gender-affirming mastectomy consist of removal of breast tissue and excessive skin, reduction and repositioning of the nipple-areola complex (NAC), and elimination of the inframammary fold (IMF) while limiting scar formation [14]. These surgeries are efficient and safe procedures that are widely performed by plastic surgeons [12].

Numerous types of gender-affirming mastectomy have been described. To choose the ideal procedure, several algorithms have been described based on the amount of breast skin redundancy or elasticity, breast volume, grade of ptosis, and skin envelope [16–20]. Generally, for smaller breast volume and adequate skin elasticity, subcutaneous mastectomies through NAC semicircular or trans-areolar incisions are preferred. For moderate breast volumes and skin elasticity, subcutaneous mastectomies with peri-areolar skin resection through concentric circular and extended concentric incisions are recommended. For larger breast volumes and poor skin elasticity, double-incision mastectomies with nipple preservation or free nipple

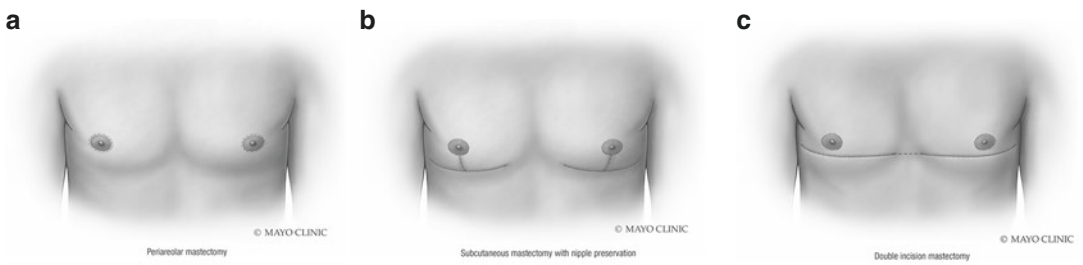

Fig. 29.1 Gender-affirming subcutaneous mastectomy. Most common types of gender-affirming mastectomies. (**a**) Peri-areolar concentric circular mastectomy; (**b**) subcutaneous mastectomy with nipple preservation; (**c**) double-incision mastectomy with free nipple grafting (Used with permission of Mayo Foundation for medical Education and Research, all rights reserved)

grafting are suggested. The use of liposuction as a single or concomitant procedure has also been proposed [14–16]. However, the final decision is usually made based on the interests and goals of the patient and the experience of the surgeon.

Even though gender-affirming mastectomies are safe surgical procedures, they are not exempted from complications. Overall, seroma, partial NAC necrosis, and self-limiting hematoma rates have been reported in 0.6–1.1%, 0–9.6%, and 1.5–2.8% cases, respectively [21]. Hematoma requiring evacuation, full NAC necrosis, and abscess formation have been described in 1.9–9.2%, 0.3–1.2%, and 1.1% cases, respectively [15, 17, 19, 21, 22]. Secondary revision surgeries are occasionally required to improve aesthetic outcomes: scar revisions 1.4–2.2%, contour correction 5.5–10.2%, and NAC revisions 0.3–2.2% [15, 17, 19, 21, 22] (Fig. 29.1).

Key Points

- Gender-affirming mastectomy aims to achieve an aesthetically pleasant male chest anatomy that aligns better with the individual's gender identity in order to reduce chest dysphoria.
- This procedure has three main goals: removal of breast tissue and excessive skin, reduction and repositioning of the NAC, and elimination of the inframammary fold.
- Final surgical technique depends on the individual's chest characteristics, interests, and goals, and the surgeon's experience.

29.3.3 Gender-Affirming Genital Surgery

Genital surgery helps in the transition of the primary sexual characteristics from female to male [23]. It is estimated that 25–50% of transmasculine individuals undergo genital surgery [24]. The ideal gender-affirming genital surgery complies with the following [11, 25, 26]:

- Performed in a one-stage operation
- Predictable and reproducible procedure with minimal scarring or disfigurement
- Creation of an aesthetically appearing neophallus and scrotum
- Achievement of tactile and erogenous sensation
- Allow standing micturition
- Obtain a natural-appearing bulk under clothes
- Allow penetrative intercourse

29.3.3.1 Hysterectomy and Oophorectomy

Hysterectomy and oophorectomy are the most common genital surgeries in transmasculine individuals (21–26%) [6, 24]. Their main goal is to eliminate the primary cis-female sex hormone source, estrogen, which plays the most important role in the formation and maintenance of primary and secondary sexual characteristics in cis-females. On the other hand, by removing the uterus and ovaries, cessation of menstrual cycles is ensured, and lifelong gynecologic care may no longer be necessary [11].

29.3.3.2 Vaginectomy

Vaginectomy is a surgical procedure that eliminates vaginal lining and closes the vagina. It is sometimes performed to relieve uncomfortable vaginal secretions [11]. This procedure is usually combined with metoidioplasty or hysterectomy. Vaginectomy is a combination of colpectomy and colpocleisis. The former refers to the removal of vaginal epithelium (lining), and the latter refers to the fusion of the vaginal walls, which creates support for pelvic organs.

Major advantages of this surgical technique are the following: complete excision and closure of the vagina, male-looking perineum, elimination of vaginal secretions, elimination of the need for pap tests, and reduction of urethroplasty complications, such as urethral stricture and fistula formation [27]. Vaginectomy is a relatively safe procedure with low short and long-term complication rates [28].

29.3.3.3 Metoidioplasty

Metoidioplasty is the least invasive variant of phalloplasty. It consists of the creation of a small neo-phallus from the hormonally hypertrophied clitoris. If combined with urethral lengthening, standing micturition can be achieved [11]. This surgical procedure can be combined with scrotoplasty and testicular prostheses implantation, hysterectomy with bilateral-oophorectomy, and vaginectomy [29]. This option is ideal for a thin to medium-built transmen without abundant mons pubis adiposity that do not desire to undergo multiple surgeries or have visible scars outside the genital area [29].

The Belgrade metoidioplasty algorithm has been described to maximize clitoral lengthening and straightening with urethral reconstruction and scrotoplasty in a one-stage surgical procedure [29]. This approach consists of dissecting clitoral ligaments and performing tabularization (if adequate urethral plate) or division-flap/graft urethroplasty (if short urethral plate) technique [29] (Table 29.2).

This procedure can be combined with urethral lengthening, preserves sensation and can provide erection, does not require preoperative hair removal, and has no donor-site scar or morbidity. It can be done in a single-stage procedure with short intraoperative time and postoperative hospital stay [11, 29]. However, major drawbacks typically include short neo-phallus, which does not commonly provide significant bulk under clothes, limited penetration, and difficulty to place an inflatable penile prosthesis (IPP) [11]. Up to 89.1% of patients can stand to void after metoidioplasty with urethral lengthening, and 51% of patients reported successful penetration intercourse [11, 30].

This is a safe procedure with high patient satisfaction (90–93%) and a low overall complication rate of 0.43% (including stricture and fistulas formation) [11, 30].

29.3.3.4 Phalloplasty

Phalloplasty is a surgical procedure that consists of the creation of a neo-phallus. Similar to metoidioplasty, this procedure can be combined with scrotoplasty and testicular prosthesis implantation with or without urethral lengthening. Surgical techniques for phalloplasty are broadly divided into pedicled flap and free flap phalloplasty [11]. All of them are unique procedures with specific advantages, disadvantages, functional outcomes, and complication profiles. There is no perfect or universal surgical approach for phalloplasty, and each case should be individualized [29].

Pearls and Pitfalls

- The ideal donor site allows adequate tissue and bulk, skin color match and primary closure, and has minimal morbidity.
- The most common drawback is the lack of intrinsic sexual function.
- To achieve tactile and/or erogenous sensation, adequate neurorrhaphy is paramount.
- For musculocutaneous flaps, adequate neurorrhaphy is paramount to achieve erection by stiffness, widening, and shortening of the neo-phallus.
- Flap-based phalloplasties achieve anatomically sized neo-phallus and create adequate bulk under clothes.
- Flaps that require preoperative hair removal add expenses and time.
- Any hair-bearing skin used for the neo-urethra can lead to chronic infection or obstruction.

- ***Pedicled Flap Phalloplasty***

  Pedicled flap phalloplasty is limited by the type and quantity of tissue available that can reach the recipient site, which is the genital area. Several pedicled flaps have been described for phalloplasty including the anterolateral thigh flap, suprapubic abdominal wall-based flaps, groin flaps, and gracilis flap.

  – ***Anterolateral Thigh Flap Phalloplasty***

    The anterolateral thigh flap phalloplasty is the second most popular flap-based phalloplasty. This flap has a generous size to harvest. Most of the skin paddles are 10–15 cm wide × 12–18 cm long [11]. Split-thickness graft or tissue expanders are used to cover the donor site defect. Its major advantages are that it avoids the pathognomonic scar of the radial forearm phalloplasty, has a robust vascular supply from the dominant-muscle perforating branch from the descending branch of the lateral circumflex femoral artery, has a pedicle long enough to reach the genital area, and has similar skin color and normal-appearing bulk that enables penetration without IPP in some cases [11, 31]. Additionally, the tactile sensation can be achieved with the lateral femoral cutaneous nerve neurorrhaphy to the dorsal clitoral nerve [11, 31]. Its disadvantages are that it requires preoperative depilation, no intrinsic sexual function, and challenging urethral lengthening due to flap thickness [11].

  – ***Suprapubic Abdominal Wall-Based Flaps and Groin Flaps Phalloplasties***

    The suprapubic abdominal wall-based flap for phalloplasty is based off the inferior epigastric and circumflex iliac vessels, and the pedicled groin flap for phalloplasty is based off the superficial and deep iliac circumflex arteries [11]. Both achieve anatomically sized neo-phallus and adequate bulk under clothes with no need for microsurgical anastomoses [11]. In addition, penetration can be possible with IPP or segment of the iliac crest (particularly for groin flap phalloplasty). The groin donor site matches skin color and has minimal risk of donor site morbidity [11, 32]. Major disadvantages are poor penile sensation due to the lack of nerves for coaptation, no intrinsic sexual function, and variable/unreliable vascular supply [11].

    Major complications are related to the neo-urethra and include stricture and/or fistula formation [32]. However, these are significantly less if the neo-urethra is created in two stages [32]. Both surgical techniques have been associated with high patient satisfaction and good functional outcomes [33].

  – ***Pedicle Gracilis Flap Phalloplasty***

    The pedicled gracilis flap phalloplasty is based off branches of the medial femoral circumflex artery. Skin grafts around a catheter are used to create the neo-urethra, and the gracilis flap is placed around to form the neo-phallus [11, 33]. Major advantages are the achievement of anatomically sized neo-phallus, bulk under clothes, no microsurgical anastomoses, penetration due to contracting neo-phallus, and low-

risk donor site morbidity [11]. This procedure is also used to repair strictures, fistulas, and scrotoplasty complications [11]. Major drawbacks are the inability to have an intrinsic sexual function, hair depilation requirement, and skin graft donor site coverage [11].

- ***Free Flap Phalloplasty***

  Free flaps allow the surgeons to perform microvascular anastomosis between donor and recipient vessels. A wide variety of tissue options are available for neo-phallus reconstruction. The most common free flap phalloplasties are the radial forearm flap phalloplasty, fibula flap phalloplasty, and latissimus dorsi flap phalloplasty [11]. The anterolateral thigh flap can be also used as a free flap for phalloplasty depending on the pedicle length and tension.

  – ***Radial Forearm Flap Phalloplasty***

    The radial forearm flap phalloplasty is the most common type of flap-based phalloplasty [11]. This flap is based off the radial artery. This thin and pliable full-thickness flap makes it an ideal option for the formation of the neo-phallus and urethra using the "tube-within-tube" technique [33–36]. Neo-phallus length can range from 7.5 to 16 cm [33]. The medial and lateral antebrachial cutaneous nerves are usually preserved to perform neurorrhaphy with the ilioinguinal nerve and dorsal nerve to achieve erogenous and tactile sensation [34]. The Allen test should be performed preoperatively to confirm adequate perfusion of the non-dominant hand [34].

    Major advantages of this technique are anatomically sized neo-phallus, normal-appearing bulk under clothes, robust vascular pedicle, penetrative sex with IPP, and low complication rates [11]. In addition, the radial forearm flap can create both the neo-phallus and urethra. The major and most important drawback is the donor site morbidity. The forearm defect is large, unique, and visible, usually requiring split or full-thickness skin grafts [11]. This donor site morbidity is pathognomonic for this surgery. The most common donor site complication is regrafting of the arm [33]. On the other hand, the majority of complications are related to urethral reconstruction or penile prosthesis placement [11, 33]. Other important disadvantages are the requirement of hair depilation, skin color mismatch, no intrinsic sexual function, and long and complex surgery that requires expertise [11]. However, it has high overall satisfaction [11, 33] [11, 33, 35].

  – ***Fibula Flap Phalloplasty***

    The fibula flap phalloplasty is an osteocutaneous free flap phalloplasty. This flap is based off the peroneal vessels. Neurorrhaphy can be performed with the lateral or posterior cutaneous and the ilioinguinal or dorsal clitoral nerves, respectively, to achieve tactile and erogenous sensation. Long-term follow-up shows minimal bone resorption [11, 37]. These flaps provide a permanent rigid neo-phallus with minimal quality of life changes [33]. Major advantages are the achievement of anatomically sized neo-phallus, adequate bulk under clothes, robust vascular pedicle, well-hidden donor site, and possibility of penetration without IPP [11]. Up to 90% of patients are able to achieve micturition in the standing position, and 51.7% are able to have penetrative sexual intercourse [33]. Major complications of this approach include urethral complications with prefabricated neo-urethra, such as urethral stricture and stenosis in 24.6% cases [33]. Urethral prelamination is necessary due to the rigidity of the flap [11]. Other drawbacks are no intrinsic sexual function, poor tactile and erogenous sensation, depilation requirements, risk of leg/ankle instability, leg splinting and physical therapy, and skin color mismatch [11].

  – ***Latissimus Dorsi Flap Phalloplasty***

    The latissimus dorsi flap phalloplasty is a musculocutaneous flap designed for the creation of the neo-phallus. This flap is based off the thoracodorsal neurovascular bundle [33, 38]. In order to achieve volun-

Table 29.3 Clinical outcomes after genital-affirming surgery in transmasculine patients [33]

Technique/flap type	Neo-phallus length (cm)	Tactile sensation (%)	Urinary function (voiding while standing) (%)	Sexual function (erections/ intercourse) (%)
Metoidioplasty	4–10	100	94.1	100
Anterolateral thigh	10	75	66.7	60
Abdominal-based	3.7–16	75	37.3	19.6
Groin-based	7.5–15	100	100	100
Gracilis	4–15	100	100	100
Fibula		100	90	51.7
Radial forearm	7.5–14	98.4	97.5	21.7
Latissimus dorsi	7–17	100	100	14.8

tary contraction of the neo-phallus, a neurorrhaphy can be performed between the thoracodorsal motor nerve and a branch of the obturator motor nerve [11, 38]. The muscle contraction leads to an "erection" by stiffness, widening, and shortening of the neo-phallus that permits sexual intercourse, which simulates erection in 85–92% [11, 38]. However, only 14.8–42% reported having penetrative intercourse [11, 33, 38].

The major advantages of this flap are the anatomically sized neo-phallus, bulk under clothes, long, robust and reliable vascular pedicle, hidden donor site with minimal functional loss, and closure by primary intention [11]. Up to 83% of patients reported donor site morbidity as acceptable [38]. Major drawbacks are no intrinsic sexual function, suboptimal sensation, and necessity of electrostimulation to promote muscle contraction, and tonic muscle contraction is impractical for penetration [11]. The most common complications are fistula (13.2%) and hematoma (13.2%) [33]. Most patients reported to be satisfied with the results [33] (Table 29.3).

29.3.3.5 Additional Procedures

- ***Scrotoplasty***

  Scrotoplasty is a surgical procedure that can be performed at the time of the metoidioplasty or phalloplasty [11]. Since labia majora comes from the same embryologic structure and are anatomic equivalents, they have similar skin color, hair, texture, and sensation, making this tissue an ideal candidate for achieving scrotal anatomy [11, 39]. This surgical procedure consists of joining the labial majora in the midline to achieve masculine scrotal anatomy. Then, the superior-based labial flaps are raised and rotated medially 180° before approximating labial majora folds to reach cis-male anatomic position [39]. The labia majora provides sufficient volume to neo-scrotum; however, in occasions, the use of a gracilis flap and/or the placement of silicone testicular prostheses is needed to augment the volume [11].

- ***Testicular Prostheses Implantation***

  This technique is performed as a secondary procedure. This surgical technique consists of performing a mid-scrotal vertical incision or a horizontal incision at the scroto-phallic transition [40]. After two separate pockets are created, implanted testicular prostheses are selected depending on the neo-scrotal size [40]. Patients are recommended to not place any pressure to the neo-scrotum for at least 4 weeks [40].

  Postoperative complications have been described to be related to infection, extrusion, discomfort, prosthesis leakage, or urethral problems [40]. Up to 20.8% require explantation of one or both prostheses due to postoperative complications [40]. Smoking is an important risk factor for infection and prothesis explanation [40].

- ***Penile Prostheses***

  Penile prostheses are placed in patients that desire a neo-phallus rigid enough for penetrative sex [11]. Flap-based phalloplasties performed with autologous bone or cartilage do

not require penile prostheses. Penile prostheses are implanted 6–12 months after phalloplasty when sensation is present to prevent pressure necrosis [11]. Due to the lack of tunica albuginea, several accommodations are made to prevent migration of the penile prosthetic cylinders within the corpora and/or erosion [11]. Penile prosthetic cylinders can be enfolded in a sheath of synthetic graft material and attached to the pubis with permanent sutures [11, 41]. The most common short-onset and late-onset complications were infections (4.2%) and mispositioning (12.6%), respectively [36, 41]. About 50% of original implants remain in their original place after 4 years [41, 42].

29.4 Gender-Affirming Surgery in Transfeminine Individuals

The estimated prevalence of transfeminine individuals is estimated to be around 6.8 per 100,000 [43]. Gender-affirming surgical techniques for patients on the transfeminine spectrum can be subdivided into three categories: facial feminization, chest reconstruction (colloquially known as top surgery), and genital surgery (colloquially known as bottom surgery).

29.4.1 Facial Feminization

Facial feminization surgery (FFS) refers to a set of procedures that can be performed to confer a more feminine appearance to the facial features (Fig. 29.2). Each patient who undergoes FFS will have distinctive needs and desires; hence, surgical approaches and options should be individualized. These surgical procedures can include both bony and soft tissue surgeries of the face including hairline, neck, and thyroid cartilage. Some of the facial feminization surgical principles are shown in Table 29.4.

29.4.2 Gender-Affirming Augmentation Mammoplasty

The principles of augmentation mammoplasty, or breast augmentation, are similar for transgender and cisgender patients. In both, the goal is to increase breast size and improve the shape of the chest. However, anatomical differences between transfeminine and cis-feminine patients should be considered when planning the surgery. Transfeminine individuals typically have broader chests, larger and hypertrophied pectoral muscles, smaller and more laterally placed NAC, and shorter inter-nipple and nipple-to-inframammary fold distances compared to cis-female chests. The SOC recommends the use of hormone therapy for a minimum of 12 months, although it is not a requirement for this surgical procedure. Prolonged hormone use can promote significant breast parenchymal growth, define a fold, and enlarge the NAC.

Surgical techniques involve the placement of breast implants (saline or silicone implants) or tissue expanders under breast tissue (Fig. 29.3). In general, the subpectoral plane or dual plane is often used to avoid rippling [44]. However, in patients with hyperthrophied pectoralis muscles, implant placement in the subpectoral plane will accentuate the prominent muscle and produce a displeasing and undesired wider breast base. In these cases, a prepectoral (subglandular) placement is recommended. Typically, these devices are inserted through periareolar, axillary, or inframammary incisions.

In some occasions, fat is taken from other parts of the body using liposuction and injected into the breasts as an adjunct to make implants less visible or palpable or to help narrow the cleavage between breasts (fat grafting in the medial poles) [2]. Less commonly, fat grafting alone is offered for augmentation mammoplasty. Other adjunct techniques can help address the anatomic differences between transgender and cisgender individuals. For

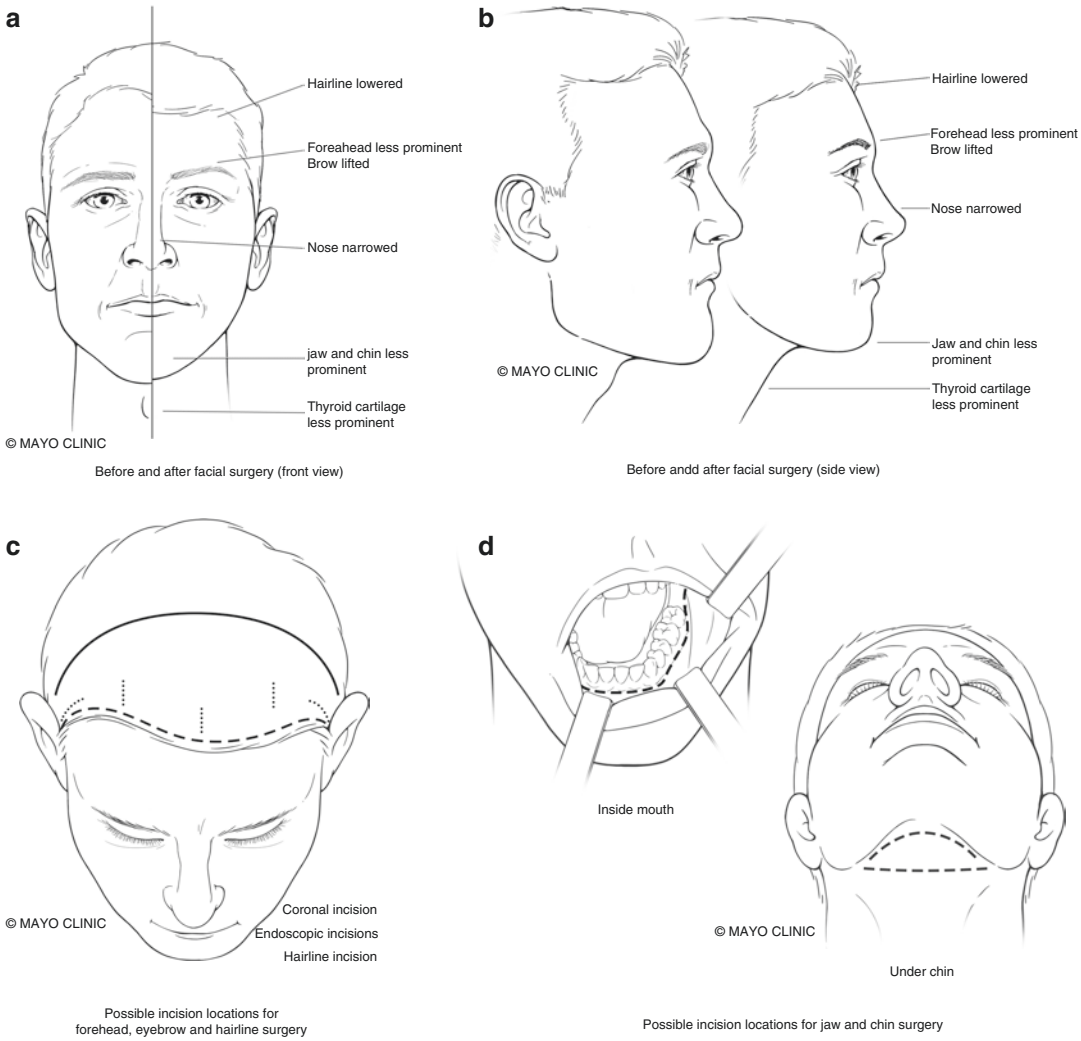

Fig. 29.2 Facial feminization surgery for transfeminine individuals. Main surgical outcomes in facial feminization from a frontal view (**a**) and a lateral view (**b**). Different incision locations for facial feminization in the upper third (**c**) and in the lower third of the face (**d**) (Used with permission of Mayo Foundation for medical Education and Research, all rights reserved)

instance, NAC repositioning by eccentric circumareolar skin excision may be performed to compensate for the more lateral location of the trans-feminine NAC.

Similar to other major surgeries, patients are at risk for bleeding, infection, and adverse reactions to anesthesia. Additional complications may include seroma formation, hematoma, chronic breast pain, capsular contracture, asymmetry of the breasts, and implant displacement, infection, or exposure.

Tips and Tricks

Breast cancer screening recommendations mirror those for cisgender patients, regardless of gender-affirming augmentation mammoplasty. Breast cancer screening by means of examination and mammography is appropriate for transfeminine patients who have taken hormones for 5 years or more and who are aged 50 years or older [2].

Table 29.4 Surgical principles for facial feminization in transfeminine individuals

	Facial feminization
Hairline	To lower or advance the hairline and correct temporal points with transplanted hair
Forehead	To perform burring and/or osteotomy of the frontal bone depending on the presence of frontal sinus and projection of the brow ridge
Eyes	To perform orbital shaping
Rhinoplasty	To create a smooth dorsal septum with a proper nasofrontal angle, nasolabial angle, and angle of the nose • Spread grafts are useful and must be thinned • The radix should be positioned more posterior to the glabellar prominence
Chin and jaw	To narrow the posterior portions of the mandible • The layers of the outer table of the mandible are burred and removed to narrow the jaw • Sometimes masseter reduction is performed • Reduction genioplasty osteotomies are sometimes required
Thyroid cartilage	To reduce thyroid cartilage prominence • Chondrolaryngoplasty that consists in the incision directly to the thyroid cartilage • Sharp removal by burring or rongeur • Indirect approach is made by submental incision • Care should be taken to avoid damaging the vocal cords upon insertion on the larynx

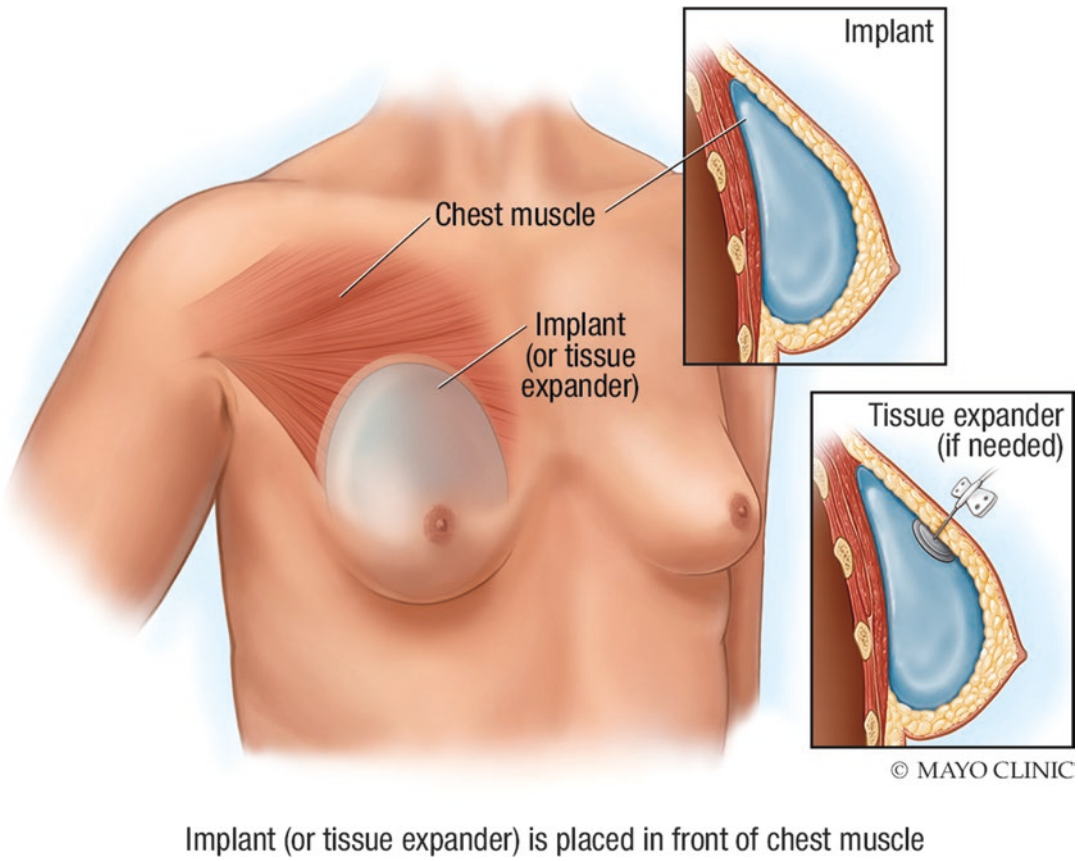

Fig. 29.3 Gender-affirming augmentation mammoplasty depicting implant (or tissue expander) positioning in the prepectoral (subglandural) plane (Used with permission of Mayo Foundation for medical Education and Research, all rights reserved)

29.4.3 Gender-Affirming Genital Surgery

Gender-affirming genital surgery for transfeminine individuals, also known as trans-female or male-to-female bottom surgery, is the surgical reconstruction of all anatomically male genitalia to external female genitalia. Approximately, 55% of transfeminine individuals undergo or desire vaginoplasty [45]. This procedure includes bilateral orchiectomy and the creation of a new vaginal canal with potential erogenous sensation within the canal, functional feminine vulva, hooded sensate clitoris, labia majora, and labia minora. Various techniques have been described to perform vaginoplasty, and most have been adapted from procedures designed to treat vaginal agenesis [46]. The ideal technique has not been determined due to the lack of sufficiently large comparative studies. However, the most common technique worldwide is penile disassembly with skin inversion technique [47]. Genital surgery is generally the final stage of the gender affirmation process and is associated with significant improvement in both mental and sexual health quality of life (QOL) [47].

Key Point
Orchiectomy is a relatively straightforward procedure that can be performed prior to vaginoplasty as a separate procedure or at the same time of the vaginoplasty (usually preferred).

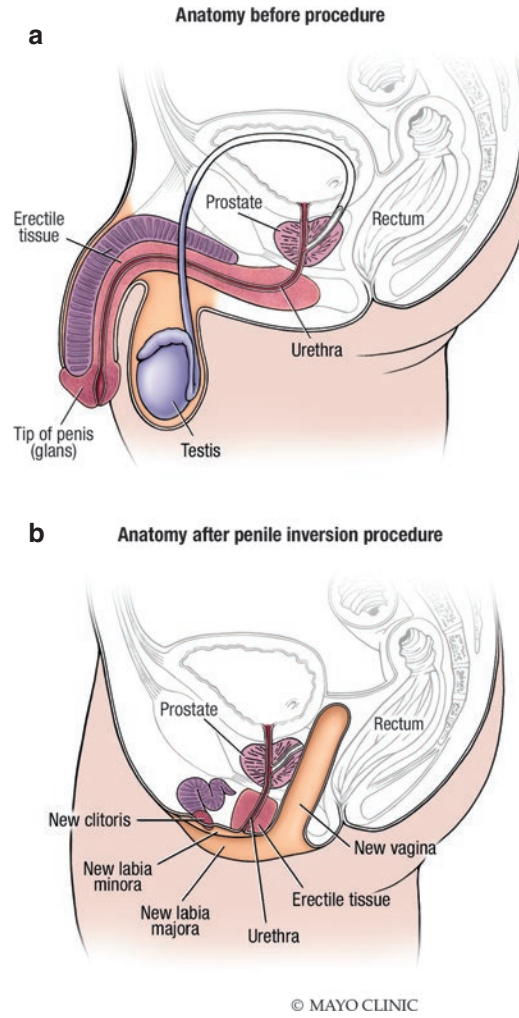

Fig. 29.4 Depiction of the anatomy before (**a**) and after (**b**) penile inversion vaginoplasty (Used with permission of Mayo Foundation for medical Education and Research, all rights reserved)

29.4.3.1 Penile Inversion Vaginoplasty

Penile inversion vaginoplasty is technically less complex and less invasive compared to other techniques and provides great aesthetic and functional results. In this technique, the penile skin is used to construct or re-create the labia majora and introitus vaginalis (Fig. 29.4). The vaginal linning is created using scrotal skin flaps, and the clitoris is built from sensitive skin at the dorsal aspect of the glands. Depending on the size of the glans, a neurovascular sensate flap (the "O" flap) can be placed into the anterior wall of the neovaginal canal to create a G-spot [48]. Nevertheless, patients with penile hypoplasia (penile shaft less than 8 cm) pose a challenge to the surgeon, as they usually do not have sufficient penile skin. In such cases, full-thickness scrotal, lower abdominal or thigh skin grafts, or inferiorly based scrotal flaps are used to create the posterior and/or distal aspect of the neovagina. Usually, patients need preparation before

surgery including patient education, hair removal, and physical therapy to improve preoperative pelvic floor dysfunction [49].

Surgical complications include complete or partial necrosis of the neovagina or labia (0–8%), fistula formation from the bladder or bowel into the vagina (0–5%), stenosis of the urethra and/or the new introitus vaginalis (7–15%), prolapse (1–8%), formation of granulation tissue, inadequate scarring, asymmetries, chronic pain, erectile tissue persistence, and anorgasmia [47]. Revisions are necessary occasionally, as this is not a cosmetic procedure but reconstructive in nature. These revisions include removal of scar or granulation tissue, correction of asymmetries, fat grafting to improve contour, and debulking of bulbous muscle to improve entry and the angle of entry to the vaginal canal for improvement of cosmesis.

Tips and Tricks

Preservation of all the compartments of the penis and careful dissection without tension during inset improves final results. Always maintaining good hemostasis decreases swelling and improves cosmesis. Surgical loupes are suggested to perform an adequate dissection of the neurovascular flaps.

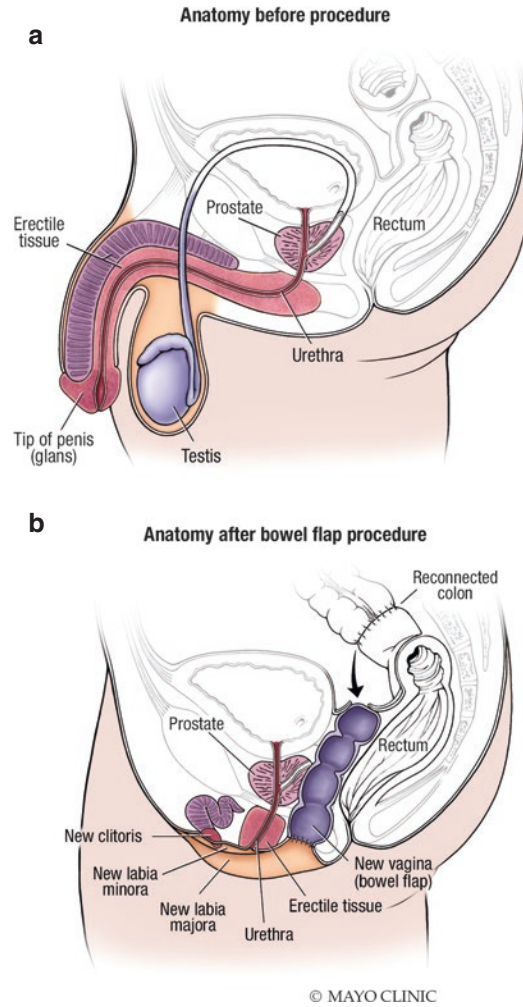

Fig. 29.5 Depiction of the anatomy before (**a**) and after (**b**) intestinal vaginoplasty. Notice the bowel anastomosis at the level of the intestinal segment used for neovaginal reconstruction (Used with permission of Mayo Foundation for medical Education and Research, all rights reserved)

29.4.3.2 Intestinal Vaginoplasty

Intestinal vaginoplasty consists on the isolation of colon or ileal segments (through open or minimally invasive approaches) and transfer into the neovaginal space (Fig. 29.5) [50]. The advantage of using an intestinal conduit is reliable length, texture and lubrication. However, it should be noted that an intra-abdominal surgery is required, and there is risk of pouchitis, peritonitis, adhesions, mucocele, and constipation [51]. The following complications have also been reported: complete or partial necrosis of the neovagina or labia (0–8%), fistula formation from the bladder or bowel into the vagina (2–20%), stenosis of the urethra and/or the new introitus vaginalis (9–16%), and prolapse (1–8%). Furthermore, colonic mucosa is more vulnerable to sexually transmitted diseases [4, 51]. This technique can be used for primary reconstruction, but has been more commonly used as a secondary procedure for failed penile inversion vaginoplasty.

29.4.3.3 Other Less Common Techniques

Split-thickness or full-thickness skin grafts, which are not limited by a vascular pedicle, can be used for vaginoplasty. This ensures that there

can be significantly more skin harvested if required to line the neovaginal cavity. Nonetheless, a circumferential skin graft tends to scar and contract leading to neovaginal stenosis in 33–45% of cases [4, 52] representing a real disadvantage of this technique. In addition, undesirable scarring or hypopigmentation of donor sites are also major drawbacks. However, skin grafting may be used with other approaches when there is not enough tissue for the neovaginal creation from penile skin alone [46].

Other options for neovaginal reconstruction are emerging and include but are not limited to the use of peritoneum, buccal mucosa, amnion grafts, or decellularized tissue [53]. Some patients who do not desire penetrative vaginal intercourse and want to avoid postoperative vaginal dilations or those who are high-risk surgical candidates may be offered zero-depth vaginoplasty. In this technique, patients undergo reconstruction of external genitalia but do not undergo neovaginal reconstruction, which decreases operative time and surgical complications.

Key Point

Penile inversion technique is the most common procedure performed for transfeminine individuals who want to proceed with vaginoplasty. However, adequate technique selection and detailed discussion of outcomes and complications in addition of having realistic expectations are necessary to improve quality of care and patient satisfaction.

Take-Home Messages

- A multidisciplinary team approach is essential to offer a comprehensive and holistic surgical approach to transgender and gender-nonconforming individuals.
- An open, welcoming, and transgender-friendly environment is always necessary in order to improve patient satisfaction and patient comfort.
- Every surgical intervention should be based on the Standards of Care for the Health of Transsexual, Transgender, and Gender-Nonconforming People provided by the World Professional Association for Transgender Health (WPATH).
- Patient education based on scientific literature and evidence-based medicine should be encouraged prior to any type of surgical intervention.
- The goal of gender-affirming surgeries is to alleviate gender dysphoria by improving the congruence between an individual's gender identity and their sex assigned at birth.
- Gender-affirming surgeries are medically necessary elements in the treatment of gender dysphoria and should be the last step of the transition process to avoid regrets and improve patient satisfaction.
- Gender-affirming surgery has exponentially increased in the last several years, so proper and formal programs are a must in order to provide state of the art medical care.
- Clinical and basic science research based on prospective randomized clinical trials and surgical innovation should be encouraged, thus, improving the quality of care provided to the transgender community.

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Further Reading

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Regenerative Surgery

30

Valerio Cervelli and Gabriele Storti

Background

Regenerative surgery is a relatively recent branch of plastic reconstructive and aesthetic surgery. Even if it rapidly developed, its origins, in its modern form, trace back only to 30 years ago. Its ultimate purpose is to either cure or replace organs and tissues that have been damaged by diseases, traumas, or congenital defects.

The concept of regeneration has always fascinated humans since ancient times. The myth of Prometheus laid its grounds on the capacity of the liver to regenerate.

Regeneration implies a healing process that leads toward tissues functionally and histologically identical to those damaged. The complete absence of scar tissue could be considered the ideal marker of a full and successful regenerative process, even though it is far to be reached at the moment.

Nowadays, there is a wide range of tools that can be used in this field, some of which are readily available in daily clinical practice, while others require specialized structures and high budgets.

Generally speaking, regenerative surgery strategies aim to make use of new materials, expanded in vitro or isolated cells, and factors able to guide their differentiation or proliferation, sometimes even combining some of the techniques above in order to either supply an efficient substitute to missing tissues, both structurally and functionally wise, or favor the regeneration of the damaged ones. Other strategies can encourage the organism's natural response and steer its healing mechanisms toward a total *restitutio ad integrum*.

Regarding plastic surgery, regenerative surgery strategies often involve adipose tissue and adipose-derived stem/stromal cells (ADSCs), either alone or combined with scaffolds or platelet-rich plasma (PRP).

30.1 Introduction

30.1.1 History and Development of Regenerative Surgery

The first instances of fat grafts trace back to the end of the nineteenth century and the beginning of the twentieth century. These initial attempts

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M. Maruccia, G. Giudice (eds.), *Textbook of Plastic and Reconstructive Surgery*,
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entailed an autologous transfer of en bloc adipose tissue portions from one spot to another.

The first description of fat transfer dates back to 1893 when Gustav Neuber, a German surgeon, harvested some fat tissue from the arm and transplanted it to the lower orbit to release adherent scars derived from osteomyelitis and to correct volume loss. Even though the initial results were good, Neuber experienced quite soon high resorption rates.

In 1895, Vincent Czerny, another German surgeon used a fist-sized lipoma removed from the gluteal area to fill in the defect left by a partial mastectomy.

From Berlin, Eugene Holländer described in 1912 the fat infiltration in two patients affected by lipoatrophy of the face, also providing photographic documentation.

Parallelly, in 1910, Lexer, who was a maxillofacial surgeon, described the fat transfer as a possibility to treat aging faces and in 1919 published a book in two volumes where he described the use of fat grafting for multiple reconstructive purposes, including traumas, hemifacial microsomia, tenolysis, and treatment of knee ankylosis.

Such a wide use of fat transfer suggests that the adipose tissue's regenerative and reparative possibilities have been known since the beginning, at least in part.

In 1920, at the end of World War I, Sir Harold Gillies reported good results in treating with fat parcels veterans who had severe facial wounds.

In 1926, Miller was the first to write down a detailed monograph about injecting fat via cannulas to exploit it.

Nonetheless, ever since the first trial, fat grafts presented evident significant complications. The reabsorption of the grafted fat after just a few months, in particular, caused unpredictable results and the formation of oily cysts due to fat necrosis [1].

Thanks to the perfected liposuction techniques developed by Illouz and Fournier in the 1980s, it was possible to gather considerable quantities of adipose tissue that could eventually be used for fat transfer. Illouz and Fournier also attempted to inject the non-processed lipoaspirate, but the mediocre results of this process in terms of engraftment not only implied the need for important hypercorrection but also proved the technique to be hardly applicable.

In 1986, Ellenbogen understood that the fat particle's dimension was one of the most critical parameters to consider when performing a fat transfer. The fat particle's optimal size is crucial to allow a correct exchange of nutrients between the recipient site and the graft.

He used to transplant the so-called fat pearls, which were fat particles of 4 or 6 mm that he used in several aesthetic conditions, like acne scars or sunken eyes. Despite initial promising results, this technique failed in assuring long-term retention of the fat.

Later trials also showed that the oil coming from the broken adipocytes, blood, and infiltration liquids hindered the graft survival and, thus, its durability.

By the end of the 1990s, Sydney Coleman introduced, for the first time, a fat-processing standardized procedure through which it was possible to obtain reliable results [2]. Coleman's technique regarding the so-called lipostructure was based on fundamental principles to achieve a long-lasting result.

This technique can be summarized with three innovations in particular:

- Fat centrifugation at 3000 rpm for 3 min
- The infiltration of small quantities of fat
- Fat infiltration on multiple layers

Coleman's centrifugation leads to the separation of three essential layers within the lipoaspirate (Fig. 30.1).

The most superficial level is composed of oil and dead or broken adipocytes; the intermediate one is composed of vital adipocytes and other cells (including adipocyte-derived stem/stromal cells); finally, the lower one is mainly composed of blood and infiltration liquid. Coleman's innovation consisted of injecting only the intermediate level made of living cells. Moreover, the infiltration of small amounts of fat on multiple layers granted an optimum contact between the receiving site and the purified fat graft, leading to

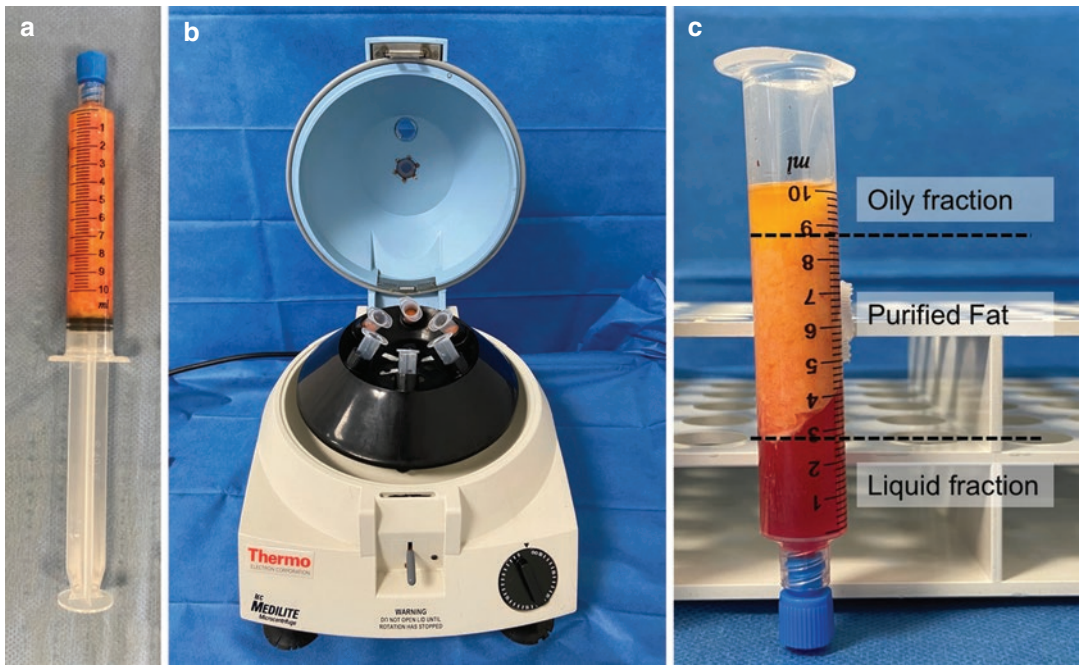

Fig. 30.1 Different steps of fat processing according to the Coleman technique. In (**a**), we can see the lipoaspirate, which is centrifuged at 1200 g (3000 rpm) per 3 min (**b**). Centrifugation allows the separation of fat into three layers from which only the purified fat will be injected (**c**)

better graft perfusion, significantly more efficient engraftment, and long-term stable results.

It was observed that in these conditions, fat grafting not only presented filling effects but improved scar conditions and, more in general, tissue and skin conditions.

It was not until 2001 that Patricia Zuk and her colleagues noted for the first time the presence, within the adipose tissue, of mesenchymal-derived cells with stem potential, then denominated adipose-derived stem/stromal cells (ADSC) [3].

This innovative discovery revolutionized fat grafting in both reconstructive and aesthetic surgery. It was particularly emphasized that ADSCs could proliferate in the recipient site; differentiate into mature cells such as adipocytes, osteoblasts, or chondrocytes; and secrete growth factors, at last, hence promoting cell proliferation and neoangiogenesis in the recipient site.

These essential effects were also exploited in plastic reconstructive surgery fields where recreating a microenvironment able to promote optimum healing by developing an efficient neovascularization and a biological niche apt to *restitutio ad integrum* was crucial.

The use of ADSCs and, more in general, of all the fat grafting-based techniques had extremely positive implications, especially for treating complex wounds, burns, and areas undergoing radiotherapy.

The term "regenerative medicine" (and surgery) was used for the first time in an article published by Rigotti in 2007, which regarded radionecrosis areas located in the thoracic region and treated with fat grafting [4]. In these patients, ADSCs were able to fix the damages caused by radiotherapy and allowed injured areas to heal.

Concurrent to the discoveries concerning ADSCs, regenerative surgery could benefit from other new techniques and products. In particular, by the end of the twentieth century, it was noted that the use of platelet-rich plasma (PRP) improved fat engraftment and aided in the creation of a pro-regenerative environment [5]. The latter proved useful for some aesthetic surgery

procedures as well, such as hair loss treatment and the amelioration of skin elasticity.

With time, it became evident that, in order to obtain optimum healing as well as a functional and mechanical recovery of damaged tissues, it was essential to not only stimulate both cell proliferation and differentiation but also promote a three-dimensional structural organization, similar to that of the initial tissue and the extracellular matrix (ECM) in it. This notion is especially true for tissues like bone tissue, which needs both correct cell differentiation and a precise spatial organization and definite mechanical properties to correctly function, especially in load-bearing bones.

For this reason, by the end of the 1980s, it was necessary to create new materials and three-dimensional constructs (i.e., the so-called scaffolds), able to mimic the physiologically existent ECM and guide cell proliferation in order to form structures similar to the original ones. Scaffolds, either biologically or chemically derived, and their eventual combination with cells and differentiating agents laid the foundations for tissue engineering.

All the techniques listed in this paragraph have been used both alone and combined, and they are among the tools available to regenerative surgery nowadays.

30.1.2 Principles and Techniques of Regenerative Surgery

30.1.2.1 Fat Grafting, the Vascular-Stromal Fraction, and ADSCs

The adipose tissue has mesenchymal origins, and it is widespread throughout the whole organism, both on a superficial and visceral level. It was initially thought that the adipose tissue was a relatively inert tissue with the sole purpose of providing thermic isolation, parenchymatous organ support, and energy storage, but that was a misconception. It later emerged that fat plays a crucial role in regulating numerous endocrine processes (such as the sensation of hunger, gaining or losing weight, the peripheral sensibility to insulin) and other innate mechanisms of the organism, like inflammation or tissue repair.

Adipocytes and other cell populations coming from the adipose tissue form a net of endocrine and paracrine exchanges, so complicated and functionally organized that the adipose tissue itself could very well be considered an actual organ.

Despite adipose tissue being mostly constituted by adipocytes in volumetric terms, it also contains many other cell populations that are more in number even if holding less volume. They include pericytes, endothelial cells, mononuclear cells, lymphocytes, and, of course, ADSCs. All of them are enclosed in the perivascular ECM. It is possible to isolate them from the rest of the lipoaspirate by breaking down the ECM net, either through enzymatic or mechanical means. The final product is called stromal vascular fraction (SVF), and it is naturally made of different kinds of cells, 20% of them being ADSCs. SVF, once cultivated in vitro through multiple steps, enables the isolation of ADSCs. For this reason, it is possible to talk about ADSCs in the strict sense only after all of these procedures.

ADSCs belong to a broader category of mesenchymal cells with stem phenotype, called mesenchymal stem/stromal cells (MSC), which can be found in several tissues.

In 2013, the International Federation for Adipose Therapeutics and Science (IFATS) and the International Society for Cellular Therapy (ISCT) agreed on a definition that classified ADSCs according to the following criteria [6]:

- Their capability of adhering to plastic and proliferating in vitro
- Their capability of differentiating into adipocytes, chondrocytes, and osteoblasts
- Immunophenotypical positivity for CD13, CD29, CD44, CD73, CD90, and CD105 and negativity for CD31 and CD45

With time, studies in vitro and on animal models have progressively clarified that adipocytes and ADSCs are the populations most involved in lipostructure.

Despite that, we are still far from fully comprehending their respective role in fat grafting and its mechanisms.

Engraftment percentages greatly vary between 20 and 80%, according to the recipient area, its perfusion, and its mechanical characteristics. Such a high variability implies low chances of predicting the final results and the almost unavoidable need for several surgeries to obtain the desired results.

The full process of engraftment has not been thoroughly understood yet. Over the years, different theories have been proposed. The two main theories regarding fat engraftment are the graft survival theory and the host replacement theory [7].

The graft survival theory was developed during the 1950s by Peer and laid the foundations for further understanding of fat grafting. According to this theory, adipocytes and cells transplanted into the recipient site are nourished by oxygen and nutrients, as long as a new vascularization coming from the recipient site reaches the graft and stabilizes it in the long term.

Thus, purifying and injecting the highest amount of living cells, particularly adipocytes, into the recipient site has been considered crucial for many years.

The host replacement theory, formulated by Yoshimura in the early 2000s, takes its premise from the notion that, after 14 days, only a small amount of the transplanted adipocytes was still vital. Adipocytes are exceptionally fragile cells, and they have a low tolerance to hypoxic damage. On the contrary, ADSCs have good resistance to the latter and can respond to ischemia/perfusion damages through increased proliferation and by differentiating into adipocytes and endothelial cells, thus triggering the formation of new blood vessels. Furthermore, they secrete additional growth factors, able to provoke neoangiogenesis, and recruit other precursor cells from the recipient site [8]. Their growing distance from the source of vascularization, as well as their different resistance to hypoxic damages, causes the formation of three concentric areas within the fat graft (Fig. 30.2):

- An outer area is closer to the vascularization and is about 300 μm thick, where both adipocytes and ADSCs survive, which goes under the name of surviving zone.
- An intermediate area between 600 and 1200 μm thick, called the regenerative zone, where adipocytes die, while ADSCs proliferate and differentiate, thus replacing dead cells. Its thickness varies according to the perfusion and the microenvironment of the recipient site.
- An internal area that oxygen does not reach hence making it impossible for both cell types to survive. Its thickness depends on the fat graft diameter and the partial oxygen pressure of the recipient site. The necrotic zone gets generally replaced by scar tissue or, in vast areas, by oily cysts.

In normal perfusion conditions, the so-called critical radius has been evaluated to be about 16 mm long. Fat grafts with longer radii have showcased signs of necrosis. Reduced perfusion and a consequently reduced partial oxygen pressure determine a critical radius reduction and thus signs of necrosis, even in smaller grafts [9].

These two theories are not mutually exclusive, and they present numerous similarities, first and foremost, regarding the crucial role of vascularization and neoangiogenesis in the recipient site. However, many of the factors regarding the engraftment process and the role that adipocytes and ADSCs play remain unknown.

Key Points

ADSCs show features of the mesenchymal stem/stromal cells (MSCs), which can be summarized as follows:

- The capability of adhering to plastic and proliferating in vitro
- The capability of differentiating into adipocytes, chondrocytes, and osteoblasts
- Immunophenotypical positivity for CD13, CD29, CD44, CD73, CD90, and CD105 and negativity for CD31 and CD45

ADSCs work with two mechanisms:

- Cell-mediated mechanisms, including self-renewal, proliferation, and differentiation
- Paracrine mechanisms determined by the secretion of growth factors

These mechanisms promote neoangiogenesis, immunomodulation, adipogenesis, and, lastly, tissue regeneration.

Several possible mechanisms have been theorized in order to explain the merely partial engraftment of lipostructure:

– Mechanical damage and the tangential forces during fat harvesting, processing, and injection
– Ischemic damage due to a scarce perfusion
– Recipient site poor compliance
– An excessive amount of fat grafting, denominated over-grafting

Many expedients have been devised in order to face these issues and improve lipostructure efficiency [10].

An optimum manipulation allows purifying the fat tissue from contaminating agents that negatively impact engraftment, such as red blood cells, fatty acids, and local anesthetics, and maximize the number of useful cells instead, thus minimizing the risk of cellular damage and consequent necrosis and apoptosis. Over-manipulation compromises the most fragile cellular elements, like adipocytes. Vice versa, a suboptimal purification may lead to reduced engraftment and the final volume being less predictable.

The optimal process for adipose tissue manipulation is far to be fully outlined. We can distinguish among different steps during fat grafting:

- Harvesting
- Processing
- Fat injection

In general, all the data about these processes are supported by low-quality clinical evidence, which does not allow us to make strong statements on the efficacy of different methods and devices [11].

The first aspect to be considered when harvesting fat is the donor site. Different donor areas have been proposed, including the abdomen,

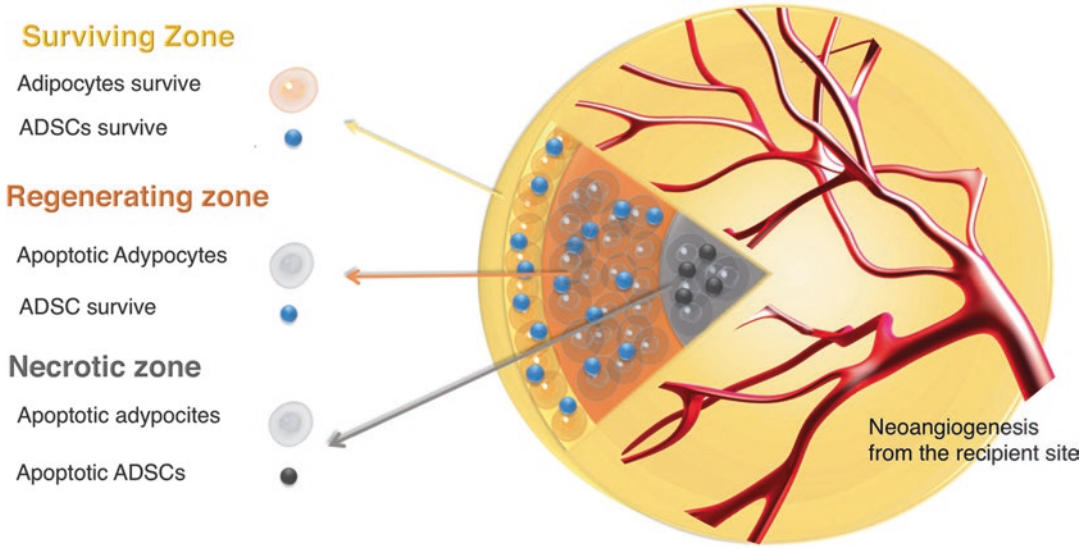

Fig. 30.2 The injected fat lobule could be divided into three different zones, which are progressively more distant from the recipient site's vessels. Going from the outside to the inside, we have the surviving zone, the regenerating zone, and the necrotic zone. *ADSCs* adipose-derived stem/stromal cells

hips, trochanteric region, inner thigh, and knee area. Furthermore, we can distinguish between superficial and deep fat compartments. Although some authors have proposed the superiority of specific donor sites like the lower abdomen and the inner tights, a general revision of the literature does not support this claim. Nonetheless, the quality of the evidence is low under this aspect.

The effect on the viability of ADSCs of local anesthetics, part of the infiltration solution, has also been debated. Even though some in vitro and preclinical evidence raised the problem of cytotoxicity of local anesthetics on ADSCs and therefore postulated a consequently reduced graft survival, these data have not been confirmed in clinical settings. While the use of local anesthetics is questioned, epinephrine is considered safe for cellular viability.

The device and the technique used for fat aspiration seem not to affect graft retention. Either syringe aspiration, as initially described by Coleman, or vacuum-assisted liposuction or water-assisted liposuction or ultrasound-assisted liposuction has similar effect on the graft, without significant benefits of one method over the others. Nonetheless, laser-assisted liposuction and the use of a negative aspiration pressure below −760 mmHg could significantly harm graft survival and adipocyte viability, which is diminished by 90%.

It has been described that the use of larger cannulas for the harvesting process helps in preserving a higher number of viable adipocytes. Nonetheless, the clinical benefits related to this observation are not clear.

The ideal processing protocol should purify the graft at a maximum level, removing all the contaminants and limiting cell dispersion and destruction. It should be a closed system to avoid external contamination, and it should be quick and cheap enough to be performed intraoperatively, thus allowing the immediate re-injection of the purified graft without elongation of the operative time.

Centrifugation, filtration with or without washing, decantation, and many other methods have been tested to obtain the best results. Unfortunately, there are no data in support of one technique over the others to date. Each technique described showed strengths and weaknesses.

The centrifugation, as described by Coleman, seems to obtain an optimal graft purification and the removal of many components that could hinder the engraftment process, including broken adipocytes, fatty acids, red blood cells, and infiltration fluid. Furthermore, it has been suggested that the centrifugation determines a higher final concentration of ADSCs in the purified graft.

However, mechanical stress during centrifugation is detrimental to the fragile adipocytes that could be disrupted in a higher number with this processing method.

The filtration, with or without washing, causes less mechanical stress to the adipocytes than centrifugation, but more than decantation. It has a discrete capacity of removal of the unwanted components and can concentrate quite efficiently ADSCs. Nonetheless, if performed with an open system, filtration could expose the graft to the air for a relatively long time and impair its viability. Furthermore, it could be complicated to perform for large quantities of lipoaspirate. Closed systems are available, but they are disposable, and the costs are higher than for open ones.

The decantation applies minimal forces to the harvested lipoaspirate and uses gravity force to separate the different components. This method preserves the adipocytic component while, on the other hand, giving suboptimal results in terms of graft purification. The decantation could be useful, especially when dealing with large amounts of lipoaspirate, but the excess of residual oil, cellular debris, and infiltration fluid could impair the engraftment.

Key Points

The technique described by Coleman is the first technique described that had reliable results in fat processing.

It is based on three main pillars:

- Syringe aspiration with a gentle negative pressure
- Centrifugation for 3 min at 1200 g, discarding the oily and the aqueous layers
- Multiplanar infiltration of the purified fat

Other techniques have been proposed over the years, aiming to modify the harvesting, processing, or injecting phase.

The main variations among surgeons are in the processing phase. The most used methods are centrifugation, decantation, and filtration with or without washing.

Nonetheless, none of these techniques has proven to be more efficacious than the others in long-term graft survival.

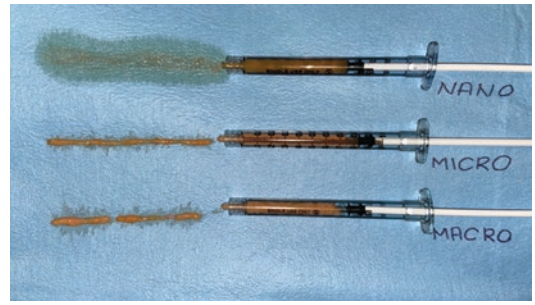

Fig. 30.3 Different fluidity of the macro-, micro-, and nano-fat graft

Over the years, new classifications of the adipose graft have emerged. The purified fat has been classified into macrofat, microfat, and nanofat, according to the injected fat particles' size. The macrofat and the microfat are harvested, respectively, with a 3 mm, two-hole cannula and with a 2 mm cannula with multiple holes, usually with sharp edges, ranging between 1000 mm and 600 mm of diameter. The different cannula sizes determine a different size of the fat lobules among macro- and microfat. The following processing method is variable, as described above. The centrifuged microfat is shuffled 30 times between two syringes connected by a Luer-Lock connector to obtain the nanofat. The emulsified fat obtained is then filtered with dedicated filters and results in a fluid product easier to inject even with thin needles. The shuffling/filtration protocol, according to the inventors of the nanofat technique, should rupture the adipocytes and allow their removal together with cellular debris, thus increasing the concentration of ADSCs and the regenerative properties of the nanonfat. Furthermore, the product obtained is extremely fluid and can also be injected in very thin areas like the eyelids.

However, no strong evidence supports the superiority of nanofat or microfat over the macrofat in terms of regenerative capacity. The main difference between these products is their fluidity and, consequently, injectability, which could guide one product's indication over the others to treat specific areas of the body (Fig. 30.3). For example, macrofat in the face could be useful for cheek augmentation on a deep plane, while nanofat or microfat is more indicated for thinner areas like the eyelids, where small volumes and extreme precision are needed.

Optimal contact between the recipient site and the graft is of capital importance to minimize the resorption and is the injection phase's primary goal.

Infiltrating fat with a small cannula in different non-confluent tunnels, on multiple layers, and in small quantities allows every fat graft to be surrounded by vascularized tissue and increases survival chances.

Moreover, graft perfusion by the recipient site plays an important role. Hence, it is necessary to assure the best possible contact between the fat graft and the receiving area and minimize mechanical stresses that may compromise vascularization.

Lastly, it has been speculated that either creating a microenvironment that favors cellular proliferation and angiogenesis or the addition of cells capable of proliferating and differentiating into adipocytes and endothelial cells may increase fat engraftment and survival. These theories have laid foundations, respectively, for the addition of PRP to lipoaspirate, a process called platelet-rich lipotransfer (PRL), and the addition of SVF or ADSCs, otherwise called cell-assisted lipotransfer (CAL).

Tips and Tricks

Even though surgeons' preferences play a fundamental role in the processing technique's choice, it is possible to consider different processing and post-processing methods according to the amount of lipoaspirate to be processed and the area to inject. For example, for a high amount of lipoaspirate to be injected into the breast, the fat's decantation could be quicker and give a sufficient degree of purification. On the other hand, to inject in the face, a centrifuged microfat could be the product of choice.

30.1.2.2 Cell-Assisted Lipotransfer (CAL)

As previously mentioned, ADSCs act in several different ways within the adipose tissue, but they can all be grouped into two different categories:

- Cell-mediated effects, including self-renewal, proliferation, and differentiation
- Paracrine effects determined by the secretion of growth factors (like the vascular endothelial growth factor (VEGF), hepatocyte growth factor, fibroblast growth factor-2 (FGF-2), and insulin-like growth factor-1 (IGF-1)) and the consequent recruitment of multiple cell populations, including preadipocytes, endothelial cells, macrophages, and fibroblasts, which get stimulated toward neoangiogenesis, immunomodulation, adipogenesis, and, lastly, tissue regeneration

The importance that every step holds within the whole procedure's economy is yet to be determined. However, based on the previously mentioned observations and the crucial role ADSCs play during the engraftment process, in 2008, K. Yoshimura suggested, for the first time, to enrich the lipoaspirate with additional amounts of SVF or even purified ADSCs [12]. This technique was named cell-assisted lipotransfer (CAL) and originally consisted of dividing the lipoaspirate into two halves. 50% of it was thus enzymatically digested through collagenase, obtaining the SVF, which was then, in turn, mixed with the other 50% of the lipoaspirate, which was purified according to Coleman (Fig. 30.4).

Many changes to the original method were suggested over the years, especially regarding the separation of SVF, such as aggressive centrifugation, vibrational energy, vortexing, fragmentation, and ultrasonic cavitation. The benefit of using mechanical methods rather than enzymatic ones resides in lower costs and faster execution, which makes them more feasible for intraoperative use and in fewer regulatory obstacles regarding their employment.

Ultimately, mechanical approaches have lower chances of destroying ECM and thus of dissociating the SVF from it. This fact entails a greater cellular dispersion and, consequently, a low cellular yield.

Moreover, it is essential to note that only 20% of the cells within the SVF are ADSCs. For this reason, many authors proposed adding isolated ADSCs, grown in vitro, to the lipoaspirate to select better the type of cells used in the grafting process and their effects [13].

This process, however, presents many problems. First of all, it requires at least two procedures: a harvesting one, followed by cell expansion in the laboratory, and a second surgery

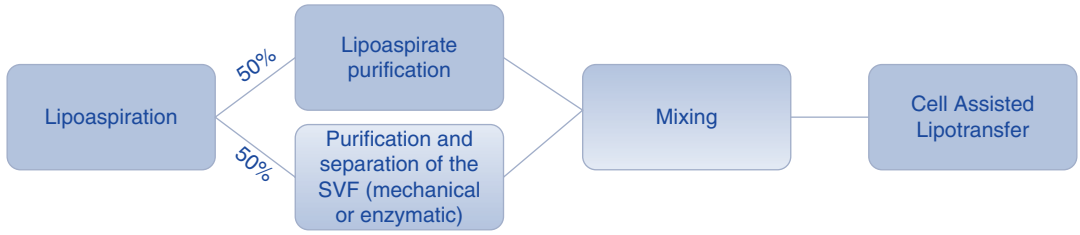

Fig. 30.4 Cell-assisted lipotransfer as described by Yoshimura

to inject the expanded cells. All these steps require extra costs and time and present numerous regulatory obstacles. Thus, this approach is still far from a solution for daily clinical use.

Some meta-analysis showed that CAL presents better engraftment and volume retention after time, especially in some areas like the face, while there is no significant advantage in the breast area. Despite that, evidence in favor of this technique is not clear enough to draw any definite conclusion [14].

Key Points

The SVF is embedded into the perivascular extracellular matrix and is constituted of different cellular types like pericytes, endothelial cells, mononuclear cells, lymphocytes, and ADSCs. ADSCs are about 20% of the cellular component of the SVF.

It is necessary to separate the SVF from the ECM and collect it to enrich the fat grafting with the SVF. This separation can be done with mechanical methods or enzymatic methods. In the EU, only mechanical methods are allowed intraoperatively without the use of GMP facilities. Nonetheless, mechanical methods have more cell dispersion and a lower cell yield.

It has not been clearly demonstrated that an enrichment of the graft with SVF like in the CAL determines a better outcome in terms of graft survival.

30.1.2.3 PRP and Platelet-Rich Lipotransfer (PRL)

Platelets take part in many physiological mechanisms, including, of course, hemostasis, inflammation, and tissue repair. During these processes, platelets undergo activation, a Ca++ mediated phenomenon that entails the release of the granules they contain.

Platelet-stored growth factors are particularly present within the a-granules and get released during their activation. Among these factors, the most important ones in the field of regenerative surgery are the platelet-derived growth factor (PDGF), transforming growth factor (TGF)-b, vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), basic fibroblast growth factor (bFGF), and, lastly, insulin-like growth factor (IGF-1), the effects of which are described in Table 30.1 [15].

Table 30.1 Principal growth factors contained in platelet-rich plasma and their functions

Growth factors	Biological functions
VEGF	Regulation of collagen secretion Stimulates migration and proliferation of vascular endothelial cells Promotes the formation of new vessels
EGF	Potent mitogen Increases the expression of genes responsible for DNA synthesis and cell proliferation Regulation of the mitogenesis in mesenchymal stem cells and epithelial cells Promotion of angiogenesis and chemotaxis of endothelial cells Regulation of collagenase secretion
b-FGF	Multifunctional protein with regulatory, morphologic, and mitogenic effect Regulation of endothelial cells, fibroblastic cells, and ADSCs Stimulation of angiogenesis and the formation of new blood vessels from the preexisting vasculature
PDGF	First responsible for connective tissue healing Important regulator of the mitogenesis in ADSCs Regulation of the chemotaxis of ADSCs Regulation of the collagen synthesis and secretion
TGF-®	Both autocrine and paracrine activity Stimulation of the proliferation of the ADSCs Regulation of the collagen synthesis Regulation of the endothelial mitogenesis Immunomodulation of macrophages and lymphocytes

ADSCs adipose-derived stem/stromal cells

PRP is a blood product meant for autologous use that is obtained through blood centrifugation. The latter allows platelets to concentrate within the plasma, increasing their numbers. Different preparation methods, mainly based on one or two centrifugation steps, have been described. However, each approach showcases a wide range of variability regarding platelet concentration,

their absolute number, and the ability to either remove leucocytes or not. Several different classifications have been proposed in an attempt to better label every technique. The classification considered as the most accurate one to date is the so-called DEPA classification [16].

The DEPA classification takes into consideration four parameters:

- Dose of platelets, i.e., the absolute platelet number within the PRP volume
- Efficiency of the platelet-concentration method, that is, the increase, measured in percentage, of platelet volume per plasma volume
- Purity of the final product resulting from the contamination with leucocytes and red blood cells
- Activation (or lack thereof) through exogenous coagulation factors

Thanks to the growth factors it contains, PRP prompts the microenvironment toward a pro-regenerative transition and increased cell proliferation and neoangiogenesis [17]. Furthermore, PRP has been proved to increase ADSCs proliferation and engraftment, with an optimum dose of 0.5 mL of PRP every mL of lipoaspirate, whenever mixed with purified lipoaspirate. Fat grafts that get mixed with PRP are called platelet-rich lipotransfer (PRL).

However, even if PRP, injected on its own, may apparently hold advantages in terms of microenvironment conditioning, as it is the case for lower limb ulcer, for example, it is hard to draw any definite conclusion to date when it comes to adipose tissue survival.

It is mostly unclear whether there may be an efficient minimum dose, both regarding the absolute platelet number and the platelet concentration capacity. There are also still doubts regarding the eventual benefits offered by PRP activation in terms of efficacy. Finally, comparing and classifying all the studies to obtain good-quality, clinical scientific evidence is challenging, considering the heterogeneity of the applied preparation methods and, consequently, their resulting PRP [18].

Key Points

The most important reasons for fat graft failure can be summarized as follows:

- Mechanical damage
- Ischemic damage
- Reduced capacity of the recipient site
- Overgrafting

Over the years, different strategies have been employed to overcome these possible stressors on the graft. The strategies employed can be grouped into three main categories:

- Improvements in the surgical technique that include an increase in the vital cells available, a reduction of the cellular loss, and an optimal purification of the graft
- Enrichment of the graft either with cellular products like SVF or ADSCs or with factors enhancing proliferation and differentiation like the PRP
- Pre-conditioning and preparation of the recipient site with techniques like the external expansion or the reverse expansion and use of scaffolds

30.1.2.4 Scaffolds and Tissue Engineering

Every tissue showcases not only the cellular component but also an extremely specialized supporting structure, consisting of ECM. This structure is particularly relevant for spatial and three-dimensional tissue organization and the physical and mechanical properties of said tissues.

In regenerative surgery, tissue engineering aims to artificially recreate the specific properties every human tissue possesses to fulfill its function.

In order to create a result as similar as possible to the model tissue, this branch uses several composite components.

There usually is a cellular component (e.g., ADSCs); proliferative and differentiating fac-

tors, like PRP; and a three-dimensional scaffold, either naturally or synthetically made. Scaffolds can also be used on their own to direct and guide the organism's natural healing processes.

An ideal scaffold should possess high biocompatibility to trigger a minimal inflammatory and immunologic response and an optimum integration and biodegradability capacity so that with time it can be entirely replaced by the autologous tissue. Additionally, it should retain elasticity and similar mechanical support to one of the substituted tissues, and these characteristics should be maintained until said scaffold gets totally integrated and finally absorbed. These features are especially relevant when scaffolds are placed in load-bearing areas, like for long bone reconstruction [19].

Scaffolds can be built using either synthetic materials, like inorganic ceramics, titanium, biodegradable synthetic polymers (e.g., polylactic acid (PLA) or polyglycolic acid (PGA)), or biological materials such as collagen and decellularized tissue matrix (porcine dermis, bovine pericardium, decellularized fat tissue, demineralized bone tissue).

In recent years, some of these materials (e.g., synthetic biopolymers) made it possible for even more structurally complex scaffolds to be constructed through 3D printing.

Despite the great potential of these materials, there are still several problems to be faced. First of all, scaffolds on their own need to be integrated, which implies the need for neoangiogenesis coming from the surrounding healthy tissues within the scaffold itself.

Hence, scaffolds that are either too thick or surrounded by not properly vascularized tissues cannot get integrated and re-absorbed, or they could even cause an inflammatory reaction.

On the other hand, scaffolds combined with cells harvested in vitro or with growth factors entail numerous steps in vitro, higher costs, and strict regulatory norms, controlling their quality and use on humans.

Pearls and Pitfalls

When examining the reasons for the adipose graft failure, the fat grafting process should be considered in its wholeness. R. Khouri illustrated this concept when he compared the fat grafting to a farmer planting a seed in the ground. To have a successful harvest, we need to consider the 4 S: soil (the recipient site), seeds (the graft), sowing technique (the surgical procedure), and support (the post-surgical aftercare). If we focus only on one of these aspects, like the graft, and we do not consider all the others, our modifications would probably fail to improve graft survival.

30.1.3 Clinical Applications in Regenerative Surgery

In plastic surgery, clinical applications of regenerative surgery range from aesthetic surgery to reconstructive surgery. Different areas of expertise in regenerative surgery cover almost all the fields in plastic surgery, even though in some of them, the experiences are still limited and often preclinical. Nonetheless, regenerative surgery is part of the everyday clinical practice in many clinical settings and is often the gold standard for treating specific conditions.

30.1.3.1 Breast Surgery

Regenerative surgery found an important area of application in breast reconstructive surgery. Fat grafting proves to be one of its most useful tools in the reconstructive path of many women affected by breast cancer.

Fat grafting is versatile, and it allows from small touch-ups to replacement of eventual volume deficits resulting from quadrantectomies and even total, post-mastectomy breast reconstructions in selected cases.

Furthermore, lipostructure, either alone or combined with ADSCs or PRP, is incredibly use-

ful in treating irradiated breasts, considering ADSCs' neoangiogenetic and immunomodulatory effects. However, the oncologic risk these effects could eventually produce should also be taken into consideration. Some shadows have been cast on fat grafting in oncologic patients by the possibility of eliciting tumor cell proliferation and disease relapse.

Many data in vitro showed that the co-cultivation of ADSCs and cells derived from breast cancer lineages resulted in an increased proliferation of the neoplastic cells and a shift toward a more aggressive and invasive phenotype through the induction of the epithelial-to-mesenchymal transition. This data could be explained by the high secretory activity of the ADSCs, with a sustained release of growth factors like IGF-1 and PDGF, which promote proliferation, or the VEGF that triggers the neoangiogenetic cascade. Furthermore, in some animal models of cancer, the mesenchymal stem/stromal cells in general, and the ADSCs, in particular, showed a positive tropism for the tumor microenvironment.

Nonetheless, preclinical data seems not to be confirmed by the clinical evidence, even though some authors claimed an increased risk for patients bearing foci of ductal in situ carcinoma.

However, data about the regenerative options' oncological safety are often derived from retrospective studies with observational or case-control designs. Unfortunately, few prospective data are available, with short follow-ups and randomized clinical trials missing.

Lipostructures have proved reasonably safe in patients who have undergone mastectomies, while it should be used cautiously in patients with previous quadrantectomies who present residual breast tissue. In these patients, it is necessary to wait for adequate time free from the disease. Moreover, the oncologic safety of procedures like CAL or PRL has not been conclusively proved yet [20].

Pearls and Pitfalls

Some radiological findings in patients who underwent a lipofilling procedure are oil cysts, fat necrosis, and macrocalcifications. Inexperienced radiologists could misinterpret these findings as suspicious lesions or disease relapse. Therefore, it is essential to refer these patients to breast cancer centers or radiologists trained in examining patients with a history of lipofilling for the radiological follow-up. Furthermore, the MRI is a fundamental tool in the evaluation of these findings.

In light of these data, fat grafting for breast augmentation in aesthetic surgery should be cautiously evaluated before use.

Even though the idea of performing a breast augmentation without implants sounds incredibly promising, it is still hard to be realized in everyday clinical practice. As mentioned before, the main problem is the possible oncogenic risk associated with fat grafting and the use of ADSCs. Moreover, the volumetric increase is limited by fat resorption and often could need more than one session of fat grafting to reach the desired result. All these limitations often hinder the possibility of achieving significant volume augmentation and restrict the use of this technique to small increases of breast size. However, regenerative surgery in aesthetic breast surgery gives excellent results when used as hybrid surgery, together with implants. In particular, fat grafting could increase coverage in thin areas where the implants are more visible, e.g., in the upper pole.

Key Points

The American Society of Plastic Surgeons (ASPS) stated that the lipostructure could be considered safe in post-mastectomy patients. However, in patients with post-

quadrantectomy or post-lumpectomy defects and residual glandular tissue, fat grafting should be considered cautiously. Some retrospective data showed a possible role of the adipose graft in the progression of ductal in situ carcinomas. Even though many other studies did not show any rise in the oncologic risk, it is appropriate to wait an adequate time free from the disease before starting with lipofilling sessions in patients with a history of quadrantectomy or lumpectomy. Furthermore, a thorough radiological evaluation to exclude disease relapse is mandatory before the surgery.

30.1.3.2 Wound Healing and Scar Treatment

Volume filling, neoangiogenesis, and collagen synthesis induced by growth factors underlie the usage of regenerative surgery procedures treating scars and burns.

In this case, the regenerative effect mediated by the ADSCs is combined with the volumetric effect of the graft, which infiltrates the scar and detaches adhesions, often in combination with the mechanical release of adherent scars via techniques like rigottomies, laser, or microneedling.

Similarly, regenerative surgery is beneficial for treating ulcers and complex wounds. Employment of ADSCs and PRP improves perfusion in the treated area and regulates the organism's natural response toward a repairing phenotype.

The effect of regenerative surgery for wound healing, scar, and burns treatment relies both on cellular mechanisms and on paracrine effects. The paracrine effects have a fundamental role in conditioning the microenvironment and promote the healing process by recruiting more progenitor cells and the modulation of the inflammatory process. Growth factors like the VEGF help in recreating a proper vascular capillary network in poorly perfused areas. Furthermore, the TGF-b helps enhance the collagen synthesis and reduces the local inflammation via the macrophage population's shift from a pro-inflammatory M1 phenotype to a pro-reparative M2 phenotype. The immunomodulating effects of the ADSCs and the PRP proved useful in treating the local effects of autoimmune diseases like scleroderma and lichen sclerosus.

For an optimal *restitutio ad integrum*, in wound care, it is also essential to minimize scar tissue formation and favor a three-dimensional cellular organization similar to the original tissue. The use of biological scaffolds, such as porcine dermis or bovine collagen-derived ones, allows guiding the reparation processes to obtain a less scarred and more elastic skin and soft tissues.

Scaffolds are also convenient for reconstructing osteochondral defects, but we are still far from a daily clinical application of these constructs even if promising results were achieved in this field.

30.1.3.3 Facial Aesthetic and Reconstructive Surgery

Lipostructure currently is at the center of many face-rejuvenating techniques, and it helps restore the natural volumes in those areas where the natural fat tissue faded away.

Stimuli to the formation of new blood vessels and the synthesis of new ADSCs and PRP induced collagen have been used to improve skin elasticity and counteract photo-aging damages.

The use of fat transfer in the face helps to replace those adipose compartments which underwent progressive decay over time. Lipostructure could be extremely useful alone when it helps to replace a volume loss with a like-for-like concept (Fig. 30.5). Compared to a synthetic filler, it has longer, often permanent, results and total biocompatibility, being autologous tissue. However, sometimes, it can give unpredictable results because of resorption, and it could need more than one procedure.

Lipostructure is useful alone, but it is also a fundamental component of the so-called hybrid surgery. Hybrid surgery exploits traditional surgical techniques like face lifting, mid-face lifting, and blepharoplasty together with regenerative techniques. Hybrid surgery finds its best indication in all patients who had not only a volume

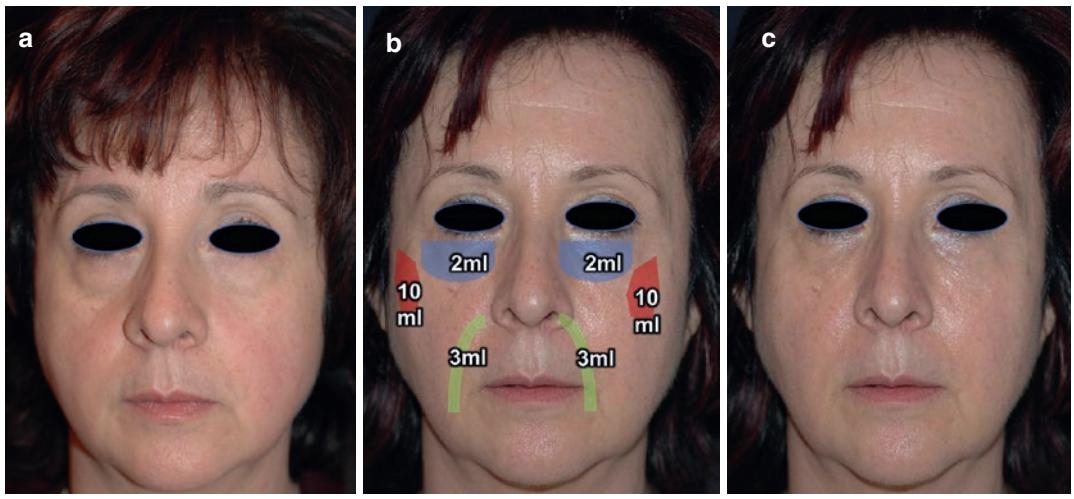

Fig. 30.5 Face rejuvenation using fat transfer. In (**a**), we can see the patient preoperatively, while in (**b**), we can see the different types of fat graft used (macrofat in red, microfat in green, and nanofat in blue) and the areas of injection. We can see the patient at 1-year post-op in (**c**). We can notice a general improvement in the skin texture and improved fullness of the zygomatic area and the nasolabial folds. Furthermore, the rejuvenation of the tear trough area with reduced visibility of the nasojugal groove is noticeable

loss but also ptosis of the natural fat compartments. The traditional surgery relocates the ptotic fat compartments in their anatomical position, while the fat graft replaces the lost volume. Furthermore, liposuction for fat harvesting could be directly performed on the face, thus helping contour redefinition and enhancement.

As mentioned above, the use of different types of fat graft (macrofat, microfat, and nanofat) allows correcting precisely each area of the face, even the thinnest ones like the tear-trough area, thus avoiding overgrafting, which could be detrimental on the face.

The use of fat transfer and PRP in face surgery has also been tested in reconstructive settings, with good results. In particular, it helps in replacing the volumes lost in the Parry-Romberg syndrome and correcting the consequent deformity. For similar reasons, fat grafting has also been used on the face to treat the cutaneous manifestation of scleroderma because it improves skin quality, its elasticity, reduces the scarring, and corrects contour deformities, recreating fullness.

30.1.3.4 Regulatory Issues

For the European regulation authority, fat grafting is feasible for autologous use in the intraoperative setting. Centrifugation, filtration, decantation, and mechanical methods of separation of the SVF are considered minimal manipulation, and therefore they do not require the use of Good Manufacturing Practice (GMP) facilities. Furthermore, purified fat or the SVF should be used for homologous use, i.e., following a like-for-like principle. Therefore, every use of these cells, either in areas where they are not physiologically present or in processes in which they do not physiologically take part, has to be considered only in a controlled setting after the approval of an ethical committee.

Processes like SVF separation with collagenase, ADSC isolation and expansion, and tissue engineering are considered, according to the European legislation, as major manipulations and require a GMP laboratory to be performed.

While the regulation about cellular products is uniform in the whole EU, legislation about PRP differs in each country.

30.1.3.5 Future Perspectives

Regenerative surgery has tremendous potentialities that are only partially exploited in everyday clinical practice at the moment. Immunomodulating properties of ADSCs are proving to be useful in treating autoimmune diseases like Crohn's disease. Furthermore, their versatility in differentiation encourages their use in tissue engineering and as carriers of drugs or nanoparticles. Unfortunately, safety concerns are still to be solved, and the costs are too high at the moment to think of an immediate translational application despite many promising preclinical experiences.

Take-Home Messages

- Regenerative surgery is a crucial element in many fields, both in aesthetic and reconstructive surgery.
- Fat grafting is a regenerative technique widespread in everyday clinical practice and allows achieving good results with limited costs and low morbidity for patients.
- Survival of the fat graft, which ranges from 20 to 80%, determines the low predictability of the outcomes and necessity of multiple procedures.
- An optimal technique for harvesting, processing, and injecting the adipose tissue has not been identified yet.
- A complete survival of the adipose graft is hindered by several factors, including low perfusion, mechanical stressors, low compliance of the recipient site, and over-grafting.
- The enrichment of the purified fat with PRP, SVF, or ADSCs seems to improve the efficacy of the grafting techniques even though data are still conflicting.
- The use of biological or synthetic scaffolds helps recreate the original features of the ECM and orient the reparative processes in a three-dimensional way.
- Combination of cellular components, scaffolds, and differentiating agents laid the grounds for tissue engineering.
- Regenerative techniques in everyday clinical practice involve fields like face surgery, breast surgery, wound healing, and many others.
- Many regenerative techniques' oncological safety is still debated, and many regulatory issues have still to be faced before reaching a translation of many techniques from bench to clinical practice.

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31 Advanced Reconstructive Plastic Surgery

Dicle Aksoyler and Hung-Chi Chen

Background

In the past, multiple staged operations were performed for reconstruction. These operations required longer hospitalization times, longer physical therapies, poor functional outcomes, complications, and negative psychological effects on patients. The advent of microsurgical techniques and advances of flap surgery have permitted for achieved reconstruction of multilayer defects including with the bone, muscle, soft tissue, and nerves spontaneously. Moreover, possible outcomes have been captivating patients and keeping them compliant to postoperative period. For instance, super thin flaps have become first-choice foot reconstruction instead of previously used bulky muscle flaps. So, patients do not need to find custom-sized shoes or have trouble with ambulation anymore. Hypopharyngeal cancer sufferers used to have mechanical and irritant voices with the use of external devices. Now, they have smooth and understandable voices created by intestinal flaps. Lymphedema patients used to be retired in early ages due to recurrent infections and ambulation disability. After vascularized lymph node flaps and lymphaticovenular anastomosis, they are able to turn back their normal routine activities or occupations. Improvements in surgical field commence developments in society with keeping patients strong both psychologically and physically.

31.1 Introduction

In the 1500s, Tagliacozzi described nose reconstruction with pedicled flaps from the arm, and until the 1960s, those same techniques of random pedicled flaps had still been performed for reconstruction. In the 1960s, it was thought that designing a flap based on axial vessels provided great viability to distal component of the flap. This information had led to surgeons for new investigations. In 1963, McGregor described the forehead flap [1]. In 1965, Bakamjian described the deltopectoral flap [2]. In 1967, the first clinical application of operating microscope was used in complete thumb replantation by Konatsu and Tamai [3]. In 1966, the first successful composite tissue transplantation for humans, second toe to thumb transfer, was described by Yang and Gu [4]. In 1972, McLean

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and Buncke harvested free omental flap for cranial defect [5]. In 1973, Daniel and Taylor performed the first free fasciocutaneous groin flap [6]. In the 1970s and 1980s, Mathes and Nahai introduced the concept of muscle and musculocutaneous flaps. The well-described reconstruction options from the head and neck, trunk, and upper and lower extremity illustrated complete algorithm for whole body reconstruction [7]. In 1981, Ponten reintroduced another option for securing a large cutaneous flap that totally omitted a muscle [8]. Afterward, Cormack and Lamberty defined the basic classification for fasciocutaneous flaps [9]. In 1987, Taylor and Palmer shared the concept of "angiosome" or "vascular territory" and also choke vessels [10]. These descriptions opened the era of perforator flaps. Approximately 400 cutaneous perforators have been described so far. After the description of perforator flaps based on major vessels, Wei and Mardini described the freestyle perforator flaps. According to their proposal, any region of the body with an audible, pulsatile Doppler signal can be chosen as a donor site. The flap can be designed and raised in any region of the body that meets the unique requirements of skin color, thickness, texture, and donor site morbidity [11]. Masia et al. proposed to plan and design a DIEP flap based on the distribution of perforators on the multidetector row computed tomography and subsequently with non-contrast magnetic resonance imaging [12, 13].

Recently, Novadaq SPY imaging (Novadaq Technologies, Inc., Bonita Springs, Florida), a fluorescent angiography system that presents basic and efficient intraoperative real-time surface angiographic imaging, has augmented our understanding of the physiology of these flaps. This technology is helpful for evaluating vascular anastomosis and flap perfusion intraoperatively and facilitates surgical decision-making [14]. All of these developments encouraged surgeons to seek other types of reconstructions to present better results both in form and in function and repair the defect with similar type of tissue. Supermicrosurgery, voice reconstruction, lymphedema surgeries, harvesting of intestinal flap using laparoscope, combined chimeric flaps, and composite tissue allografts are also part of advanced microsurgery.

31.2 Perforator Flaps

Advances on the field of reconstructive surgery such as newly developed imagining techniques to demonstrate pedicle-perforator-tissue association, cadaver researches to show detailed flap anatomy or its possible variations, and delicate microsurgical instruments and concerns for more aesthetic appearance in both the recipient and donor sites developed the next frontier in the field of microsurgery which was "perforator flaps—a balance between form and function." The principle of performing perforator flaps is based on the measurement of the particular tissues required for reconstruction and, in retrograde manner, dissection from perforator to main pedicle to provide arc of rotation for use as a pedicled flap or transferring it as a free flap (Table 31.1).

31.2.1 Breast Reconstruction

The development of perforator flaps was initiated with autologous breast reconstruction. Autologous breast reconstruction has undergone continuous development beginning with transverse rectus abdominis (TRAM) flap in 1979 [15]. After that, techniques were developed to carefully dissect the perforating vessels in a retrograde manner through the muscle to preserve function of abdominal musculature. Deep inferior epigastric artery perforator flap (DIEP) was based on the concept of providing natural tissue breast reconstruction with the implied protection of the abdominal wall from surgical damage. Initially, DIEP flap was described for head and neck reconstruction. Afterward, it was popularized for breast reconstruction, and since that time, DIEP has been preffered as the most common approach for breast reconstruction [16]. Yet, in the circumstances of insufficient abdominal tissue for DIEP flap due to low body mass index, poor perforators for DIEP or previously used DIEP alternative reconstruc-

Table 31.1 Overview of perforator flaps according to location

Head and neck region	Upper extremity	Thorax
Transverse cervical artery PF Submental artery PF	Posterior circumflex humeral artery PF Profunda brachii artery PF Brachial artery PF Ulnar artery PF Radial artery PF Posterior interosseous artery PF Anterior interosseous artery PF	Thoracoacromial artery PF Suprascapular artery PF Dorsal scapular artery PF Dorsal intercostal artery PF Lateral intercostal artery PF Anterior intercostal artery PF Subcostal artery PF Circumflex scapular artery PF Thoracodorsal artery PF Internal thoracic (mammary) artery PF Lateral thoracic artery PF Posterior intercostal artery PF Lumbar artery PF Parasacral artery PF
Abdomen	**Pelvis**	**Lower extremity**
Superior epigastric artery PF Superficial inferior epigastric artery PF Deep inferior epigastric artery PF	Deep circumflex iliac artery PF Internal pudendal artery PF Superior gluteal artery PF Inferior gluteal artery gluteus maximus PF	Common femoral artery PF Lateral circumflex femoral artery PF Medial circumflex femoral artery PF Profunda femoris artery PF Superficial femoral artery PF Descending genicular artery PF Popliteal artery PF Medial sural artery PF Lateral sural artery PF Peroneal artery PF Anterior tibial artery PF Posterior tibial artery PF Medial plantar artery PF Lateral plantar artery PF

PF Perforator flap

tion options were sought in the field of microsurgery [17].For instance; Profunda Artery Perforator flap (PAP) due to its hidden scar in donor site or providing bilateral symmetric breasts [17], Transverse Upper Gracilis flap (TUG) due to its hidden scar in donor site [16], Combined PAP-TUG flap; for harvesting bulky tissue especially if the contralateral breast is already C or D cup [18], Superior Gluteal Artery Perforator flap (SGAP) or Inferior Gluteal Artery Perforator flap (IGAP); due to their adequate pedicle length (5–10 cm) and large volume of fat, easily hidden scar under the short pants [19], Superficial Inferior Epigastric Artery Flap (SIEA); especially in the circumstance of poor DIEP perforators have been considering different options for breast reconstruction [16]. Instead of total mastectomies, breast-conserving surgeries have been performed with additional chemoradiotherapy. After this type of surgery, patients usually have lateral site of partial breast defects. To cover the excised area, lateral intercostal artery perforator flap or thoracodorsal artery perforator flaps have been used as applicable choices [20, 21].

Key Point
Unlike other reconstructive procedures, cosmetic results are important for patients with breast cancer treatment due to close association between femininity.

31.2.2 Head and Neck Reconstruction

Thoracodorsal artery perforator flap offers wider arc of rotation for locoregional coverage of the defects of the upper extremity, shoulder, neck, axilla, and chest [22].

The anterolateral thigh flap is a workhorse flap in reconstructive surgery as a pedicled or free flap to cover wounds all over the body [22]. Posterolateral thigh flap is an alternative free flap for ALT flap to cover head and neck defects.

31.2.3 Perineum Reconstruction

As a result of trauma, decubitus ulcer, or spine surgery, which can cause lumbal defects, these defects can be reconstructed with lumbar artery perforator flaps [22].

Profunda artery perforator flap is a reliable option for regional coverage of pressure sores and vulva and perineal reconstruction and also can be considered as a free flap for coverage of the lower extremity or breast reconstruction [22]. Moreover, it can be combined with transverse upper gracilis flap (PAP-TUG) for obliterating the fistulas of perineal defects as pedicled design [18].

Superficial femoral artery perforator flap not only offers robust blood supply but also provides wide locoregional tissue for coverage of wide leg defect related to soft tissue tumors or traumas [22].

31.2.4 Lower Extremity Reconstruction

The defects of pretibial, malleolar, over the Achilles' tendon, ankle, and anterior knee regions can be covered with lower extremity perforator flap such as pedicled anterior tibial artery perforator flap, medial sural artery perforator flap, posterior tibial artery perforator flap, and peroneal artery perforator flap [22] (Fig. 31.1a–e).

31.2.5 Trunk Reconstruction

The ALT flap can be combined with tensor fascia lata and vastus lateralis musculocutaneous flaps based on lateral circumflex femoral artery pedicle for locoregional abdominal wall reconstruction [23].

Following burns, facial scarring, contractures, congenital nevi, vascular tumors in children, and scalp defects, pre-expanded perforator flaps can be designed as a pedicled or free flap [22].

Tips and Tricks

Pedicle propeller design perforator flaps overcome the main obstacle of length-to-width ratio on the restriction of local flaps. Their applicability have been expanded to reconstructions of the head and neck, upper extremity, lower extremity, trunk, and perineum [22, 24].

31.2.6 Freestyle Perforator Flaps

Recently, a new concept, "freestyle perforator flaps," has been well recognized and successfully performed especially for patients with diabetes and previously irradiated or traumatized extremities where it is hard to find a reliable recipient vessel as a source of pedicle with proper flow. Freestyle flaps can be harvested as pedicled or free flaps and can be composed of different tissue types. Once a perforator is identified, it can be dissected from distal to proximal to exclude any anatomical inconsistency. Identifying the perforators are essential, and they can be easily detected by a simple handheld Doppler ultrasound probe.

Tips and Tricks

The location of the perforator near the defect is identified and using this as a recipient vessel eliminates the need to expose any major vessels, thus decreasing the risk for injury and postoperative swelling of the leg [25].

One of the main drawbacks of harvesting perforator flaps is their inconstant anatomy of the pedicle or perforator [26].

Identification of exact location of dominant perforators using handheld Doppler or imaging modalities (multidetector row computer tomography) is beneficial in placement and design of flaps to incorporate vascular territories of dominant perforators [27].

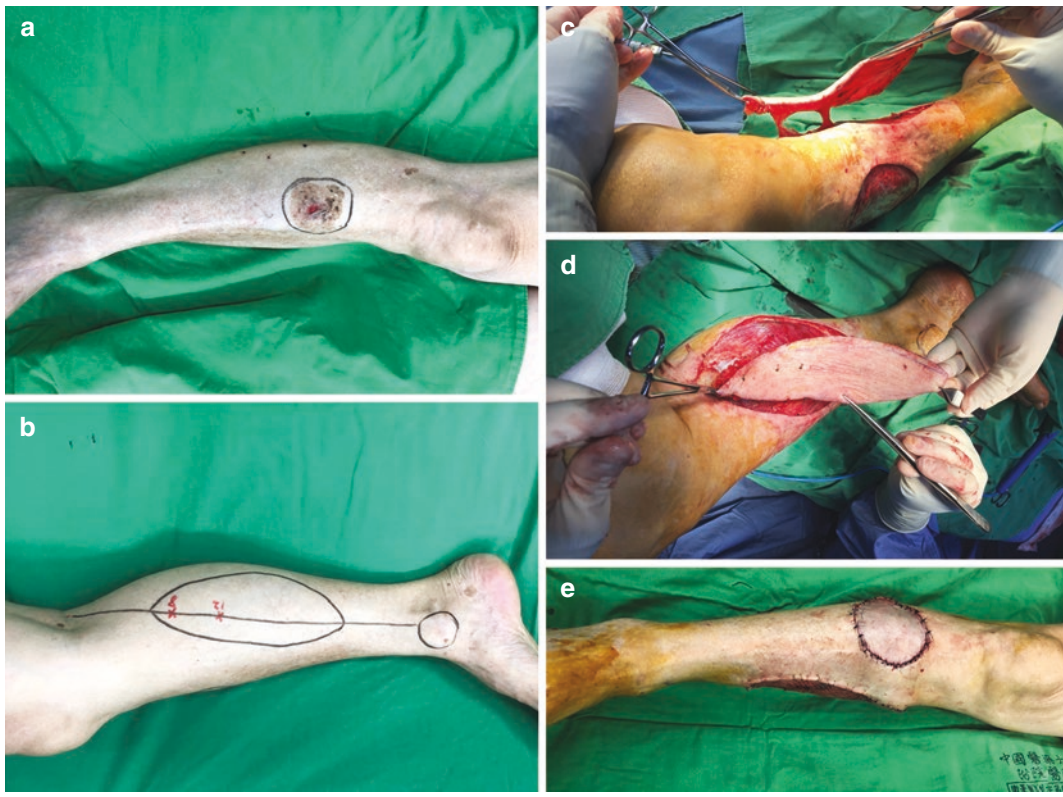

Fig. 31.1 (**a**) Patient was referred by dermatologist due to suspicious premalign hyperpigmente lesion on the pretibial reion. Previous pathology report had excluded the malignant melanoma and squamous cell carcinoma. (**b**) Perforators was founded the line between posterior edge of lateral malleolus and midpopliteal fossa. Usually perforators start proximally 6–8 cm below this line from the superior edge. (**c**) MSAP flap was harvested based on two perforators. (**d**) Rotation of flap can be seen. (**e**) Closure of the wound

31.2.7 Supermicrosurgery

The concept of supermicrosurgery was initially determined by Koshima et al. that it was feasible to raise flaps based on perforator vessels with a caliber of less than 0.8 mm and perform safe anastomosis of these vessels to reconstruct soft tissue defects in different areas of the body [28]. After initial description it has been extended to "technique of microneurovascular anastomosis for smaller vessels and a single nerve fascicle, and also microneurovascular dissection for these small vessels less than 0.3–0.8 mm [29]. Day by day, this technique has gained popularity, and required ultra-delicate devices, special instruments, and microsutures have been developed. Due to supermicrosurgical innovative technology, distal interphalangeal replantations, super thin perforator flaps, toe-tip or vascularized toenail transfers, partial auricular flap or concha flap for eyelid and tracheal loss reconstruction, vascularized nerve grafts, lymphaticovenular anastomosis for lymphedema, and vascularized appendix transfer for penile urethral loss have been performed [28, 29] (Fig. 31.2a–c).

Key Points

Nowadays, this concept has been redefined as the perforator-to-perforator anastomosis. If the pedicle of the flap is short or recipient vessels lie too deep to perform anastomosis, then supermicrosurgical techniques can be applied to overcome these obstacles. When the perforator or an end vessel has a strong pulse, it can be checked with intraoperative handheld Doppler or with the use of a microscope and can be used as a recipient vessel. Preoperatively computed tomography angiography (CTA) can be obtained for perforator mapping [18].

31.2.8 Combined Flaps (Conjoined Flaps, Composite Flaps, Chimeric Flaps)

Despite the general applications of workhorse flaps in reconstructive microsurgery, the research continues for alternative, reliable, and safe donor sites with consistent anatomy and low morbidity to offer three-dimensional reconstruction. The major advantages of combined flaps are several. First, their reliable dual blood supply provides watershed areas at the edge of each angiosome. This robust perfusion from one flap to other one is contributed by choke vessels. Second, their proposed multistructural tissue reconstruction is achieved in one stage [18].

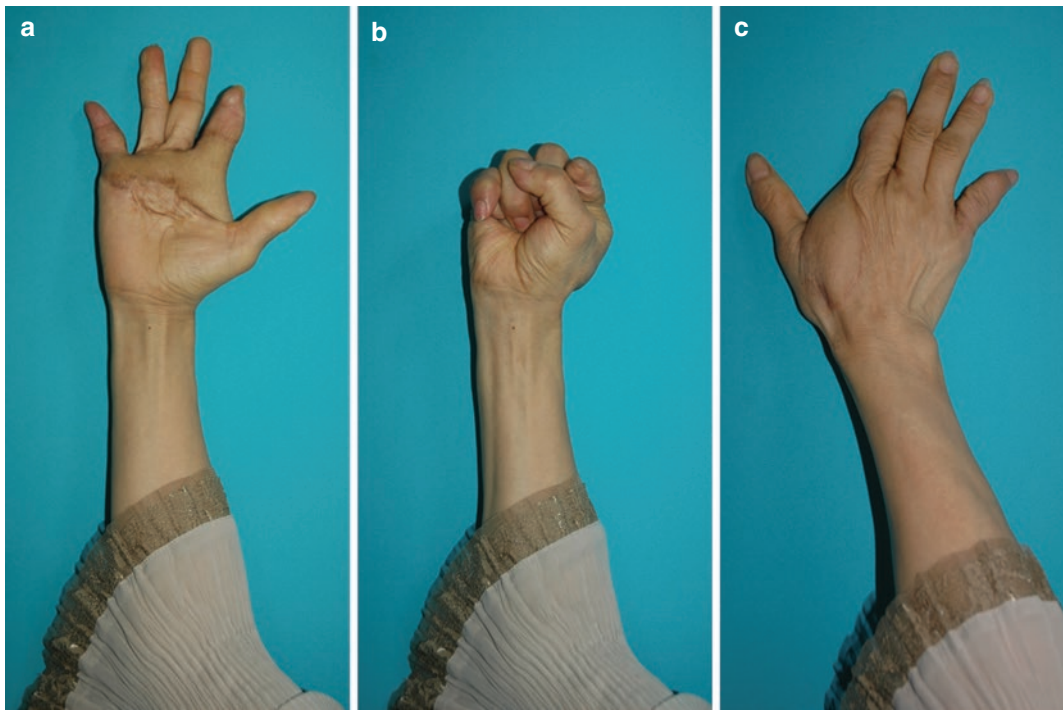

Fig. 31.2 (**a**) SCIP flap (superficial circumflex iliac perforator flap) can provide a very thin coverage for the hand, fingers, and other places such as around the ankle which need thin flap for reconstruction. This was the SCIP flap for coverage of right palm, fingers, and thenar web. The picture showed that the fingers could extend fully. (**b**) The fingers could flex fully with the thin flap. (**c**) This was the dorsal view of the right hand

31.2.8.1 Conjoined Flaps

Conjoined flaps are a combination of at least two anatomically distinct territories, each having its own independent vascular supply yet joined with some common physical boundaries [30]. For instance, as an alternative approach for upper extremity tumor resections until the forearm level including regional lymphadenectomy, supercharged latissimus dorsi-groin conjoined flap can be considered. The vascularized lymph nodes can be harvested in the groin flap, and superficial circumflex iliac artery can be used as a pedicle. Functional muscle transfer can be handled with pedicled latissimus dorsi musculocutaneous part [31]. This combination can also be a useful reconstruction of wide anterior chest wall defects with provision of bulky fat-muscle and skin components to obliterate the defect [32].

31.2.8.2 Combined Flaps

Several defects located in the upper extremity, lower extremity, mandible, maxilla, orbita, or scalp might require a combination of skin, muscle, nerve, or bone components for proper reconstruction which are derived from different embryologic structures. These types of extensive composite defects cannot be covered with local muscle flaps or bone grafts. Due to increased scar tissue formation and lack of available healthy recipient vessels, composite flaps should be considered as the first line instead of two-stage approaches [33]. For instance, fibula osteoseptocutaneous or osteoseptomusculocutaneous flap is the first choice for composite flap which contains the bone, skin, and muscle. This flap provides almost 22–26 cm of bone in adults, reconstructs the defects from angle to angle, has reliable blood supply after several osteotomies, carries reliable bone stock for osteointegrated dental implants, possesses not only broad and long pedicle but also thin and pliable skin paddle which can be easily manipulated to fill the defects on both intra and extraoral sites, and also can be carry with extra muscle for additional soft tissue deficiency, use as a flow through free flap which improves its blood supply and also act as vascular runoff for required second free flap, provides two team approach while harvesting the flap due to its location and has acceptable donor site [34, 35].

31.2.8.3 Chimeric Flaps

Chimeric flaps allow simultaneous transfer of multiple varied tissue components from a single donor site with extended length of movement for reconstruction [30].

For instance, chimeric latissimus dorsi (LD) or thoracodorsal artery perforator flap with rib is a reliable combination. In this approach, one or two ribs can be harvested with partial serratus anterior muscle (SA) based on serratus branch and pure skin or skin and muscle component can be added with either TDAP flap or latissimus dorsi musculocutaneous flap based on thoracodorsal vessels. The large caliber of vessels without involving any peripheral artery disease ensures its robust blood supply. Furthermore, the significant donor site commonly is not encountered neither in a functional nor aesthetic way [33]. The LD/TDAP-SA/rib flap remains one of the best indications in reconstruction of metatarsal bones, previously failed or recurrent head and neck reconstructions with mandible defect in either free or pedicled way, hemifacial microsomias with temperomandibular joint hypoplasia, upper extremity pathologies with soft tissue deficit such as: humerus, ulna, radius, metacarp, and calvarial reconstructions [33, 36] (Fig. 31.3a–f).

31.2.9 Endoscopic Approaches

The endoscopic approach has been gaining wide acceptance in the field of reconstructive plastic surgery, and the advantages of laparoscopic surgery have been acknowledged [37].

When only muscle tissue is sufficient to meet the reconstructive requirements in order to avoid long scars on the back, abdomen, or leg, the endoscopic approach can be considered the first choice. The methods of harvesting muscle flaps with the endoscope-assisted approach with or without the assistance of a balloon dissection device have been described and can be considered as reliable and applicable in several aspects [38, 39]. First, the dissection plane is easily identified, and the areolar plane helps secure the pedicle or muscle perforators. Second, pedicles lie around the fat tissue

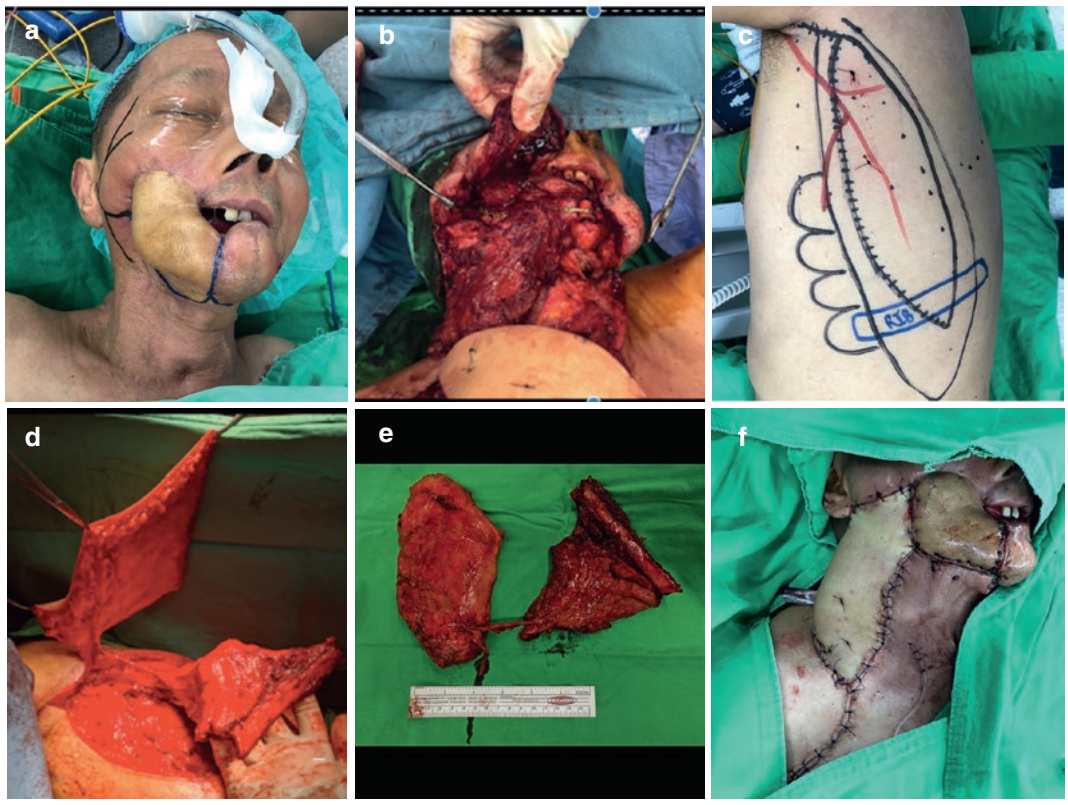

Fig. 31.3 (**a**) Patient had been treated by free fibula flap for buccal cancer. Following radiotheraphy, patient had osteoradionecrosis, shrinkage on the flap skin, and drooling. (**b**) After excision of the necrotic bone and release of contraction deltoid branch of thoracoacromial artery and vein were prepared for anastomoses. (**c**) Drawing and surgical plan of TDAP-serratus flap with eighth rib. (**d**) The chimeric flap was harvested. The rib was attached to the serratus anterior muscle and split of muscle harvested due to avoid of winging scapula. (**e**) Flap was on the table. TDAP perforator and serratus branch accompanied to thoracodorsal artery and vein. (**f**) Inset of flap. Neck contracture was also broken with extra soft tissue

either below the muscle or located in the intermuscular septum. Third, their pedicles are usually located vertically as a straight line compared to transversally located mesenteric pedicles that are also surrounded by highly rich vascular arcades. Fourth, in the balloon-assisted approach, inflating the balloon provides an easily blind dissection of the posterior muscle sheath, from the adjacent muscle above in the loose areolar plane [38, 40].

Recently, free or pedicled jejunum, sigmoid colon, omentum, or ileocolon flaps have been described for reconstruction of esophagus, sternum, voice or vagina [41, 42].

Pearls and Pitfalls

Laparoscopy creates minimal distortion to the abdominal cavity with less expected postoperative analgesic usage. Also, it prevents scarring with the suprapubic region [43] or prevents the use of long-term analgesics and bed confinement.

Yet, the complications of mesenteric hematoma [41], conversion to laparotomy [41, 44], cardiovascular problems [44], pedicle injury, and hernia in donor site have been questioned in the applicability of har-

vesting intestinal free flaps laparoscopically. Therefore, harvesting intestinal flaps using laparoscopy has not been acknowledged as much as harvesting muscle flaps laparoscopically.

31.3 Diversion Loop for Reconstruction of Upper Esophagus in the Case of Epiglottis Injury

During swallowing, an obligatory breath occurs at the end of each swallow. The laryngeal vestibule is secured by laryngeal elevation and closure of the epiglottis over the glottis. Therefore, oral intake shunts into pyriform sinuses and then into the esophagus. As a result of caustic injury, impaired pharyngeal contractility or poor pharyngolaryngeal sensation can cause accumulation of saliva and food in the vallecula and pyriform sinus. Damage of epiglottis can lead to continuous aspiration, choking, or lack of voice production in the long term [45, 46].

A diversionary loop technique offers to separate the airway from the food passage. After harvesting of free jejunum flap, its upper end is attached to the oral vestibule, and its lower end is anastamosed to the thoracic esophagus. Using this technique, each swallow is escaped from damaged epiglottis to prevent choking (Fig. 31.4a–d).

Key Points

The mechanism of food transit of this new pathway is based on gravity, action of cheek muscles, and peristalsis of jejunum. This method allows patients to continue oral intake without a feeding tube and not only reduces the risk of choking and aspiration but also improves their voice production.

31.4 Voice Reconstruction with Intestinal Flaps

Sound production arises from the larynx as a fundamental tone which is adjusted with actions of the tongue, lips, palate, pharynx, teeth, and related structures for converting sound to speech. After total laryngectomy, patients struggle with the catastrophic predicament of the lack of mechanism for voice production.

The voice can be created via fistula between the posterior wall of the trachea and the anterior wall of the esophagus. Tracheoesophageal prosthesis is a small, silicone-valve device and is inserted into a surgically created tracheoesophageal fistula. Even though it requires minimal training for use, its disadvantages such as high cost and possibility of prosthesis dislocation, aspiration, and tracheal stenoses have interrogated its reliability. Recently, free ileocolon flap and free appendix flap have been gaining popularity for voice reconstruction.

The colon provides perfect size match with the oropharynx; if the defect starts from the oropharynx, then an ileocolon flap can be used for reconstruction of the pharynx and cervical esophagus with ascending colon segment, and voice tube can be created with a segment of the ileum. Ileocecal valve acts as a one-way valve to prevent regurgitation of food into the voice tube [47] (Fig. 31.5).

In patients who lack voice only, the ileocecal valve flap with a small patch of cecum or appendix flap can be used as a voice prosthesis substitute. Both of them are conduits which convey air from the trachea to the pharynx and produce phonation with the patient's own characteristic voice [47].

Key Points

When the patient needs to speak, tracheostoma can be occluded with a thumb or finger so that the air is captured from the trachea into the voice tube, through the one-way ileocecal valve to the neopharynx (the colon) and then into the pharynx and eventually the mouth for articulation.

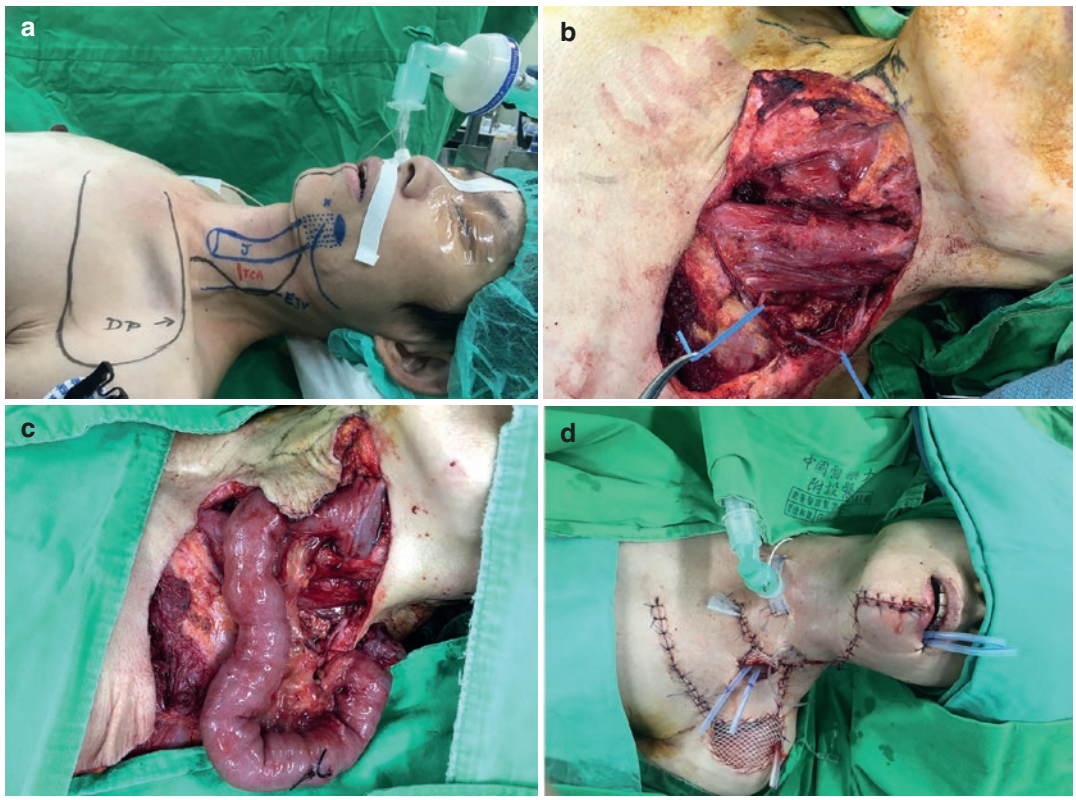

Fig. 31.4 (**a**) 38-year-old woman in an outpatient clinic due to choking and decreased oral intake ability following caustic injury. Diversionary loop with free jejunum flap was planned. External jugular vein (EJV) and TCA (transverse cervical artery) were prepared as recipient vessels. (**b**) External jugular vein (EJV) and TCA (transverse cervical artery) were dissected off meticulously. (**c**) Superior edge of jejunum flap was planned to inset gingivobuccal sulcus, and distal end of flap was planned to left neck temporarily for observation. (**d**) After the inset, two nasogastric tubes were inserted into jejunal lumen temporarily to keep passage open, deltopectoral flap was harvested for covering both flap and anastomoses, and split-thickness skin graft covered the donor site

31.5 Lymphedema Treatment

Improvements in microsurgery and supermicrosurgery have had major impacts on the treatment of lymphedema. The combination of lymphatic bypass-lymphaticovenular bypass-anastomosis (LVA) and vascularized lymph node transfers has been performed to restore lymphatic flow.

Vascularized lymph adipose flap including autologous lymph nodes can be harvested using small perforator vessels as a recipient. Superficial circumflex iliac artery flap, gastroomental flap, supraclavicular artery perforator flap, and submental artery perforator flap contain lymph nodes and are used as vascularized lymph node flaps.

LVA can be performed by anastomosis between the subdermal venous plexus and distal lymphatic vessels. The rationale of this bypass relies on two different mechanisms. First, distal lymphatic vessels are less affected by lymphedema, and this makes them available for bypass. Second, the venous pressure is lower in subdermal venules, and thus less venous backflow is predicted with more permanent improvement [15].

Key Points

The lymphatic vessels can be dyed by patent blue or can be traced with indocyanine green fluorescence lymphangiography that enables surgeons to locate and make inci-

sions precisely over the functional lymphatics. LVA has been well performed in patients with early-stage lymphedema under less fibrosis tissue formation (Fig. 31.6a–f).

Tips and Tricks
LVA has been performed in early-stage lymphedema patients as a prophylactic procedure under local anesthesia. The recommended number for proper treatment is at least five LVA in each affected extremity [28, 29].

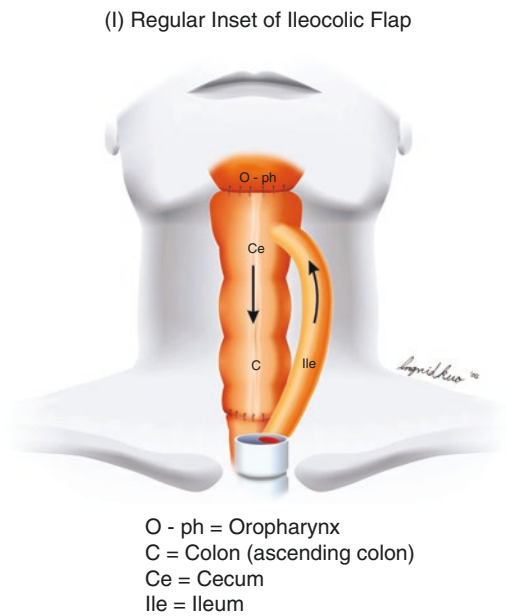

Fig. 31.5 After total pharyngolaryngectomy, a segment of ileocolon flap can harvested from the ileocecal region. It can be transferred to the neck with colon segment for reconstruction of the pharynx and cervical esophagus, and the ileum segment is used as a voice tube. When the patient wants to speak, he can use his thumb or index to occlude the tracheostome so that the air in the lung can be driven through the ileum segment and ileocecal valve into the pharynx to produce voice. With the articulation of the tongue and oral floor, the patient can speak

31.6 Lymphatic Cable Flap for Chyloperitoneum

After the thrilled outcomes with vascularized lymph node transfer in treating lymphedema, proposed surgical treatment for intractable chyloperitoneum was described by using deep inferior epigastric artery (DIEA) and deep inferior epigastric vein (DIEV), with surrounding fat and lymphatic tissue. This LCFT (lymphatic cable flap transfer) offers an extraperitoneal bypass of the diseased intra-abdominal lymphatics and physiologically drains the chylous acid through an extraperitoneal route in order to bypass the obstructed intra-abdominal lymphatic system [48].

31.7 Composite Tissue Transplantation

In 1954, the first successful human transplant, kidney transplant, was performed by a plastic surgeon. After this pioneer performance, Dr. Joseph Murray was rewarded with a Nobel Prize in Physiology or Medicine in 1990. Since then, combining success in replantation and advances in the field of microsurgery brought about the possibilty of composite tissue transplantations (CTA). Various complex structures ambriologically derived from different layers which can combine with nerve, bone, muscle, skin, mucosa, and adnexial extensions can be transplanted simultaneously while performing CTA.

The first successful human hand transplantation was done in 1998 by Dubernard et al. in France [49]. In 2005, Dubernard et al. performed the first human partial facial transplantation. Since than, more than 30 patients have been reported with partial to full face transplantation including the bone and mucosa to provide craniofacial restoration [15].

Especially for facial transplantation, three-dimensional computer modelling has become a mandatory part in planning to perform proper

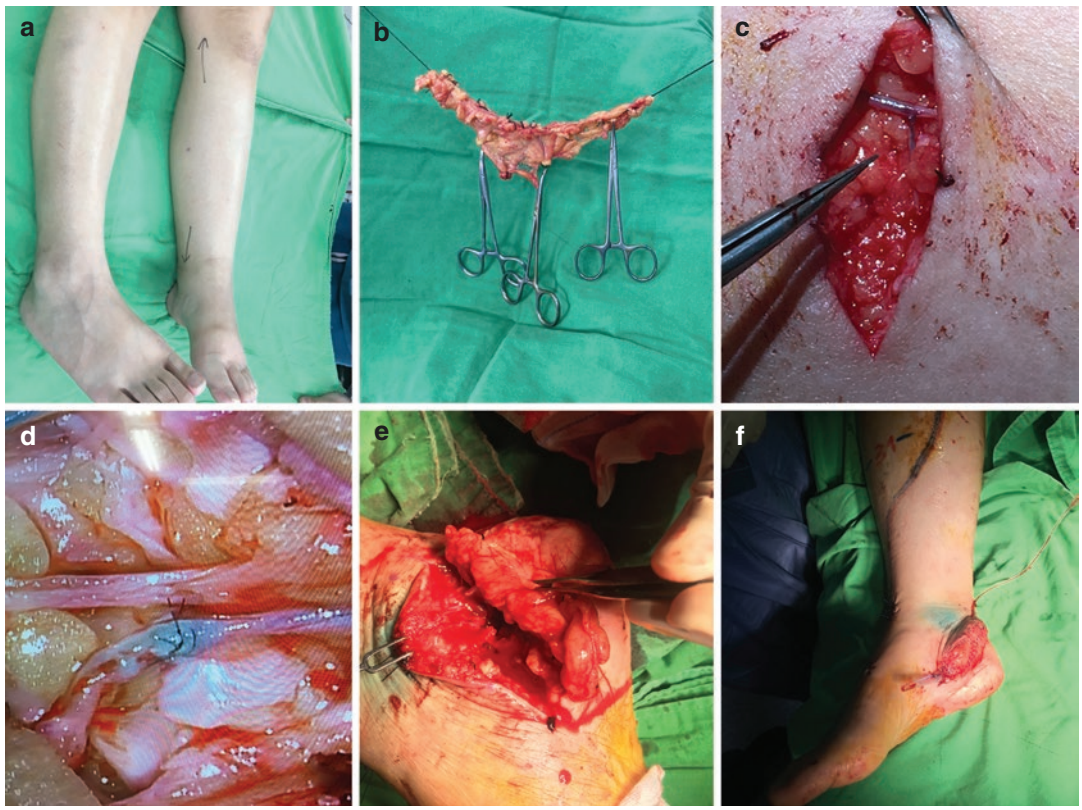

Fig. 31.6 (**a**) Patient had been suffering grade 3 lymphedema following treatment of cervical carcinoma. Recurrent cellulitis, leg discrepancy, difficulty of walking, and aesthetic concerns were the main complaints. (**b**) Right gastroepiploic artery-based lymph node flap (omentum) was harvested endoscopically by the general surgeons. It was stored in ice for 3–4 h to get sufficient time for lymphaticovenular anastomoses. (**c**) After the Patent blue injection the blue dyed lymphatic vessel anastomosed to superficial vein in side-to-end manner. (**d**) Another blue dyed lymphatic anastomosed to superficial vein in an end-to-end manner. Lymphaticovenular anastomosis which is performed to improve the lymphatic flow from lymphatic system to the venous system. It is indicated for mild cases of lymphedema in the extremity. (**e**) The gastro-omental flap divided in two pieces. 40% of the flap was placed in the ankle. Medial plantar artery and vein were used for anastomoses. 60% of the flap was attached to the popliteal region. The medial sural artery and vein were used for anastomoses. (**f**) The inset of flap in the ankle region. Some parts of flap were covered with split-thickness skin graft

osteotomies and to reduce ischemia time [50]. Nowadays, different centers worldwide have been reporting successful results for unilateral or bilateral hand-forearm, lower extremity, abdominal wall, uterus, larynx, and face transplantations. Unlike solid organ transplantations which are performed for life-threating pathologies, these reported composite tissue tranplantations have been performed to improve quality of life, to overcome functional disabilities, or to increase chances of fertility [15].

Pearls and Pitfalls

Immunosuppressant drugs broadly suppress the immune system, and they are associated with opportunistic infections, risk of neoplastic formation, and vital end organ toxicities. Due to these side effects, medical ethics of composite allotransplantation have been questioned by the authorities to ensure its necessity for life or its worthiness to face with these problems.

Therefore, researchers keep going to develop better immunosuppressive regimens not only for reducing these side effects but also for improving their efficacy in decreasing the rejection rates.

Take-Home Messages

Decreased donor site morbidity is first and foremost advantage of using perforator flaps [26].

Having intraoperative handheld Doppler is useful to ensure viability of flap. Moreover, infrared scanning laser-assisted indocyanine green fluorescent dye angiography is considered more feasible to determine perforator [12].

The key principle of handling successful design of freestyle perforators is being familiar with location of dominant perforators around the body, starting with basic knowledge from traditional workhorse flaps used in microsurgery [22].

Natural secretions and spontaneous peristalsis of the intestinal flap equip it with a self-cleansing capacity and prevent obstruction of the voice tube [47].

Offering surgical approaches described above are demanding and requiring experienced surgical team or long time to be get experienced.

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Transplant and Plastic Surgery

32

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Background

Vascularized composite allotransplantation (VCA) is an innovative field of plastic surgery that relies upon both advances in microsurgery and immunosuppression. VCA procedures offer patients who have exhausted traditional reconstructive options the ability to reintegrate into society and regain function. The path to successful VCA stretches back to the fourth century, when hand transplant was first postulated as a means to aid trauma victims [1]. Since the first successful hand transplant was performed in 1998, the VCA field has expanded immensely and now includes a variety of transplanted tissue types, including face, uterine, penile, abdominal wall, and laryngeal transplants [2]. The intersection of reconstructive surgery and transplantation leads to unique challenges, including the risk and benefit of obligatory lifelong immunosuppression for non-life-saving surgeries. Furthermore, functional outcomes rely upon nerve regeneration into transplanted tissue. Furthermore, ethical and practical concerns still abound as the field of VCA grows. This chapter provides a broad overview for the plastic surgeon of the current state of the VCA field and the challenges that this new frontier faces.

32.1 Introduction

Vascularized composite allotransplantation (VCA) is an innovative frontier in plastic surgery, offering patients who have exhausted the traditional armamentarium of reconstructive techniques an opportunity for both functional and aesthetic restoration [3]. VCA transplants are unique in that, unlike solid-organ transplants, they are comprised of a large spectrum of tissue types, including skin, subcutaneous fat, muscle, bone, cartilage, supporting ligaments, nerves, and tendons, and combine the complexity of microsurgery with post-transplant immunosuppression management. VCA is an emerging area in reconstructive surgery that may be a viable option for patients with extensive and devastating

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injuries. Advances in reconstructive microsurgery and transplantation immunology have permitted many successful transplants, including abdominal wall, hands, face, larynx, peripheral nerves, and vascularized tendons. However, different tissues in VCAs have varying antigenicities, and the risks of obligatory lifelong immunosuppression remain a major challenge. In addition to the complications of immunosuppression such as increased incidence of opportunistic infection, malignancy, and end-organ toxicity, chronic rejection often negates favorable long-term results.

The pathway to successful VCA has relied upon advances in both microsurgical reconstruction and immunosuppression. Jacobson and Suarez published the first successful microsurgical vessel anastomosis in 1960, leading to the ability to perform complex free-flap surgeries, ultimately used also in VCA [4]. In parallel, advances in solid-organ transplantation established the foundation for the immunosuppression necessary in VCA. Joseph Murray's first kidney transplant between identical twins in 1954 demonstrated the surgical feasibility of solid-organ transplant [5]. The late 1950s saw the publication of seminal papers in immunology, which demonstrated the potential to induce functional tolerance of solid organs through chemical immunosuppression [6, 7]. This research ultimately led to the introduction of clinically used immunosuppression, such as azathioprine in 1961. The early 1980s saw a significant improvement in immunosuppressant medication with the introduction of the first calcineurin inhibitor—cyclosporin [8]. These advances were crucial to the implementation of VCA.

The importance of advancing immunosuppression protocols was demonstrated by the first published hand transplant performed in Ecuador by Robert Gilbert in 1964 [9]. The patient was placed on the limited immunosuppression available at that time consisting of corticosteroids, azathioprine (Imuran), and a single dose of radiation. This transplant was rejected within 2 weeks from transplant. It did, however, demonstrate that the technical aspects of the procedure could be performed. Subsequent animal studies led to the first successful hind limb transplant in pigs with an updated immunosuppressive therapy of cyclosporin, mycophenolate mofetil, and prednisone [10]. Furthermore, the introduction of FK 506 (tacrolimus) in solid-organ transplant in the 1990s led to a more potent immunosuppressive regimen [11]. These more potent immunosuppressants allowed for the first successful hand transplant to be performed in 1998 by Jean-Michel Dubernard in France [12].

Key Point
The success of VCA has immensely relied upon advances in immunosuppression protocols, leading to current protocols that have enabled composite allotransplantation with long-term success.

Since the first hand transplant, the field of VCA has evolved immensely. The first partial face transplant was performed in 2005, also in France, leading to new possibilities for patients with complex facial deformities [13]. The field of VCA has further evolved and now encapsulates a variety of transplants, including penile, uterus, abdominal wall, and laryngeal transplants, all described in this chapter [2].

Although VCA has many similarities to solid-organ transplantation, the challenges that VCA faces are unique. VCAs may be crucial to social integration and improve the ability of self-care, but they are not life-saving and thus shift the risk-benefit calculations for lifelong immunosuppression and its accompanying complications. Furthermore, the success of VCA is contingent on functional outcomes, which, in most cases, is dependent on successful nerve regeneration.

32.2 Hand Transplant

Humans postulated about limb transplantation as far back as the fourth century [1]. The first hand transplant, however, was performed in Lyon, France, in 1998 and the second in 1999 in Louisville, Kentucky, USA [12, 14]. Since these

initial hand transplants, over 120 additional transplants have been performed. Transplants have occurred in geographically desperate locations covering North America, Latin America, Europe, Asia, and Australia.

The technical aspects of hand transplant greatly mirror that of hand replantation surgery. However, there are notable differences. First, in hand replantation, tissue availability is largely outside the surgeon's control. This includes the availability of soft tissue, which is often missing from the initial injury. Furthermore, in hand replantation, forearm length is sometimes shortened to account for the loss of missing bone and to allow primary vascular anastomosis (without the need for vein grafts), primary nerve repair (without the need for nerve grafts), and primary tendons repair (without the need for tendon grafts). In contrast, in VCA, there is greater control over final arm length, since the donor and recipient forearm osteotomies can be carefully planned and precisely executed to match original length. Finally, flexor and extensor tendon tension can be reestablished to optimize functional outcomes [15].

The surgical procedure involves bony fixation, vessel anastomosis (of the radial or ulnar artery and one or two veins), nerve coaptation (median, ulnar, and radial, as well as some more distal branches depending on the level of injuries including the palmar cutaneous branch of the median nerve and the dorsal ulnar sensory nerve), and reapproximation and repair of flexor and extensor tendons.

Key Point
In many respects, the technical aspects of hand transplantation surgery mirror those of hand replantation. However, there is greater control over final arm length since the donor and recipient forearm osteotomies can be planned.

Over 75% of patients have reported improved quality of life following hand transplantation [16]. Disabilities of the arm, shoulder, and hand (DASH) scores of 72 published hand transplants at 1 year post-transplant were an average of 38, and at 10 years post-transplant an average of 16, demonstrating quantitative functional improvement [17, 18]. Most patients reported enough motor function to perform acts of daily living (Fig. 32.1).

32.3 Face Transplant

Face transplantation is an innovative procedure for patients with facial deformities who have exhausted traditional reconstructive options. Over 40 facial transplants have been performed worldwide for defects from a variety of etiologies, including ballistic injuries, animal attacks, severe burns, and advanced neurofibromatosis type 1 [19].

Transplants have included both soft tissue and underlying bones, including the maxilla and mandible [9, 13] (Fig. 32.2). Motor function is restored by performing a neurorrhaphy between the donor and recipient's facial nerve, either distally at the level of the facial nerve branches (to prevent potential synkinesis from aberrant regeneration) or proximally at the level of the facial nerve trunk. Depending on the type of the transplantation, coaptation of the infraorbital and inferior alveolar nerves is performed to aid in sensory restoration. The difference in synkinesis between proximal and distal coaptation has not been thoroughly evaluated. Our group prefers distal facial nerve coaptation to minimize the theoretical chance of aberrant reinnervation, and, hence, minimize the chance of synkinesis, and to hasten functional recovery given the short distance the nerve fibers need to regenerate to reach the target muscles.

Key Point
Distal nerve coaptation in face transplant, minimizing the length of regeneration necessary into donor tissue, may quicken functional recovery as well as minimize synkinesis.

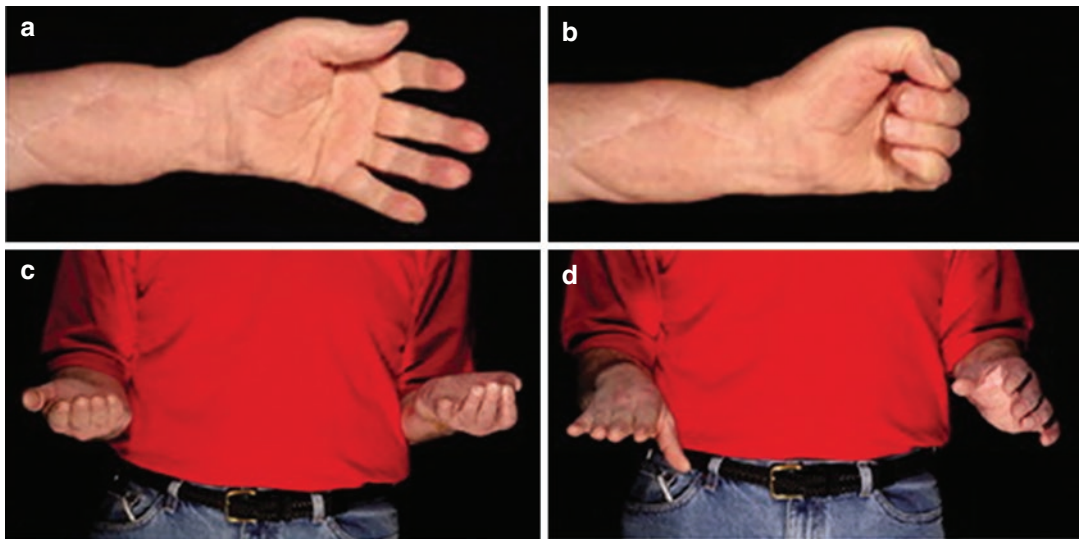

Fig. 32.1 The recipient of the first US hand transplant demonstrates functional results 5 years post-surgery: (**a**) extension, (**b**) flexion, (**c**) supination, and (**d**) pronation (Kvernmo, H. D., Gorantla, V. S., Gonzalez, R. N., & Breidenbach III, W. C. (2005). Hand transplantation: A future clinical option? *Acta Orthopaedica*, *76*(1), 14–27)

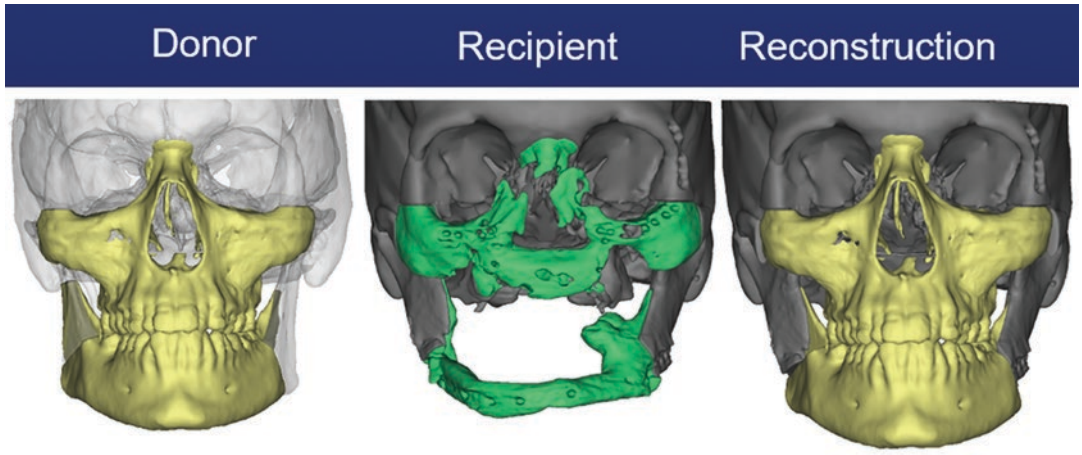

Fig. 32.2 In the case performed at Mayo Clinic, the recipient's extensive defect is demonstrated in the middle. Virtual surgical planning enabled preoperative decision-making in planning osteotomies and an ideal reconstruction (©SamirMardini 2021. All Rights Reserved)

Vessel anastomosis choice in face transplant is also largely dependent upon the tissues transplanted and the defect to be reconstructed [20]. For most parts of the face, the facial vessels can be used. Venous outflow can be established via the common facial vein. The facial vein is often sufficient to drain the face. If it is feasible to include the internal maxillary to provide better blood supply to the maxilla, this is also an option. To include the entire scalp, the posterior occipital should also be included. Although outcomes in face transplant are not standardized, systematic reviews have demonstrated that facial transplantation leads to an improved quality of life and functional outcomes in almost all reported cases [21]. For example, sensory improvement occurred

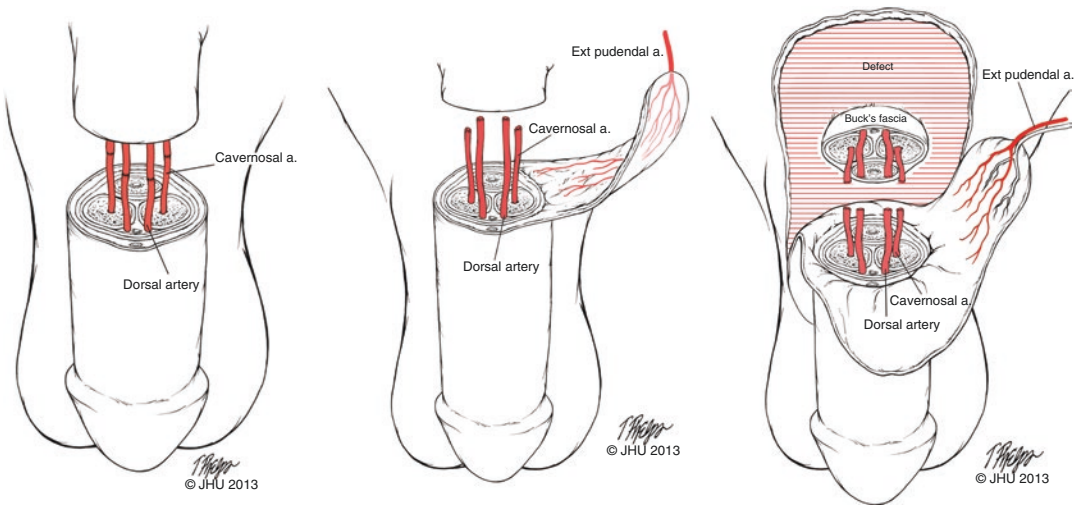

Fig. 32.3 The vascular anatomy and anastomoses performed in penile transplant (Tuffaha, S., Sacks, J., Shores, J., Brandacher, G., Lee, W. A., Cooney, D., & Redett, R. (2014). Technical Approach to Penile Transplantation. *Vascularized Composite Allotransplantation*, *1*(1, 2), 69–70)

between 3 and 8 weeks post-transplant [22]. Improvement in breathing, speaking, and facial movement was enhanced in 93, 71, and 76% of published cases, respectively. Motor recovery occurred for most patients between 6 and 18 months. Despite the need for more standardized outcomes measurements, it is clear that facial transplantation has restored many of the recipients' abilities to integrate into society as well as led to immense functional improvement, including decannulation and removal of feeding tubes in most cases in which they were initially present.

32.4 Penile Transplant

Penile transplants provide the opportunity to restore urogenital function. The first penile transplant was performed in 2006 in Guangzhou General Hospital in China [23]. This transplant was successful surgically, but the patient requested it removed 14 days following surgery due to psychological concerns. This emphasizes the need for extensive presurgical recipient screening and counselling in VCA.

Penile transplant requires collaboration with a urologist to restore urogenital integrity. In the first reported case, the urethral mucosa of donor and recipient was re-approximated, as was the corpora spongiosum and the tunica albuginea [24]. Anastomoses included the superficial and deep dorsal veins and the dorsal penile artery and nerve. The first successful long-term penile transplant was performed in South Africa in 2014 due to complications from a circumcision. Due to fibrosis of the dorsal penile artery, the inferior epigastric and superficial external pudendal arteries were used [25]. To date, two other penile transplants have been performed successfully (Fig. 32.3).

32.5 Uterine Transplant

Uterine transplantation is a surgical option for women who present with absolute uterine factor infertility due to congenital Müllerian anomalies such as uterine agenesis or malformation, a surgically removed uterus or another acquired condition of the uterus (such as intrauterine adhesions) leading to implantation failure [26].

In uterus transplantation, the vascular pedicle of the internal iliac artery and vein of the donor are anastomosed with the external iliac artery and vein of the recipient [27]. Alternatively, the great

saphenous vein has been utilized as a graft to anastomose the short ends of the uterine vessels of the transplant to the recipient's external iliac vessels. The donor and recipient vaginas are then anastomosed. In cases of congenital uterine agenesis, the creation of a neovaginal vault prior to surgery is necessary.

The first live birth following uterus transplantation occurred in 2014 in Sweden reported by Brännström [28]. More than 60 uterine transplants have been performed, with 18 live births currently reported [29]. The majority of these cases reported return of menstruation within the first 3 months after surgery. All infants born following uterine transplants had normal Apgar scores at 10 min. A systematic review (22 studies and 3 press releases) of safety and efficacy outcomes of uterus transplantation and IVF for congenital or acquired uterine factor infertility in the first 52 recipients showed that 38/52 (73.1%) of surgical procedures led to the restoration of uterine function in recipients, 12/52 (23.1%) of recipients experienced postoperative complications requiring hysterectomy, and 2/52 (3.8%) of procedures failed due to intraoperative complications [30]. About 40% (16/38) of patients achieved a pregnancy, including two women who gave birth twice. In this systematic review, uterine transplantation-IVF pregnancies led to 16 deliveries, and all newborns were healthy. Six out of 16 (37.5%) pregnancies faced major complications during gestation, and preterm births occurred in 10/16 (62.5%).

Unlike the other transplants described, a uterus transplant is designed to be temporary and removed by hysterectomy following the desired number of births. Also in contrast to other VCA surgeries described in this chapter, 80% of reported transplants have utilized a living donor [29]. This leads to even more necessary screening and ethical concerns, as discussed later in this chapter.

32.6 Abdominal Wall Transplant

Abdominal wall transplant is a procedure that is an alternative option to primary wall closure in patients undergoing intestinal and multivisceral organ transplants [31] (Fig. 32.4). In 20% of intestinal transplant patients, primary closure of the abdominal wall is not technically feasible; VCA provides an opportunity to perform simultaneous abdominal wall transplantation from the same donor with no additional risk of immunosuppression.

Abdominal wall transplant vessel anastomosis can be performed using the iliac vessels of the donor to the recipient's iliac or femoral arteries [32]. Therefore, a microscopic approach must

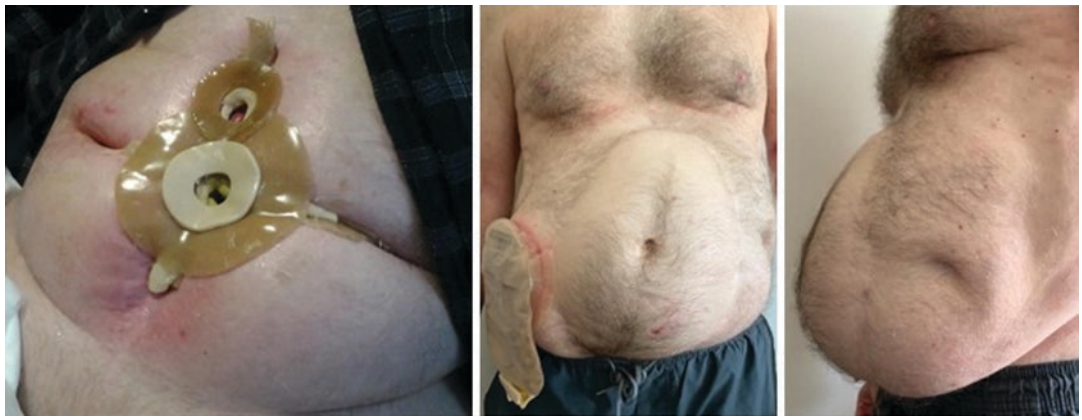

Fig. 32.4 66-year-old male recipient of an abdominal wall VCA and intestinal transplant due to Crohn's disease. Left, Pretransplant (TPN-dependent with multiple fistulas); middle and right, 9 months post-transplant (Honeyman, C., Dolan, R., Stark, H., Fries, C. A., Reddy, S., Allan, P., ... & Tempelman, T. (2020). Abdominal Wall Transplantation: Indications and Outcomes. *Current Transplantation Reports*, 1–12)

then be used to supply the abdominal wall, anastomosing the donor and recipient epigastric vessels. Temporary revascularization of the abdominal wall VCA is also possible via the recipient's ulnar or radial arteries [33]. This is a particularly valuable technique for fragile patients to reduce operative time and enable simultaneous intestinal transplant and abdominal wall perfusion. The abdominal wall VCA can then be pedicled for 4–6 weeks on the ulnar or radial arteries until the transplant establishes vascular supply from the recipient's adjacent abdominal wall, when they can be divided.

Key Point
For fragile patients, revascularization of the abdominal wall transplant is possible via the recipient ulnar or radial arteries; the transplant can reestablish vascular supply from the adjacent abdominal wall, and the pedicle can then be divided after 4–6 weeks post-transplant.

Currently, 46 abdominal wall transplants have been performed [34]. Further, standardized quality of life assessment of these patients is necessary. So far, there has been no evidence of enhanced immune rejection of intestinal or solid-organ transplants among these patients. In fact, the skin of the abdominal wall may provide an additional monitoring sentinel mechanism to assess rejection of the underlying solid organ or intestinal transplant. However, there is a dire need for enhanced data regarding the long-term outcomes of these transplants.

32.7 Laryngeal Transplant

The goal of a laryngeal transplant is to enable a patient to breathe without a tracheostomy, swallow and maintain airway patency, and voice production. The first successful long-term laryngeal transplant was performed at the Cleveland Clinic in 1998, with two other subsequent transplants at UC Davis (2012) and in Poland (2015) [35]. These followed the first initial transplant in 1969 in Belgium, in which the patient was maintained on immunosuppression for 8 months following his transplant but eventually succumbed to a recurrence of a stromal tumor upon which immunosuppression was stopped [36].

As in almost all VCAs, the technical details of the procedure are dependent on the tissue transplanted and the initial defect [37]. Anastomoses are reported between the donor right superior thyroid and recipient superior thyroid artery. The donor right brachiocephalic vein is anastomosed with the recipient internal jugular vein. Alternatively, the donor right internal jugular vein was anastomosed with the recipient's common facial vein in another case. Additional anastomoses can be performed between the inferior thyroid arteries and transverse cervical arteries, the middle thyroid vein, and the left jugular vein dependent on the recipient anatomy.

Nerve reinnervation, leading to potential normal phonation in speech following transplant, is paramount [38]. This is dependent upon neurorrhaphies between the superior laryngeal nerves of the donor and recipient and recurrent laryngeal nerves of the donor and recipient.

The outcomes of laryngeal transplant have been dramatic, including one patient stating his first vocal words in 20 years only 3 days following surgery [39]. Cough reflex returned at 3 months postoperative. Sixteen months following surgery, objective measures of phonation in this patient were near normal levels. The other two patients also reported improvement in quality life following the ability to phonate again. Clearly, laryngeal transplant presents an opportunity to dramatically improve quality of life in patients who are unable to independently phonate.

32.8 Unique Aspects of VCA

32.8.1 Ethical Concerns

Ethical controversies in VCA have moved beyond abstract existential questions of identity crisis that dominated the field prior to the first

successful face and hand transplants [40]. Ethical conundrums today involve more practical aspects of these procedures. This includes whether age and gender-mismatched transplants are acceptable or whether it is permissible to perform face transplants on blind individuals or children [41]. Both uterine and penile transplants invoke additional ethical controversies and risk-benefit analyses, such as whether these transplants should be offered to gender reassignment patients. The need for lifelong long immunosuppression raises concerns as to what functional and aesthetical gains justify the risk of long-term immunosuppression.

32.8.2 Recipient Screening

As in solid-organ transplant, pretransplant psychological screening of recipients is a topic of utmost importance. As illustrated in this chapter through failures in long-term VCA procedures, recipient investment in the success of the transplant is vital [42, 43]. A full understanding of the risk of immune rejection is absolutely crucial. A transplant psychiatrist is a vital member on the VCA team in both pretransplant screening and post-transplant follow-up. Furthermore, social support structures are important to the long-term success of VCA patients.

Key Point
Psychosocial screening in VCA recipients is absolutely essential, as is the involvement of a transplant psychiatrist on the VCA team.

32.9 Donor Selection

Unique to VCA are the additional aspects of donor suitability that are not necessary in solid-organ transplant [44]. This includes the matching of Fitzpatrick skin type as well as age- and gender-matching donors and recipients in the case of face and hand transplant, although hand transplants have occurred between mismatched genders with similar-sized hands. These additional concerns, in addition to the immunological matching also necessary in solid-organ transplant, lead to fewer acceptable donors for a recipient.

32.10 Nerve Regeneration

Unlike solid-organ transplant, VCA outcomes not only are dependent on reperfusion of tissue and successful immunosuppression but also rely on nerve regeneration for functional outcomes [45]. The often variable return of motor and sensory function following VCA is ultimately dependent on the success of nerve regeneration. Although current suture repair techniques have resulted in positive outcomes in both hand and face transplant, there is still immense opportunity for improvement in both quality and timing of nerve regeneration. This includes investigation into the effect of immunosuppression on nerve regeneration, particularly of tacrolimus, which has demonstrated positive effects on enhancing regenerative capacity [46]. Tacrolimus has been shown to enhance the effects of nerve growth factors by increasing cellular sensitivity to growth factors as well as reducing local inflammatory response. Furthermore, research in the utilization of exogenously delivered neurotrophic factors to enhance peripheral nerve regeneration are also crucially relevant to the field of VCA [47, 48]. The effects of electrical stimulation, including intraoperative direct muscle stimulation or stimulation of the proximal nerve stump, also appear promising in enhancing peripheral nerve regeneration [49].

Key Point
Overall, the success of VCA is intimately intertwined with the success of peripheral nerve regeneration. Further research on the interplay of immunosuppression and nerve regeneration is essential.

32.11 Virtual Surgical Planning and 3D-Printed Guides

Three-dimensional computed tomographic (CT) imaging, computer modeling, and virtual surgical planning (VSP) offer practical tools for VCA (Fig. 32.5). Virtual surgical planning has demonstrated benefits in surgical accuracy and in reducing operative time in complex reconstructive procedures [50]. VCA procedures are extremely intricate procedures in which virtual surgical planning can provide utmost guidance intraoperatively. This includes the planning of osteotomies outside of the operating room, in a controlled environment in which the recipient defect and donor anatomy can be strategically assessed [51]. This is particularly important in both face and hand transplant, as our team found it essential in performing a face transplant. Virtual surgical planning can lead to 3D printed osteotomy guides, which then leads to bony cuts created in the ideal location for both arm length matching to the contralateral arm (in the case of hand transplant) or ideal planned facial plating (in the case of face transplant). Furthermore, intraoperative navigation can also be utilized if 3D-printed guides are not available to direct the location of osteotomies, and mixed reality also provides another innovative modality to aid in surgical decision-making [52].

Key Point

We recommend a close working relationship with biomedical engineers, whom we find crucial to the VCA team in the planning of these surgeries and creation of 3D-printed surgical guides.

32.12 Immunosuppression

The risk-benefit ratio of VCA is heavily influenced by the negative effects of immunosuppression and the non-life-saving nature of these transplants. Current protocols at most VCA centers are based on solid-organ transplant immunosuppression protocols [53]. This include induction with polyclonal antithymocyte globulins or anti-interleukin-2 monoclonal antibody preparations, followed by maintenance immunosuppression with a calcineurin inhibitor (commonly Tacrolimus), antiproliferative agent (commonly mycophenolate mofetil), and corticosteroids. Acute rejection is common among VCA patients and typically treated with oral or intravenous steroids, T cell-depleting agents, and in some program also with topical corticosteroids or tacrolimus. As expected, as we have seen longer follow-up of VCA recipients, as with other solid

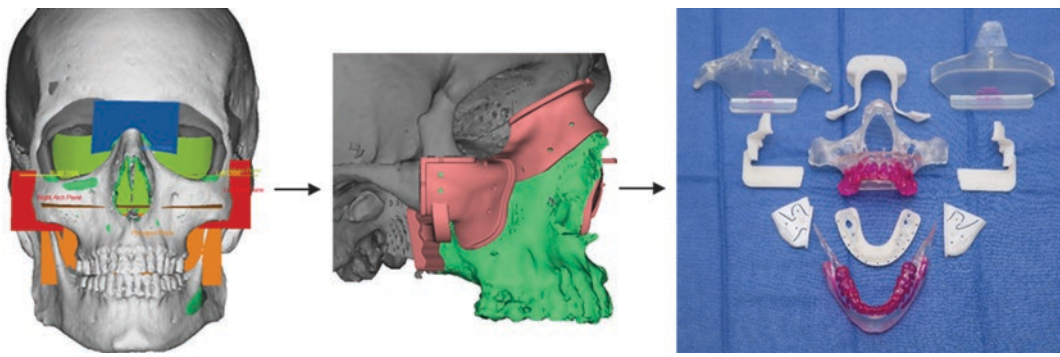

Fig. 32.5 Preoperative virtual surgical planning of osteotomy location then enables the 3D printing of osteotomy guides for a more efficient surgery and ideal reconstruction (©SamirMardini 2021. All Rights Reserved)

organs, chronic rejection has been observed and has resulted in some graft losses.

Since VCA transplants are non-vital transplants, strategies to decrease the toxicity of immunosuppression protocols as well as promoting tolerance induction would benefit the applicability of these transplants. This more so than other solid-organ transplants that are life-saving or life-prolonging. Furthermore, unlike solid-organ transplant, monitoring of rejection in VCA and graft dysfunction is not based upon lab values, as it is in the case of kidney or liver transplants. One promising avenue is inducing immune chimerism through allogeneic stem cell transplantation from the donor in parallel with VCA [54]. Furthermore, cell therapy strategies are also promising advances in this field [55, 56]. However, more research on these promising avenues needs to be performed before they see widespread adoption.

Take-Home Messages

- VCA is an innovative field that seeks to restore function and social reintegration to patients who have exhausted the armamentarium of conventional reconstructive options.
- VCA transplants differ from solid-organ transplants in that they are comprised of many tissue types.
- The success of VCA relies both upon the technical success of the surgical procedure and also on the immunosuppression protocol and the outcomes of nerve regeneration into donor tissue, enabling functional recovery.
- Virtual surgical planning and 3D printing has enabled immense complexity in VCA by enabling some operative decision-making to occur outside of the OR. This is immensely helpful in these complex cases to ensure ideal donor-recipient anatomical fit with planned osteotomies.
- Psychosocial screening and recipient preparation is essential in VCA. This includes close collaboration with a transplant psychiatrist to ensure long-term psychosocial success.
- VCA procedures are highly reliant on interdisciplinary collaboration and require a team with a wide range of specialties, including but not limited to reconstructive surgery, transplant, psychiatry, nursing, biomedical engineering, pharmacy, and physical therapy. Only through this collaborative effort is VCA ultimately successful.

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Part VI

Aesthetic Plastic Surgery

Aesthetic Plastic Surgery

33

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Aesthetic surgery is erroneously believed to be a modern discipline; actually, the oldest evidence is represented by the papyrus of Edwin Smith, dating back to the 3000 BC, where different face plastic surgeries are described. Furthermore, from India, we have precise traces related to nose reconstruction procedures (800 BC). In Italy, in the fifteenth century, Antonio Branca, from Catania, described the so-called Italian method for nose reconstruction which was based on the use of the epidermis of the arm.

The first breast surgeries were performed in 1897, when the French surgeon M. Pousson attempted a mammoplasty to reduce a large breast. Around the same time in Austria, Robert Gersuny performed breast augmentation with paraffin injections. In 1962, silicone breast implants, designed by the American Thomas Cronin, appeared for the first time.

Aesthetic surgery procedures are of great help to correct physical defects, partially or totally, allowing an increase in patients' confidence and self-esteem.

The aforementioned physical defects can be genetic, or they may arise either as a consequence of the physiological aging process or due to para-physiological events.

The most commonly involved portions of the body include the nose, ears, and breasts. These sites, due to the important role they play in interpersonal relationships, when not in accordance with common aesthetic standards, can be limiting.

According to the American Society of Plastic Surgeons, in 2018, more than 1.8 million aesthetic surgical procedures were performed in the USA, with breast augmentation being the most commonly required (314,000 surgeries, +48% change 2018 vs. 2000).

33.1 Mammary Gland

33.1.1 Augmentation Mammoplasty

One of the most frequently performed aesthetic surgery procedures is breast augmentation. The surgery aims to increase breast volume through implants (prosthesis) implanted either behind the glandular breast tissue (subglandular placement) or under the pectoralis major muscle (submuscular placement). The insertion of an implant,

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occupying space, pushes the glandular tissue forward, increasing the overall breast volume.

According to the American Society of Plastic Surgeons, more than 347,000 women between 19 and 34 years old undergo breast augmentation each year.

The choice of the implant highly depends on the patient's preferences and body type. If patients desire naturally looking breasts, anatomical implants will be the best choice since they have a teardrop shape which appears to be really similar to natural breasts creating a smooth upper pole and overall non-operated look.

Otherwise, if the patient's main concern is about upper pole fullness, then round implants can be the best option.

Breast implants are made of an envelope (silicone or polyurethane) which can alternatively contain silicone gel or physiological solution.

The silicone gel prosthesis is the most used and confers the characteristics of consistency, softness, and mobility, typical of the breast. These implants are subjected to very careful tests to establish their safety and efficacy. Cohesive silicone gel implants have the great advantage that, in case of tearing, the gel inside does not spread throughout the body. They even reduce the risk of postoperative wrinkling. The cohesive silicone gel gives a feeling of naturalness to the breast and also maintains normal body temperature; therefore, it is now considered the most suitable material. Silicone breast implants do not interfere with breastfeeding or with the sensitivity and specificity of any diagnostic test (mammography, ultrasound, biopsies, etc.).

The second type of prosthesis are saline implants, which are full of water and salt. The main quality of this type of filling is the fact that it's harmless: in case of spill, the solution is absorbed by the body. This type of implant has the advantage of being inserted into the patient's body empty and folded. Another advantage is their size. Indeed, saline implants are the only breast implants that can be filled through a removable tube, adjusting the size by adding or removing fluid through the filling tube. This gives the patient the opportunity to correct any error in the dimensions initially chosen.

The surface of the breast implants can be classified as follows:

- Macro-textured prosthesis, with rough surface.
- Micro-textured prosthesis, with poorly rough surface.
- Smooth prosthesis. They present a higher risk of rotation and capsular contracture. Among these, "nanotextured" implants should be included. The latter are characterized by a minimally rough, almost smooth surface. The advantages are that they allow to reduce the length of the skin incisions necessary for their introduction, and by implanting them, we obtain a softer and more natural consistency.

The incision for implant introduction can be placed at the level of the axilla (armpit), areola, or lower breast fold (inframammary fold). In general, all breast augmentations are minimally invasive procedures, involving incisions that are only a few centimeters in length.

The inframammary approach, often called the crease incision, is the most common approach for implant placement. The incision is performed in the fold under the breast, called the inframammary fold, where the breast meets the chest wall.

The periareolar and inferior emi-areolar incisions consist in an incision around the entire darker outer edge of the areola concerning the former and a semicircle on the lower half of the areola for the latter. The implant is then inserted through the incision and placed into position.

The transaxillary approach requires placing an incision in the crease of the armpit, through which the surgeon creates the implant pocket and inserts the prosthesis. The implant is filled with saline after it has been placed in the chest pocket.

Another possibility is represented by the umbilical approach, although it is difficult and rarely used.

Potential surgical complications could be divided into pre- and intraoperative complications and further into early and late postoperative complications.

Preoperative and intraoperative complications derive from poor planning (wrong choice of the surgical access, incorrect measurement) or poor surgical technique (over-dissection of the implant pocket, implant malpositioning, excessive bleeding).

Early postoperative complications include hematoma, seroma, infection, and implant malpositioning.

Late postoperative complications include infection, seroma, capsular contracture, distortions, implant visibility, implant malposition, implant rippling, wrinkling and palpability, implant rupture, and poor scar healing.

Rupture is a long-recognized complication of all breast implants that can be caused by a strong impact to the breast, surgical error, cracks that develop over time, excessive capsular contracture, or, rarely, pressure exerted during a mammogram. Both saline and silicone implants are equally vulnerable to implant rupture.

A saline implant rupture is generally easy to detect because the saline fluid leaks out over a short period, so the breast appearance changes quickly and noticeably; it suddenly looks smaller and deflated. Some patients experience breast pain, changes in nipple sensation, or skin tenderness. They may even show signs of capsular contracture.

Unfortunately, silicone implant ruptures are more difficult to detect because the silicone gel does not rapidly leak from the implant but gradually seeps into the breast pocket, and it remains in the body, sometimes spreading to nearby lymph nodes. Some women experience pain or tenderness in the affected breast or changes in the breast contour.

Capsular contracture is the most common complication following implant-based breast surgery, and it is one of the most common reasons for a second surgery. Therefore, it is important to understand why this happens and what can be done to reduce its incidence.

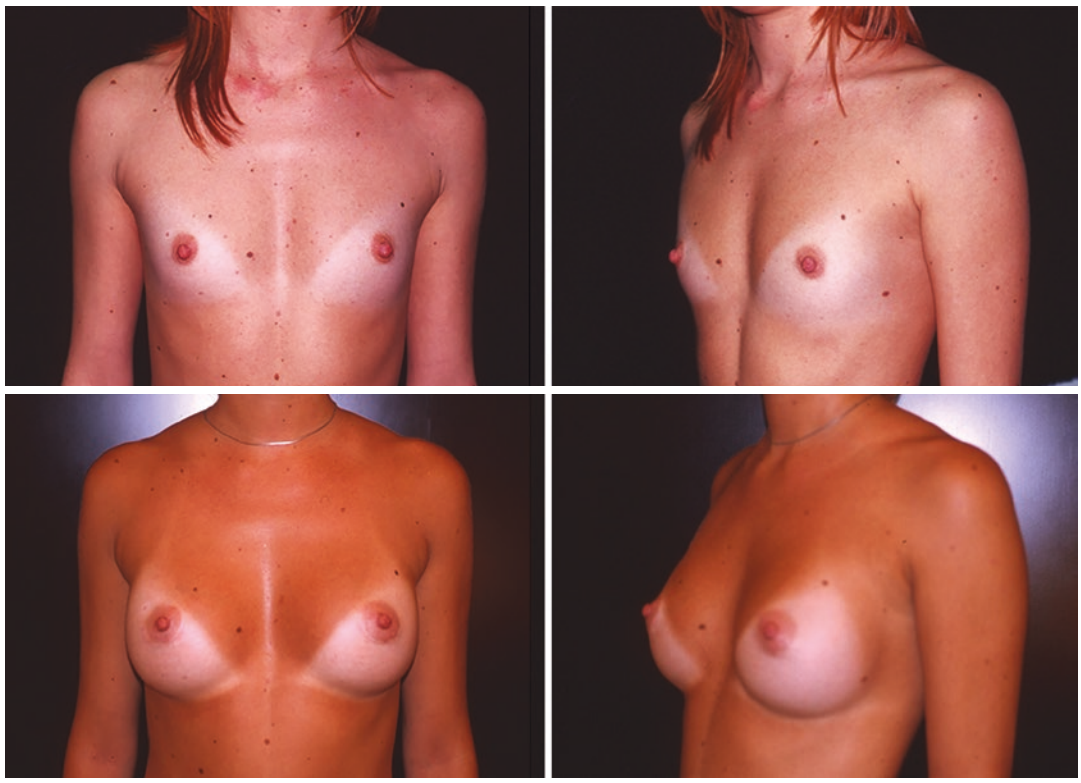
Capsular contracture is caused by an excessive fibrotic reaction to a foreign body (the breast implant), and it has an overall incidence of 10.6%. It can appear as an early capsular contracture (few months after surgery or years later).

Risk factors include the use of smooth (vs. textured) implants, a subglandular (vs. submuscular) placement, use of a silicone (vs. saline) filled implant, and previous radiotherapy to the breast.

Capsular contracture is graded by the Baker scale and follows these criteria:

- Grade I: The breast is soft and appears normal, and the capsule is flexible.
- Grade II: The breast looks normal but is somewhat hard to the touch.
- Grade III: The breast is hard and has some distortion caused by contracture, or instead, it may be significantly distorted, and it can appear with a rounded shape, or the implant may be tilted upward.
- Grade IV: Contracture looks more advanced than grade III, often causing severe hardening of the capsule and pain.

The surgical correction of capsular contracture is known as capsulectomy, a procedure where all or a part of the thickened capsule around the breast implant is removed and, at the same time, a replacement of the breast implant is required.



33.1.2 Breast Reduction

Breast reduction surgery, also known as reduction mammoplasty, is a procedure performed to remove excessive breast parenchyma, adipose tissue, and skin from the breasts to achieve a breast size in proportion with the body and to alleviate the discomfort associated with overly large breasts.

Women often opt for this procedure not only for aesthetic reasons, but because they suffer from back problems, curvature, and posture alterations.

Reduction mammoplasty can be performed at any age, although it is essential that the breast is fully developed.

The surgery is mainly performed under general anesthesia, and the duration varies depending on the complexity.

For smaller reductions, the incision is periareolar together with a vertical incision from the areola to the mammary groove. On the other hand, for larger breast volumes, an additional incision along the breast fold (inverted-T technique) is required. Following the incision, excessive glandular tissue is removed together with adipose tissue and the skin. The reconstructed mammary cone is then repositioned, and the nipple-areolar complex is readapted to the new breast mound.

While the risks of a reduction mammoplasty are minimal, some women may suffer from:

- Decrease or loss of sensation in the nipples or breasts
- Asymmetrical results
- Poor scarring
- Problems with breastfeeding

33.1.3 Mastopexy (Breast Lift)

Mastopexy aims to elevate the breasts to reach the position they occupied prior to middle age,

children, and breastfeeding and at the same time to restore their youthful shape.

To achieve the desired result, the excess skin must be removed, and the nipple has to be replaced; the outcoming scars, consistently with the amount of skin removed, can be of three types:

- Periareolar (around the perimeter of the whole areola).
- Periareolar and vertical (in addition to the scar around the areola, a vertical scar from the areola to the inframammary sulcus).
- Inverted-T scar (in addition to the second type it presents a further scar in the inframammary sulcus). This type of mastopexy is performed when the excess skin to be removed is considerable.

All these techniques can be used with or without employment of breast implants.

33.1.4 Gynecomastia Correction

Gynecomastia is defined as the pathological development of one or both male mammary glands. This condition is common in elderly men, but it is also observed in young people.

The volume of the breasts can increase for different reasons. Oftentimes, the cause of gynecomastia is due to a patient's overweight, hormonal alterations, or the intake of certain drugs such as anabolic steroids.

Many times, the causes may not be identifiable, and the problem is limited only to aesthetic damage. Gynecomastia often involves both breasts, but sometimes can be unilateral, with further aesthetic discomfort, also due to asymmetry.

Gynecomastia may be defined as an excessive development of the mammary gland (real gynecomastia), an excess of fat deposited in this region (false gynecomastia), or an excess of both mammary gland and adipose tissue (mixed gynecomastia). They can be determined through medical consultations and ultrasound scan.

Surgery for gynecomastia differs whether the increase in volume of the breasts is due to an excess of adipose tissue or it is associated with an increase in size of the mammary gland. In the first case, the procedure for the correction of gynecomastia is carried out removing excess adipose tissue through liposuction. Instead, if the gynecomastia is due to an increase of the mammary gland, it is necessary to remove the glandular tissue surgically by a small cutaneous incision at the periareolar site, on the border between the dark skin of the areola and the pale skin, in order to perform a subcutaneous mastectomy.

33.2 Rhinoplasty

Rhinoplasty is among the most commonly performed aesthetic surgical procedures in plastic surgery that enhances facial harmony and the proportions of the nose and corrects impaired breathing caused by structural defects of the nose.

Patients seek rhinoplasty for different reasons: nose reconstruction after an injury, improvement of airway function, correction of birth defects, and aesthetic reasons.

Rhinoplasty can modify nose size in relation to facial balance and harmony, straighten a crooked nose, refine or reduce a bulbous nasal tip, correct nasal tip asymmetry, correct nostrils asymmetry and position, and correct a nasal bump, and in case of a secondary rhinoplasty, we can revise poor nose job results.

There are two different approaches to rhinoplasty: open rhinoplasty and closed rhinoplasty.

Open rhinoplasty (external rhinoplasty) is performed by making a small incision on the columella, called trans-columellar incision, and it allows plastic surgeons to open the skin of the nose or unveil the nose.

On the other hand, concerning a closed rhinoplasty approach (endonasal rhinoplasty), two incisions are made within the inside of the nose (inside the nostrils). It is through these incisions that all the nasal defects are addressed. In this way, all the necessary incisions remain completely hidden within the nostrils.

Each approach has its advantages and disadvantages: the closed technique takes a shorter

time to be completed, it is less invasive, it leaves no visible scars, and it causes less swelling resulting in a shorter recovery time. On the other hand, as there is limited visibility of the tissues and cartilages, the surgeon can make limited changes with limited precision; it is a "blind" procedure. In addition, following surgery, the incisions can weaken the nasal structure, undermining structural stability of the nose.

Concerning open rhinoplasty, the main advantage is that it allows better visualization of the cartilages that will be addressed in the surgery. An open rhinoplasty gives plastic surgeons the ability to manipulate and alter nasal shape with more control and precision. Moreover, the stabilization of the nose after surgery is easier in open rhinoplasty with respect to closed rhinoplasty.

On the other side, open rhinoplasty is longer and more invasive, so recovery time will be a little longer, and it takes more time for swelling and bruising to disappear.

33.3 Liposuction

Used for aesthetic purposes since 1977, today, liposuction is still one of the most frequently requested plastic surgery procedures by both men and women. This technique involves removing excessive adipose tissue deposits in specific areas of the body, such as the chin, neck, abdomen, arms, hips, buttocks, and thighs, thereby contouring the body into a slimmer, more balanced shape. In addition, liposuction can sometimes be employed for breast reduction or treatment of gynecomastia.

There are different types of liposuction:

- Ultrasound-assisted liposuction that uses ultrasonic energy to break down fat, so that it can be easily removed.
- Power-assisted liposuction: the procedure is performed with a cannula that is manually

moved back and forth, allowing the surgeon to pull out fat.
– Laser-assisted liposuction: a technique that uses a laser to break down fat, and later a cannula is employed to remove fat.
– Tumescent liposuction: the most commonly used procedure that involves the infiltration of tissues prior to liposuction with a sterile solution in order to make the area stiff and swollen. Then, a cannula is inserted and connected to a vacuum which will aspirate the fat.
– Liposuction with radiofrequency: the thermal energy generated from the radio waves melts the fat tissue, which is then aspirated.

Liposuction is normally done for cosmetic purposes, but it is sometimes used to treat certain conditions such as lymphedema, lipodystrophy syndrome, extreme weight loss after obesity, or lipomas.

Like any major surgery, it carries risks of bleeding, infection, and an adverse reaction to anesthesia, but complications may also include pulmonary embolism, fluid collection (seroma), and hematoma.

The maximum volume of adipose tissue that is recommended to be removed is 6% of the patient's weight.

33.4 Abdominoplasty

Abdominoplasty, also known as a "tummy tuck," is designed to improve the shape and tone of the abdominal region, by removing excess fat and skin. The result is a flatter and firmer abdomen.

Even patients with normal body weight and proportion can present an abdomen that protrudes or is characterized by looseness and sagginess. The most common causes of this condition include aging, genetics, pregnancy, prior surgery, and significant fluctuations in body weight.

Abdominoplasty allows also to correct abdominal wall defects (hernias, diastasis recti, etc.).

There are several types of abdominal plastic surgeries; it is possible either to remove large amounts of fat and excess skin or to correct moderate fat accumulation. Nowadays, three types of abdominoplasty are widespread:

- Mini abdominoplasty: performed for cases in which only an aesthetic correction is needed. A small amount of skin and adipose tissue involving the area below the navel is removed. This technique involves a single incision just above the pubic mound, through which the surgeon will tighten loose muscles and remove excess skin to restore a smooth, flat abdominal wall. It does not involve any intervention on the navel.
- Complete abdominoplasty: in this case, the maximum amount of skin and adipose tissue over the abdominal muscle is removed. Through a horizontal or u-shaped incision above the pubic mound, the surgeon will remove excessive skin and tighten the abdominal muscles. The navel is usually detached and repositioned on the new abdominal wall.
- Torsoplasty: a circumferential abdominoplasty used to remove excess cutaneous and subcutaneous tissue of the lumbar and dorsal areas.

An abdominoplasty carries various risks, including:

- Fluid accumulation beneath the skin (seroma). Drainage tubes which are left in place after surgery can help reduce the risk of excess fluid accumulation.
- Poor wound healing. Sometimes, areas along the incision line heal poorly or begin to separate.
- Unexpected scarring. The incision scar is permanent but is placed along the hidden bikini line. The length and visibility of the scar varies from person to person.
- Tissue damage or death. During a tummy tuck, fat tissue in the abdominal area might get damaged or die. Smoking increases this risk. Depending on the size of the area, tissue might heal on its own, or it may require a surgical touch-up procedure.
- Changes in skin sensation. During a tummy tuck, the repositioning of abdominal tissues can affect the nerves and consequently sensi-

tivity in the abdominal area, and, less frequently, it may affect also the upper thighs.

33.5 Thighplasty

Thighplasty (thigh lift) is a procedure used to tighten and improve the overall appearance of thighs. Candidates for this procedure present with very loose skin in the thigh that has become less elastic, or they have thighs with a saggy, dimpled, or flabby appearance. A thigh lift can reduce sagging in the inner or outer thigh. It is often a procedure performed on patients who have massive weight loss.

The surgery takes place under general anesthesia or spinal anesthesia. The procedure involves incisions extended from the inguinal region to the inner face of the root of the thigh and the removal of excess skin. Sometimes, it is advisable to add a longitudinal scar of a few centimeters along the most hidden medial face of the thigh in order to obtain a better correction and a better skin tone of the whole region. The skin is then stretched upward and anchored with deep stitches to the underlying tissues. Permanent scars are obtained but hidden in the inguinal fold and covered by a normal slip.

In the case of a circumferential lift, the excision affects the overall circumference of the thigh with a final scar corresponding to the circumferential incision.

33.6 Brachioplasty

Arm lift, also known as brachioplasty, is an aesthetic surgical procedure that aims to improve the appearance of the inner portion of the upper arms. This type of surgery is often performed after bariatric surgery or massive weight loss: ideal candidates also have enough loose skin and elasticity to allow a good outcome.

During an arm lift, excess skin and fat are removed in the region between the armpit and the elbow.

A mini-brachioplasty can sometimes be performed although in this case the incision is concealed in the armpit area.

Significantly hanging skin usually requires a full brachioplasty in which an elliptical piece of skin and fat is removed from the back of the arm, placing the scar toward the chest wall, so that it will be concealed.

Once the excess tissue is removed, the surgeon achieves a more youthful contour to the arm re-establishing natural lines and anatomy.

33.7 Gluteoplasty (Buttock Lift)

Excess skin and fat from aging or after dramatic weight loss in the gluteal area can be improved with a buttock lift, a procedure that, in the last 10 years, has become very popular around the world. Patients can consider this procedure when they have loose and drooping skin in the buttocks, if they recently experienced significant weight loss and feel uncomfortable and if excess skin causes mobility problems.

A durable augmentation of the gluteal region is achieved either by placing silicone implants (similar to breast implants) under the gluteus muscle or by autologous adipose tissue graft (lipofilling).

An incision is performed in the intergluteal fold to emplace the prosthesis within each gluteus maximus muscle. This positioning reduces many postoperative problems previously derived from a deeper implantation of the prostheses. Then, surgery is completed with a liposculpture or lipofilling to reshape harmoniously the contour of the buttocks.

Depending on the shape the surgeon wants to achieve, the choice is between oval prostheses (anatomical) or elongated implants that could be replaced intentionally or inevitably because of the occurrence of complications even after a few or many years following the first surgery.

Like any other type of major surgeries, it carries various risks including fluid accumulation beneath the skin (seroma), poor wound healing, scarring, and changes in skin sensation.

33.8 Facelift

Facelift (rhytidectomy) is a surgical procedure whose purpose is the rejuvenation of the face: the improvement of face appearance and its consequent antiaging effect is obtained by stretching the skin and the muscles of the face and, where necessary, also through the removal or insertion of fat.

Through hidden incisions, the skin of the face is lifted and stretched, removing its excess. The underlying muscle-aponeurotic system is modeled and repositioned. In the case of facelift, the skin and the muscles are detached up to the temples and pulled upward and posteriorly. Then, the superabundant skin is removed.

The incisions are hidden from the contour of the ear and from the hair and are practiced around the earlobes and behind the ear. The size of the incisions, the detachment, the traction, and the necessary remodeling are decided by the surgeon during the preoperative visit based on the patient's needs and the surgical technique used.

If it is only a restricted area that is particularly marked by wrinkles and relaxation, it is preferred to intervene locally rather than perform a total lifting. Generally, at a young age, a mini lifting is used. It consists in a partial detachment of the skin of the cheeks in front of the ears, removing an excess portion through an incision in the head in the area of the temples.

33.9 Face Lipofilling

Face lipofilling is a surgical technique that uses excess adipose tissue coming from other portions of the body (hips, abdomen, thighs) as a filler for the face. The lipofilling allows to effectively treat different blemishes such as skin aging, wrinkles, volumetric deficiencies of the cheeks, elusive chin, and thin lips.

The procedure is performed under local anesthesia with sedation or general anesthesia and consists of withdrawing a little volume of fat from other areas of the body with blunt cannulas. Then, the fat is centrifuged and transferred with mini syringes to specific areas of the face that need filling.

The areas generally treated with lipofilling are the malar-zygomatic area, the periocular area, and the nasolabial folds, where those typical furrows related to aging are formed and where the greatest loss of volume occurs.

This surgery not only adds volume to the face, but it also improves the quality of the skin: the procedure is particularly suitable for the so-called tired face which seems rejuvenated, fresher, and fuller, thanks to the adipose tissue injections.

The fat graft is partially reabsorbed in the weeks following the procedure, although the portion that survives is preserved stable in time, differently from fillers.

33.10 Blepharoplasty

The eye is an important component of facial aesthetics, and blepharoplasty (eyelid surgery) can play a vital positive role in facial harmony and the perception of aging.

Blepharoplasty is one of the most commonly performed facial cosmetic procedures, which repairs droopy eyelids, excess skin, tired-looking eyes, circles around the eyes, and an external prolapse of the endo-orbital adipose tissue (so-called eyelid bags). Blepharoplasty is performed under local anesthesia and eventually supported by sedation.

The intervention of upper blepharoplasty involves a skin incision at the level of the upper eyelid plica; instead, the incision of the lower blepharoplasty by transcutaneous route is performed a few millimeters below the eyelashes and parallel to them; it extends along the entire length of the eyelid. The incision can be made with a scalpel, with a laser, or with radiofrequency instruments. For each clinical case, the amount of skin, muscle, and fat to be removed must be customized. Finally, sutures are placed at the level of the incision lines which are usually removed after a week.

Complications of upper blepharoplasty are usually due to the excessive removal of the skin that prevents the normal closure of the eyelids. This condition could cause a temporary nocturnal lagophthalmos with dry eyes, redness, and photophobia, especially in the morning. An aggressive upper blepharoplasty operation can also damage the levator palpebrae causing eyelid ptosis.

Lower blepharoplasty can cause the reduction of the entire lower eyelid, causing a more circular eye as an aesthetic effect. A drop of just 1 mm can cause dryness of the lower part of the cornea which clinically simulates the presence of a foreign body with diffuse redness. Even the excessive removal of fat can accentuate dark circles and give a sense of greater aging to the patient. This complication can be avoided by removing the fat conservatively or with a filler based on hyaluronic acid or using lipofilling.

33.11 Otoplasty

An otoplasty (ear surgery) is a surgical procedure that can correct the appearance of the ears changing their shape, size, and projection working on congenital defects (like protruding ears) or trauma-induced flaws or flaws from tumor removal. Generally, otoplasty improves ear protrusion without affecting the pinna, which can only be reduced through incisions that will leave small visible scars. It can be done on any patient, even if they are very young, but most surgeons prefer to wait until patients are at least 5 years of age, as the auricle is then 90–95% of adult size.

There are different types of otoplasty techniques:

- Cartilage splitting (cutting) technique that involves incisions through the cartilage and repositioning of large blocks of auricular carti-

lage. The major advantage of cutting technique is long-term stability of the results. Disadvantages include disruption of cartilaginous support and creation of contour irregularities.

- Cartilage sparing, a technique that avoids full-thickness incisions, attempts to create more effective angles and curls in the cartilage in order to decrease the incidence of contour irregularities and to maintain the structural support of the cartilage.

The most commonly used techniques include the Mustardè technique, performed for helix correction, and the Furnas technique, used for prominent concha correction.

Take-Home Messages

- Aesthetic plastic surgery is performed to reshape normal structures of the body in order to improve the patient's appearance and self-esteem.
- The physical defects can be genetic, or they may arise either as a consequence of the physiological aging process or due to paraphysiological events.
- The causes that motivate patients to undergo an aesthetic surgery procedure may be objectively definable or being perceived only subjectively.
- The most commonly involved portions of the body include the nose, ears, and breasts.
- Potential surgical complications could be divided into pre- and intraoperative complications and further into early and late postoperative complications.

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34 Plastic Surgery in the COVID-19 Era

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Background

In December 2019, a new viral pneumonia emerged in Wuhan, China, and quickly propagated across the country within weeks, becoming pandemic in months. The causal agent was isolated and identified as a *Betacoronavirus* in January 2020 and named coronavirus disease 2019 (COVID-19) by the World Health Organization (WHO).

The four genera of coronaviruses (α, β, γ, δ) present single-stranded RNA, and all of them cause animal diseases. Only in six known cases, α- and β-coronaviruses developed the capacity to infect humans. Of these, SARS-CoV caused severe acute respiratory syndrome, while MERS-CoV was responsible for Middle Eastern respiratory syndrome, both associated with high mortality rates [1].

Bats were identified as the original host of COVID-19, but other intermediate hosts as pangolins and snakes may have anticipated humans. The infection spreads through respiratory contacts, but the virus has been isolated from blood and fecal samples too. After exposure, the average time of symptom presentation is 3–7 days (range, 1–14 days), but the asymptomatic infected are contagious as well. Fever, cough, fatigue, and shortness of breath are the most common symptoms. In the 20% of cases, there is acute respiratory distress syndrome, and hospitalization becomes necessary, with the risk of elevated cardiac enzymes and acute kidney and liver injury [2].

To date, there is no validated treatment protocol for COVID-19 infection. Several clinical trials are ongoing to investigate possible medications and vaccines, although their deployment into general population appears months away.

Meanwhile, it is mandatory to flatten the curve of COVID-19 infection incidence, in order to avoid the healthcare systems' overwhelming situation in taking care of the severe cases. As the WHO recommended, quarantine, social distancing, and travel restrictions have been

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adopted all around the world. Nevertheless, healthcare services had to face unprecedented burden, with shortages of hospital resources, workers, and protective equipment. In response to this, non-urgent treatments and surgeries have been reduced or suspended, and several medical and surgical specialties apparently had to step back from the frontline in the battle against COVID-19. In this regard, plastic surgeons have not been free from the effects of COVID-19, and their daily activity has been significantly affected by the pandemic.

34.1 Introduction

On March 11, 2020, the WHO declared the COVID-19 infection a pandemic [3]. Since its first isolation in China, it spread across beyond 220 countries, and over 37 million cases were registered to date, with more than 1 million deaths [4]. It results being the largest medical challenge of the twenty-first century.

In Italy, the first COVID-19 case was registered on February 21. Since then, the infection spread diffusely, and Italy presented the highest mortality representing for some time the second most affected country worldwide after the USA [5]. In order to reduce infection rates, social distancing was implemented progressively, until a complete lockdown nationwide was imposed by the Government from March 2020. In hospitals, dedicated wards became insufficient in some critical northern regions, and other wards were turned into COVID-19 Special Units. The healthcare system was struggling to provide normal services, and military field hospitals have been established in several areas. Surgical elective activity and private practice were reduced and stopped shortly after, in order to ensure fundamental hospital resources [6].

Healthcare priorities were totally redesigned, and emergency treatment was reorganized. Nevertheless, Italian regional situations vary significantly in terms of local healthcare system capacities, resources for equipment and personal protection. Thus, even if southern regions were less affected by COVID-19, pandemic consequences hit their hospitals even harder, pointing out pre-pandemic problems.

Spain was hit immediately after Italy, becoming the third country in the world for number of deaths caused by COVID-19. As Fuertes V. et al. [7] reported, several new measures had to be adopted in Spanish hospitals too. All elective, non-urgent, and non-cancer procedures were stopped, so nurses and anesthesiologists could be relocated in COVID-19 wards. Attending plastic surgeons and residents were reduced to the minimum required, thus avoiding contagion between staff members.

Following the same trend, in the UK and in several other European countries, operating theatres were converted to ventilation pods, and anesthetic support staff was transferred from surgeries to cope with the COVID-19 patients in the intensive care units. As a consequence, elective procedures had to be put on hold [8, 9].

The virus kept hitting countries across the oceans, and USA, South America, Asia, and Africa were not spared. The rapid COVID-19 spread challenged healthcare systems all around the world and physicians of all medical fields. In such an unpredictable scenario, in which plastic surgery services might be considered of secondary importance, a reorganization as well as a redefinition of its role in patient care is mandatory. Many colleagues worldwide felt the urge to share their experience in facing this medical revolution [10–14].

It is important to keep in mind that while we all fight against the pandemic, other life-impacting diseases continue to affect population. Plastic surgeons, along with the totality of health providers, play a crucial role in guaranteeing high standards of care for every patient's necessity.

Key Point

While all medical specialties fight against the pandemic, other life-impacting diseases continue to affect population. Plastic surgeons, along with the totality of health providers, play a crucial role in guaranteeing high standards of care for every patient's necessity.

Pearls and Pitfalls

Emergencies in plastic surgery:

- Trauma involving the face
- Replantation and revascularization surgery
- Fasciotomy
- Escharotomy
- Severe tissue infection
- Exposed noble deep structures

34.2 The Response of Plastic Surgery Services

Facing the COVID-19 pandemic, fragmented directives from international, national, local, and hospital administrative levels were given to surgeons. Utilitarian theory prevailed in this pandemic disaster scenario as it was prioritized maximizing beneficence while recognizing that harm and injustice may be done on an individual level to maximize good at a societal level [15].

For plastic surgeons in particular, it has been difficult to receive a consistent framework in which they could keep on taking care of their patients. In this regard, the recommendations of the Centers for Disease Control and Prevention (CDC) and the American College of Surgeons (ACS) have been identified as a benchmark [16, 17].

According to them, elective procedures were rescheduled or cancelled. Nevertheless, sometimes, the definition of an "elective" medical procedure may be tricky and somehow debatable, especially in this field, where specific surgeries may have both elective and non-elective indications. Trauma involving the face and replantation and revascularization surgeries, along with fasciotomies and escharotomies, are considered emergencies in plastic surgery. Similarly, hand infections and the presence of uncovered noble deep structures after extensive traumas are emergent situations as well [18].

In all European Union (EU), similar restrictions were applied: only emergent and urgent surgeries were performed, as trauma surgery, oncological surgery, infections, and burn management [9].

Considering all the different pathologies referring to a plastic surgery service, what defines an "elective" procedure? There is no doubt that when facing a pandemic, it is crucial to limit surgeries in order to preserve healthcare capacity. Nevertheless, sometimes, the concept of "electivity" may be interpreted as a gray area. Usually, elective procedures are non-urgent and are scheduled in advance. On the other hand, even an elective surgery may be necessary, and some of these cases can escalate to an emergency if not treated on time. Nowadays, plastic surgeons must carefully evaluate the immediate risks and benefits of performing surgery or its delay [19]. Moreover, resource limitations should be always discussed in advance with patients, in order to maintain a trusting relationship. They have to be assured that their treatment will be continued, consistently with their autonomous desires. The European Society for Plastic, Reconstructive and Aesthetic Surgery (ESPRAS), along with national Societies, tried to help plastic surgeons in finding their path during such hazardous time. In this regard, telemedicine gained great importance, for consultation or post-surgical visits, as a useful tool to limit outpatient access to the hospitals [9].

Key Point
In plastic surgery field, the concept of electivity may represent a gray area. Elective surgery can be necessary and can escalate to an emergency if not treated on time.

A global reduction of patients admitted to plastic surgery services has been registered, with inpatient decrease over 60% [20]. Nevertheless, some admissions did not follow this trend and presented some rise in the incidence. According to Elia R. et al. [21], hand trauma related to home accidents presented significant increase, up to 15.8%.

Likewise, burn injuries caused by denatured alcohol or corrosive substances used as homemade disinfectants presented an important incidence, 22% higher than in previous years [21].

This is probably related to the lockdown effects. A long and consecutive period at home pushed people to perform self-taught procedures or to improvise carpentry works, bricolage, and gardening.

In hand surgery, severe open injuries, infections, bleeding/fungating tumors, open fractures, and tendon or ligament injuries require immediate surgery, even during a pandemic. The majority of those patients are urgent, and there is a concrete risk for the surgeons to find themselves in the condition of operating on asymptomatic carriers of COVID-19, before confirmatory test results are available. The safety of the medical team must be ensured during all procedures.

General guidelines state to prioritize life over limb, perform only the strictly necessary procedures, minimize repeated operations, and defer as many procedures as possible [22]. Obviously, complete personal protective equipment (PPE) must be at disposal [23]. Nevertheless, due to a lack of or inadequate PPE, the rate of infections of medical and nursing staff has often reached unacceptably high levels. Despite the WHO recommendations that health personnel should be equipped with PPEs such as N95 or FFP3 masks, eye protection, gowns, and gloves to protect themselves against infection, a great shortage of this material has been registered almost everywhere [24].

When safe procedures cannot be ensured, if possible, temporizing treatments, like negative pressure wound therapy or various bilayer matrix wound dressings, can delay reconstruction surgeries until a more suitable time is found.

Tips and Tricks
Complete personal protective equipment (PPE) to use in the operating room:

- Surgical cap
- Goggles
- Gowns
- Gloves
- N95 masks
- Shoe covers

Potential COVID-19 infection transmission becomes even higher when dealing with facial trauma procedures, and some guidelines have been proposed as well. According to them, surgeries that restore functionality must be prioritized, performing as much closed reductions as possible. Mucosal incisions should be limited, along with all airway procedures, suctioning, and irrigation [25].

Even if free flaps tend to be discouraged, as microsurgery is considered time- and resource-consuming, some patients may still require it. In such cases, surgeons must take in consideration that COVID-19-affected patients are at risk of disseminated intravascular coagulation, so some authors suggested to administrate heparin for at least 15 days in patients screened positive for COVID-19 and requiring microsurgery [26].

Regarding skin tumors, the risk of a significant worsening of the prognosis within 30 days has been proposed as electivity criteria. Following this statement, patients with histologic diagnosis of melanoma requiring wide excision and/or sentinel node biopsy and patients presenting bleeding ulcerated skin cancers should be considered as urgent elective cases. Alike, the treatment of

solitary cutaneous/subcutaneous metastasis derived from solid tumors and rapidly growing and suspected aggressive malignancies should not be postponed [27].

Tips and Tricks

Urgent elective cases in skin tumor surgery:

- Melanoma diagnosis that demands wide excision and/or sentinel node biopsy
- Bleeding ulcerated skin cancer
- Solitary cutaneous/subcutaneous metastasis
- Rapidly growing cutaneous masses

Breast Units faced limitations in economic and workforce resource utilization as well. As the American Society of Plastic Surgeons (ASPS) recommended, immediate breast reconstruction burden was evaluated, and resource streamlining was introduced as in unprecedented time. Telemedicine services were implemented as possible, and "same-day surgery" protocols were introduced [28]. Following the EUSOMA guidelines [29], the multidisciplinary team kept meeting once a week, with telematics conferences that replaced face-to-face meetings. While screenings were suspended, a reorganization of spaces and schedules allowed maintaining active services of diagnosis in cases of breast symptoms, aiming to preserve care of patients at the highest levels as possible. Due to the rapid COVID-19 infection spread, resource prioritization became mandatory in surgical breast treatment too. A resource-limited operative protocol for immediate implant-based breast reconstruction appeared to be a safe and economic way to guarantee oncologic and reconstructive treatment while reducing the burden and inpatient volume.

Although breast reconstruction procedures might be questioned or advocated as not urgent in a pandemic environment, potential major negative consequences must be considered. Scarring, psychological distress, and increased number of late surgical procedures with associated worse complication rates and postoperative risks may bring additional risks to patients and burden to the healthcare system [19].

According to the Italian experience described by Casella et al. [30], weekly surgical session numbers were reduced, and the length of time between diagnosis and surgery extended. As a consequence, median waiting time raised beyond the days indicated by EUSOMA [29] for both urgent and secondary reconstructive procedures. The increase in waiting times for secondary reconstructive surgery favored immediate post-mastectomy reconstructions. When suitable with the viability of mastectomy flaps, direct-to-implant prepectoral reconstruction was the first choice, and tissue expanders were placed in other cases. Autologous reconstructions were carried out when patients refused heterologous procedures or in the presence of absolute contra-indications to breast implants positioning. Pedicled latissimus dorsi flap was preferred to microsurgical free flaps, as it does not require access to intensive care units or prolonged hospital stay [31].

Moreover, in recent years, along with the concept of the *aesthetic cancer cure*, even the role of breast surgeons in Breast Units underwent an evolutionary development. The COVID-19 pandemic pushed somehow surgeons to accelerate this process, in order to refine and consolidate their role in this constantly reshaping field. The meaning of the term *oncoplastic surgery* goes far beyond the simple concept of both oncologic and plastic surgeries combination. From a wider point of view, it indicates a dynamic way of patient's care, with efficacious cancer surgery together with preservation or improvement of the breast aesthetic [32].

An optimal result is achieved only when the entire skillset is at disposal. A global multidisciplinary approach is always desirable, and usually the surgical team is composed of general and plastic surgeons. Nevertheless, according to Shaterian A et al. [33], a dual-trained surgeon is associated with improved breast reconstruction rates if compared to traditional team approach. Indeed, a surgeon trained in both breast oncology and plastic surgery may be a thorough figure with

a comprehensive understanding of breast cancer treatment, leading to wider offer of reconstructive options and higher rates of successful outcomes.

Key Point

In the battle against breast cancer and COVID-19, breast surgery is evolving, and plastic surgeons must adapt, develop new skills, and reshape themselves in a new and comprehensive role.

The pandemic that has hit the world should make us realize how suddenly our lives and profession can change and enable us to reflect on the true values that must guide us in the future [24]. Following the Darwinian sentence: "it is not the strongest of the species that survives, nor the most intelligent. It is the one that is most adaptable to change" [34].

While all efforts are aimed at stopping the pandemic, other serious and life-impacting diseases continue to affect the population. Plastic surgeons are "physicians", prior to being "surgeons". Moreover, the peculiarity of our discipline offers the unique perspective of dealing with all kinds of patients and care teams, fueling the development of ingenuity and new skills to actively participate and contribute to the COVID-19 response. For example, special wound management expertise was requested in dealing with facial wounds caused by personal protective equipment (PPE), in healthcare providers [35].

While other medical specialists fight in the frontline in the worldwide battle against COVID-19, plastic surgery shall not be considered of secondary importance. In the absence of a "gold standard" treatment, the rapid development of a safe and effective vaccine is considered the most promising way to control the pandemic [36].

In such hazardous times, plastic surgeons must adapt and consolidate their role, in order to keep on offering full support to other disciplines while ensuring high standards of care and the continuity of their surgical activity.

34.3 Learning and Sharing Knowledge While Facing the COVID-19 Pandemic

Besides radical changes in personal and working daily routine, medical students' didactic and residents' training programs underwent important modifications, to respond and adapt to the pandemic events. Institutions from all around the world reacted implementing online platforms to keep on delivering info and "education." Webinars and online exams represent modern and easy-to-apply solutions, even if limited to theoretical sharing. Residents belonging to surgical areas report that their training was somehow weakened, due to the reduced number of surgical procedures [37].

In Zingaretti N. et al.'s [37] study, a questionnaire that investigated how practical and theatrical activity has changed in pandemic was submitted to all Italian plastic surgery residents. Indeed, the majority of them reported lack of training during this period as a detrimental factor for their professional growth. It is mandatory to find alternative ways to keep on sharing knowledge and developing skills while maintaining a good quality of the educational targets.

In the last years, the classic learning Halstedian model of "see one, do one, teach one" changed into a modern proficiency-based training, thanks to new technological advancements [38]. Online videos shared on social media portals are gaining importance, as an easy and effective way to share information in the medical field, and plastic surgeons appear to be particularly fond of their use. Indeed, due to their practice with social media, they are in a unique position to provide medically sound information about COVID-19 to their followers. Despite the existence of some ethical dilemma on the appropriate use of social media in plastic surgery, in the actual context, it appears ethically justified as it benefits the public and demonstrates commitment to professional virtues [39].

Moreover, online communication became of vital importance in nowadays' extreme conditions due to COVID-19 pandemic, and webinars are virtual learning platform with several advantages. In times where social distancing is mandatory, webinars' geographic flexibility offers safe learning opportunities from expert surgeons across international boundaries [40]. Even the instant messaging service WhatsApp® can aid and deliver case-based discussions among physicians at a distance [41].

It is possible that some of these learning innovations will become a permanent addition to the "new normal" of the residency program, as an enhancement in training and clinical care.

Research and education are facing great difficulties that can be overcome only if adaptation and innovation are introduced. Given their recent spread in healthcare field and considering their potential to improve surgical training, telecommunication appears a powerful educational tool for residents and specialists [42].

Key Point

Modern pandemics like COVID-19 should be expected to happen more frequently moving forward, and the scientific community must show preparedness to confront with enemies like these.

Take-Home Messages

- On March 11, 2020, the WHO declared the COVID-19 infection a pandemic.
- Healthcare services are facing unprecedented burden, with shortages of hospital resources, workers, and protective equipment.
- Non-urgent treatments and surgeries have been reduced or suspended.
- While other medical specialists fight in the frontline against COVID-19, plastic surgeons must adapt and evolve in a new role, ensuring high standards of care and the continuity of their surgical activities.
- Research and education are facing great difficulties that can be overcome only if adaptation and innovation are introduced.

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