Treatment of Fractures in Children and Adolescents

Edited by

B.G. Weber · Ch. Brunner · F. Freuler

In Collaboration with

P. Berruex · R. Blatter · A. Boitzy · Ch. Brunner · J. Cehner
F. Freuler · F. Kern · R. Liechti · F. Magerl · R. Marti · P. Mehmann
R. Morger · G. Müller · D. Pelet · U. Saxer · R. Schenk
F. Schönenberger · G. Segmüller · K.G. Stühmer · F. Süssenbach
E. Waidelich · B.G. Weber · H. Zimmermann · K. Zöch

Translated by P.A. Casey

With 462 Figures

Springer-Verlag
Berlin Heidelberg NewYork 1980

Prof. Dr. B.G. WEBER, Klinik für Orthopädische Chirurgie, Kantonsspital,
CH-9007 St. Gallen

Dr. CH. BRUNNER, Klinik für Orthopädische Chirurgie, Kantonsspital,
CH-9007 St. Gallen

Dr. F. FREULER, Passwangstr. 31,
CH-4059 Basel

Translator: Dr. P.A. CASEY, Oberwohlenstr. 45,
CH-3033 Wohlen/Bern

Title of the original edition:
Die Frakturenbehandlung bei Kindern und Jugendlichen.
Herausgegeben von B.G. Weber, Ch. Brunner und F. Freuler
Springer-Verlag Berlin Heidelberg New York 1978

ISBN-13: 978-3-642-67273-6 e-ISBN-13: 978-3-642-67271-2
DOI:10.1007/978-3-642-67271-2

Library of Congress Cataloging in Publication Data. Main entry under title: Treatment of fractures in children and adolescents. Translation of Die Frakturenbehandlung bei Kindern und Jugendlichen. Includes bibliographies and index. 1. Fractures in children. I. Weber, Bernhard Georg. II. Brunner, Christian Ferdinand, 1937– III. Freuler, Franz, 1939– RD101.F7913 617'.15 79-16985

Softcover reprint of the hardcover 1st edition 1980

Typesetting, printing, and bookbinding by Universitätsdruckerei H. Stürtz AG, Würzburg

2124/3130-543210

Preface to the German Edition

There are many textbooks on fractures in adults, but few deal with those in children and young persons. Publications on fractures in children are usually written by orthopedic surgeons who are familiar with the problems presented by the growing skeleton.

The principles taught in the best known works on fractures in children by BLOUNT (1954), RETTIG (1957), CHIGOT and ESTEVE (1957), EHALT (1960), POLLEN (1973), and RANG (1974), differ from each other only slightly. The controversy which has surrounded the treatment of fractures in adults in recent years has never extended to childrens' fractures. Skillful *nonoperative treatment* of the latter leads to uneventful healing in the majority of cases, which cannot always be said of similar injuries in adults. "Considerable skill" is required to induce nonunion in a child, and its occurrence always results from a serious error of management.

In the adult, prolonged immobilization frequently leads to muscle atrophy, joint stiffness, and disturbances of the peripheral innervation and circulation. *Fracture treatment by internal fixation* in the manner originally described by LANE (1894), LAMBOTTE (1892, 1907, 1913), KÖNIG (1905, 1931), and DANIS (1932, 1949) has gained wide acceptance only in the last 15 years. Since 1958, MÜLLER, ALLGÖWER, WILLENEGGER, and the other members of the Swiss Association for the Study of Internal Fixation (ASIF) have been developing techniques and instruments for the operative treatment of fractures. Their aim has been not only the restoration of bone continuity and joint congruence, but also the prevention of the results of immobilization described above. The immobilization is rendered unnecessary by stable internal fixation which allows functional postoperative management of the fracture. *However, in the child, immobilization changes do not occur and their prophylaxis by internal fixation is therefore superfluous.*

The rapid bone healing and the absence of immobilization disease are the reasons for the common assumption that fracture healing presents no problems in the growing skeleton. The rapid repair rate is, of course, a considerable advantage which exists as long as the skeleton is growing. At the same time, however, injuries to the epiphyseal plate present special problems. The epiphysis is able to correct misalignment spontaneously, but is also a very vulnerable organ. Certain types of injury can lead to growth disturbances of varying severity. Both in the literature and in practice, there is still uncertainty as to the nature and consequences of injury to the epiphysis.

Thus, fractures in children present specific problems which are different from those encountered in adults, and EHALT (1960) considered the treatment of childrens' fractures to be more difficult.

From 1960 onwards, we were directly or indirectly involved in the development of the ASIF techniques as pupils of M.E. MÜLLER at the Orthopedic Clinic of the Cantonal Hospital in St. Gall. At the same time, as orthopedic surgeons, we were particularly interested in childrens' fractures.

Although there is little difference in the methods of treatment recommended by the different authors, we feel that the indications for surgery are insufficiently defined in the literature. Furthermore, some of the techniques described fail to take account of modern developments and concepts. In an earlier publication, we dealt with the

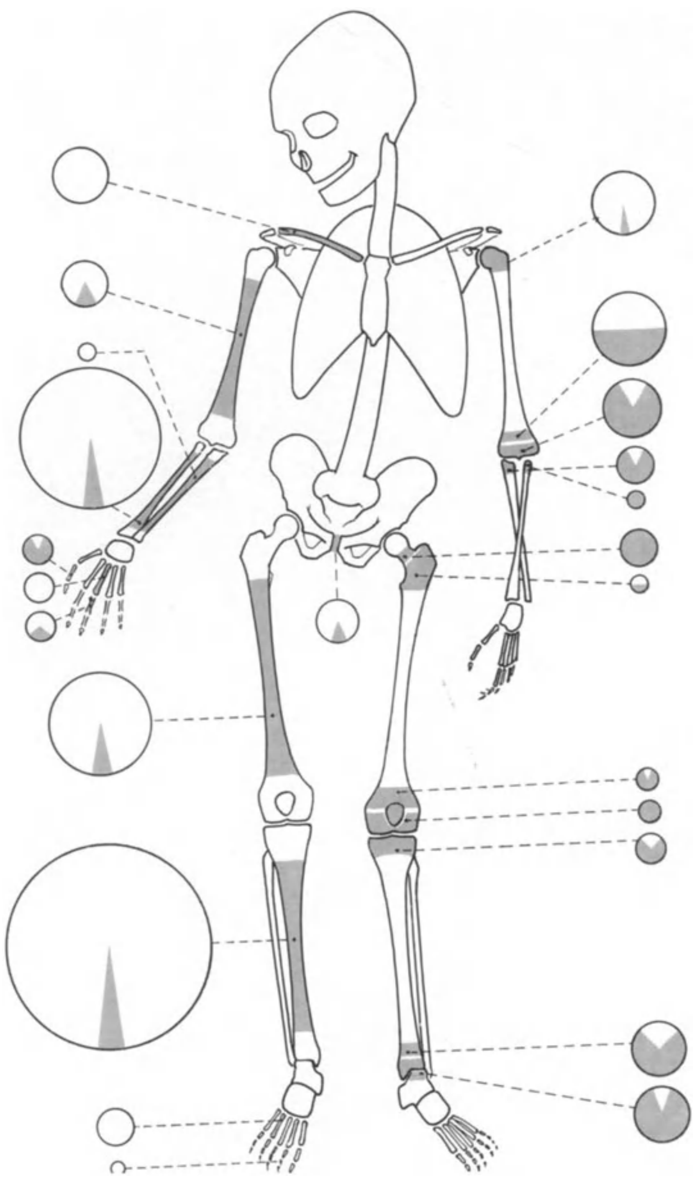
Table 1. Fractures in Children (1961–1966)

Fracture site	No. of cases	No. operated	%
Scapula	1	–	–
Clavicle	26	–	–
Humerus (subcapital)	29	1	3.4
Humerus (diaphysis)	19	2	10.5
Humerus (supracondylar)	50	24	50
Humeral epicondyle	30	24	80
Head of radius	3	3	100
Olecranon	8	6	75
Monteggia	2	–	–
Forearm (incl. distal radius)	165	3	1.8
Metacarpals	6	–	–
Thumbs	5	4	80
Fingers	7	2	28.5
Total upper extremity	351	69	19.6
Pelvis	10	1	10
Femur (trochanteric)	2	1	50
Femoral Neck	8	8	100
Femoral Diaphysis	93	7	7.5
Femur (supracondylar)	4	3	75
Patella	4	4	100
Tibia (intercondylar eminence)	6	4	66.6
Lower Leg (incl. tibia alone)	356	13	3.6
Malleoli	19	17	89.4
Separation of distal tibial epiphysis	26	18	69.2
Metatarsals	11	–	–
Toes	1	–	–
Total lower extremity	540	76	14
Total of all fractures	891	145	16.2

questions "When is surgery indicated? When is surgery not indicated?" (1967). Table 1 shows the considerable difference in frequency of the various types of fracture. Internal fixation was carried out in 16.2% of the cases. We were unable to find figures for comparison in the literature.

It can be seen from Fig. 1 that the proportions of fractures which were treated operatively differed considerably from one localization to another. These differences will be discussed at length. In March 1970 at a symposium on the treatment of fresh childrens' fractures and growth disturbances caused by fractures, our clinic advocated a policy of treatment which is still valid. Since then, the number of childrens' fractures treated by us has more than doubled. We have treated approximately 4000 fractures between 1961 and 1976.

This book describes the systematic treatment of fractures of the growing skeleton as practised in our clinic. Less emphasis is placed on the diagnosis in order to allow a fuller discussion of the problems of the fractures and their consequences. It is well known that it is easy to bring about union of a fracture in a child. Indeed, a surgeon who succeeds in preventing union almost deserves to be congratulated! The problems lie in the prevention of late complications, such as excessive growth, secondary shortening, and secondary axial deviation. On the other hand, specific action must be decided on. In each case, the surgeon must be able to defend his decision to operate or not to operate with well-founded arguments. He must choose a procedure which offers minimum risk and the maximum chance of normal healing. There is little room left for opinion – the treatment of fractures in children must be based solidly on knowledge, logic, and ability.



˙ȝ. 1. *Operative indications ac-ʼding to fracture localization.* .e size of the circle shows the quency of each type of frac-ʼe, the size of the dark segment ꜜ relative frequency of the erative treatment

In the individual chapters, the reader will encounter frequent revisions of the relevant pathophysiology; these are essential to an adequate explanation and justification of the method of treatment being recommended in each case. Even if the book is being used for reference or for help with a specific problem, it is important that the reader finds not only the technique he is looking for, but also the logic upon which it is based.

The main emphasis is laid on the treatment of fresh fractures in order to prevent complications. However, complications which have occurred should also be treated; the child should not have to resign itself to lifelong invalidity which has resulted from a "minor" fracture. For this reason, corrective surgical procedures following fractures in children are discussed and illustrated with specific cases.

The authors have followed up many fractures in order to compare their own experience with the conventional wisdom. In the process, we have learned a lot and our policies of treatment have benefited. These lessons are incorporated into the text.

The book starts with a chapter on the basic histomorphology and physiology of skeletal growth by ROBERT SCHENK.

ROBERT MORGER is a pediatric surgeon. He has written the sections on birth injury, injury to the thorax and abdomen, multiple trauma, and the battered child.

All the other chapters were written by the authors in the course of their duties at the Orthopedic Clinic of the Cantonal Hospital in St. Gall. The editors have satisfied themselves that the individual chapters reflect current policy at the Clinic.

The cases described in the different chapters are taken from different periods. This does not affect the validity of the discussions on the individual topics. Cases are also described which are especially interesting or typical of a particular condition, irrespective of whether they are included in a statistical series.

Each case illustrated is identified by the initials, age, and sex of the patient and by the file number of the roentgenogram. This eases subsequent follow-up and allows our readers to pose questions on individual cases.

The roentgenograms have been copied by a computerized scanner which compensates for changes in contrast. The quality of the copies is more even than that of the original films.

In 1976, the second volume of The Cast Manual appeared, entitled Common Splints and Traction Methods for the Treatment of Injuries in Children. By their work, the authors of that text, Freuler, Wiedmer, and Bianchini, have eased the task of the editors in preparing this book. In many places, we have been able to omit technical details and the manual techniques of nonoperative treatment; in each case, reference to Vol. II of The Cast Manual is implied.

The editors and co-authors wish to thank Mrs. M. Schaffner (photographic technician), Miss K. Schumacher (artist), and Miss U. Oetliker (chief secretary) for their invaluable and untiring assistance. We should also like to thank Springer-Verlag for publishing the book rapidly and efficiently.

St. Gall

Bernhard Georg Weber
Christian Brunner
Franz Freuler

Contents

List of Contributors

BERRUEX, PIERRE, Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

BLATTER, ROLAND, Dr., Ospedale San Giovanni, CH-6500 Bellinzona

BOITZY, ALEXANDRE, PD. Dr., 6, Ch. de Craivavers, CH-1012 Lausanne

BRUNNER, CHRISTIAN, Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

CEHNER, JOSÉ, Dr., Windeckblick 3, D-7580 Bühl-Vimbuch

FREULER, FRANZ, Dr., Passwangstr. 31, CH-4059 Basel

KERN, FRANZ, Dr., Institut für Anaesthesiologie, Kantonsspital, CH-9007 St. Gallen

LIECHTI, RENÉ, Dr., Service d'Orthopédie, Hôpital du District, CH-1260 Nyon

MAGERL, FRITZ, Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

MARTI, RENÉ, Professor Dr., Orthopädische Universitätsklinik, Binnengasthuis, NL-Amsterdam

MEHMANN, PETER, Dr., Kornhausstr. 3, CH-9000 St. Gallen

MORGER, ROBERT, Dr., Ostschweiz. Säuglings- und Kinderspital, Claudiusstr. 6, CH-9007 St. Gallen

MÜLLER, GEROLD, Primarius Dr., Landesunfallkrankenhaus, A-6800 Feldkirch

PELET, DANIEL, Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

SAXER, ULRICH, Dr., Orthopädische Universitätsklinik, Inselspital, CH-3000 Bern

SCHENK, ROBERT, Professor Dr., Anatomisches Institut der Universität Bern, Bühlstr. 26, CH-3000 Bern

SCHÖNENBERGER, FRIDOLIN, Dr., SUVA-Kreisagentur, Postfach, CH-9001 St. Gallen

SEGMÜLLER, GOTTFRIED, Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

STÜHMER, KARL-GERHARD, Dr., Orthopädische Klinik, St. Elisabethen-Krankenhaus, D-7980 Ravensburg

SÜSSENBACH, FRITHJOF, Dr., Orthopädische Klinik, Evang. Krankenhaus, D-4030 Ratingen

WAIDELICH, ERNST, Dr., Institut für Anaesthesiologie, Kantonsspital, CH-9007 St. Gallen

WEBER, BERNHARD GEORG, Professor Dr., Klinik für Orthopädische Chirurgie, Kantonsspital, CH-9007 St. Gallen

ZIMMERMANN, HERBERT, Dr., Spital Sta Maria, CH-3930 Visp

ZÖCH, KLAUS, Mühlgasse 19, A-6700 Bludenz

GENERAL PART

Basic Histomorphology and Physiology of Skeletal Growth

R. SCHENK

CONTENTS

1 Introduction

For various reasons, interest in the morphology and physiology of skeletal tissue has increased in recent years. On the one hand, this can be ascribed to the important part played by bone in calcium metabolism, research in the latter field having gained significance in the context of metabolic bone disease as well as that of the uptake and elimination of radioactive elements. On the other hand, orthopedic surgical techniques have come into use which have changed the conditions under which bone regeneration occurs. The latter developments occurred during a period of progress in the field of morphologic research which was mediated by the use of new or improved techniques and which allowed hitherto unsolved problems to be tackled and research to be extended to neighboring areas.

There is no doubt whatsoever that the growing skeleton possesses a number of special properties which play an important part in the general biology of the organism as well as in the assessment of injury and the choice of treatment. This applies to the modes of response of those cell populations in the periosteum, endosteum, and cortical canals which participate in bone growth and remodelling. The regional blood supply of these bone-forming tissues is also of considerable importance since osteogenesis is impossible without adequate vascularization.

However, the most obvious feature of the growing bone is the epiphyseal plate, whose complex structure is a prime example of finely balanced interplay between various histophysiological processes. The majority of the present contribution is devoted to the epiphyses and cartilaginous bone formation, and the review is intended to contain not only points of practical relevance, but also an account of some of the advances in research in the field of skeletal biology.

2 Histogenesis of Bone

In this section, the basic aspects of bone histogenesis are summarized (Fig. 1). Osteoblasts which are arranged in epithelial layers first form a noncalcified organic matrix known as osteoid, which contains 95% collagen and 5% proteoglycans (percentages of dry weight) (Fig. 1a). During subsequent mineralization, this osteoid becomes the site of deposition of calcium phosphate, mainly in the form of crystalline hydroxyapatite. In mature lamellar bone, mineralization occurs 8–10 days after matrix formation in a zone which is clearly demarcated under the light microscope and which is referred to as the mineralization front. The delay of 8–10 days between formation and mineralization of the osteoid can be deduced from the mineralization rate of 1 μm per day found by *Frost* (1963) using tetracycline marking, since the average width of the osteoid seam in the adult is 8–10 μm. However,

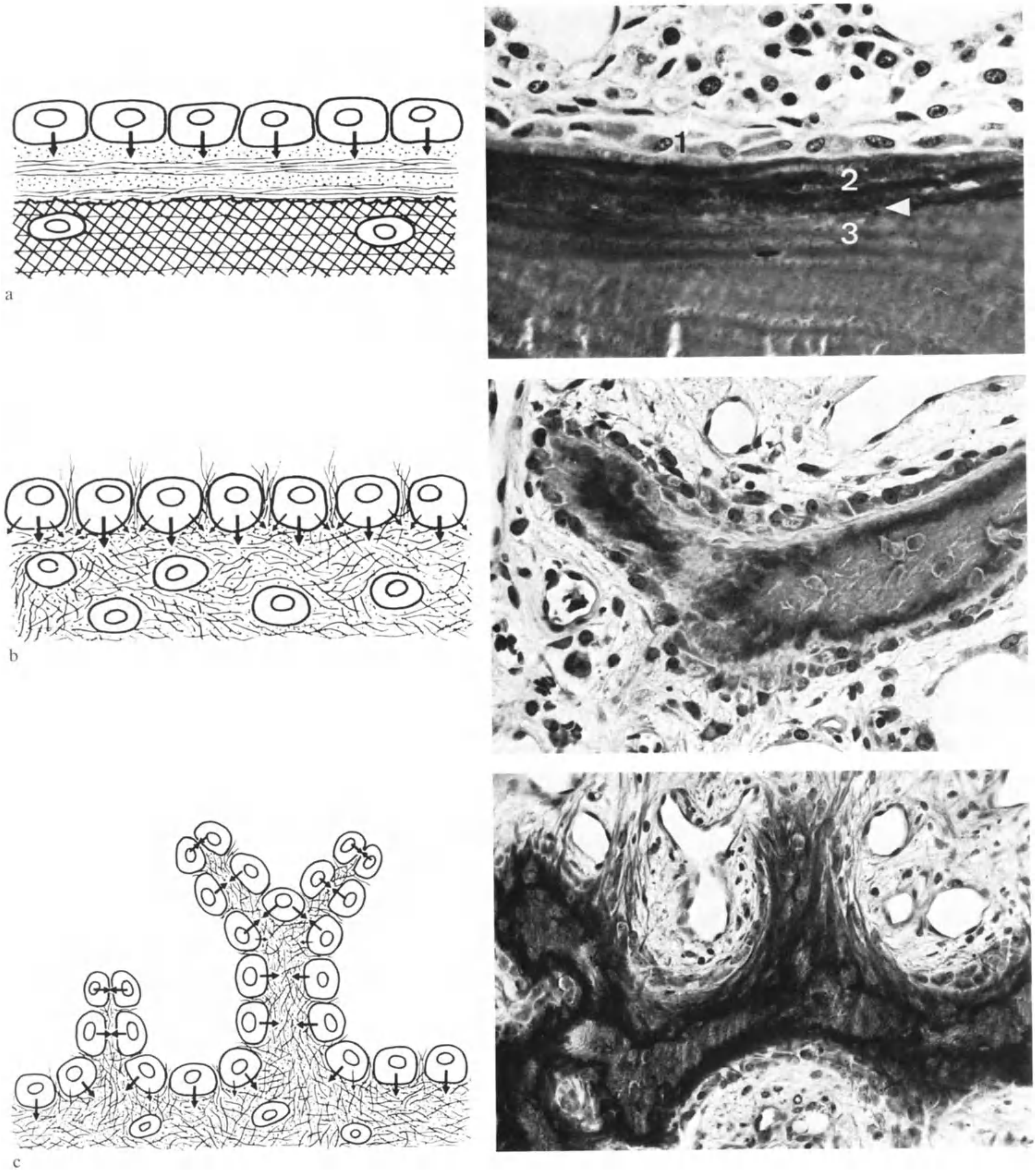


Fig. 1a–c. *Histogenesis of bone tissue*. Nondecalcified microtome sections stained by the Goldner method, with explanatory diagrams.
a) Area of apposition in lamellar bone seen in an iliac crest biopsy. (*1*) osteoblasts; (*2*) osteoid; (*3*) mineralized bone. *Arrow* indicates mineralization front. Magnification ×450.
b) Woven bone formation in human fracture callus. Magnification ×320. See text.
c) Development of a trabecular framework by woven bone in a fracture callus. The adjacent granulation tissue is well vascularized. Magnification ×200

this only applies to lamellar bone. During embryonic and fetal osteogenesis, accelerated growth, and bone regeneration, lamellar bone is usually preceded by fibrous or woven bone. The latter tissues exhibit a wide range of special histophysiological properties (Fig. 1b).

Their intercellular substance contains a spatially disordered three dimensional array of collagen fibrils which rapidly mineralizes following its formation. The osteoid seams are relatively narrow. Furthermore, the cell population in woven bone is denser than that in lamellar bone. Tetracycline marking of fibrous bone gives rise to diffuse, widespread fluorescence, so that the rate of apposition cannot be precisely determined. Woven bone also has a particular growth characteristic: it may proliferate in the form of ridges and trabeculae which combine to rapidly create a relatively extensive framework (Fig. 1c). The synthesis of lamellar bone requires a relatively flat, smooth substrate on which the lamellae are laid down in congruent layers with parallel collagen fibers, the direction changing from one lamella to the next (Fig. 1a). During this process, the osteoblasts are seen to act in a strongly polarized fashion, i.e., the extrusion of matrix material is restricted to their basal cell surfaces which are directed towards the osteoid. During the formation of fibrous bone (Fig. 1b), the osteoblasts also lay down collagen fibrils along their lateral surfaces, and these fibrils may be joined to fibers in the surrounding connective tissues, e.g., periosteum. The creation of struts and trabeculae starts with the polar rotation of two neighboring osteoblasts by 90°. These cells then commence laying down bone in a direction at right angles to their base. Pre-osteoblasts, which are derived from precursors capable of proliferation (osteoprogenitor cells), join up with the above cells and lengthen the salient trabecula at a rate which is no longer determined by apposition, but by the rate of division and differentiation of the osteoblasts and their precursors.

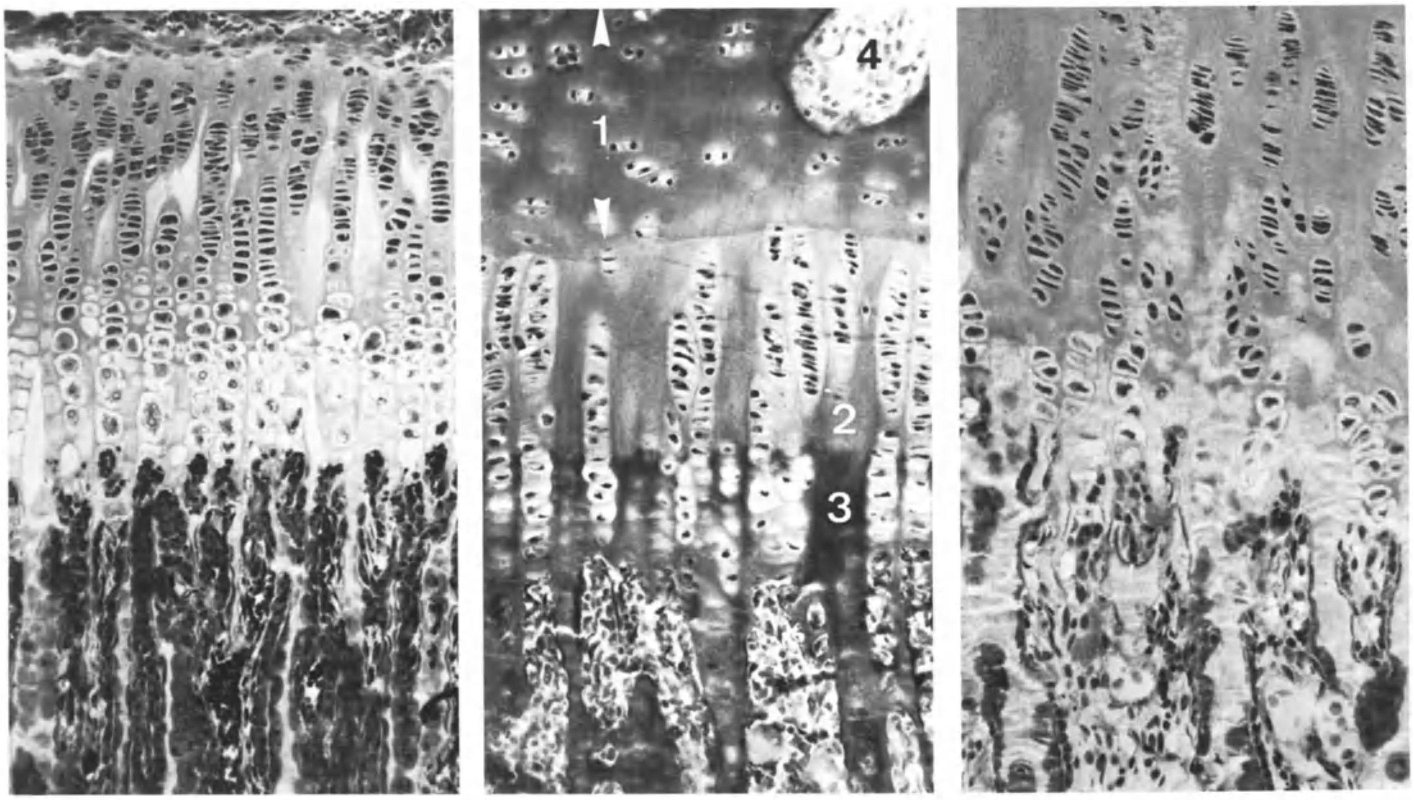
In order to understand bone formation, the reader should be aware of the decisive importance of the very close relationship between the osteoblasts and a functionally adequate capillary network. In the German literature, knowledge of this factor is primarily ascribable to the concept of "primary angiogenic ossification" described by *Krompecher* (1937). It also gave rise to extensive hypotheses on the origin of the osteoblasts; according to *Trueta* (1963), they are derived from endothelial cells, while *Friedenstein et al.* (1966) even considered blood cells to be their precursors. In fact, the osteoblast precursors are preferentially located in the walls of blood vessels, irrespective of their designations as pericytes, perivascular cells, or simply mesenchymal accessory cells. The close relationship of the osteoblasts to the capillaries is primarily explained by the high oxygen and metabolite requirements of these highly active cells.

The close interrelationship of bone formation and blood supply is an important basic concept which is essential to an understanding of fetal and postnatal bone growth. It is this factor which causes almost all skeletal development to take place via connective tissue or cartilaginous precursor stages. The main function of the intermediate supporting tissues is the maintenance and protection of the capillary blood supply to the osteogenic cells despite the varying loads placed on the tissue.

3 Forms of Embryonic and Fetal Osteogenesis

Skeletal development takes place in connective tissue or cartilage substrate, the only exception being the process described by *Krompecher* as primary angiogenic ossification which is restricted to a few stress-free areas in the skull and does not require an intermediate supporting tissue. *Intramembranous ossification* occurs in an intermediate connective tissue, examples being the ossification of the roof of the skull, the mandible, the clavicle, and the bone spurs which form at the insertions of ligaments and tendons. On the other hand, periosteal bone apposition can only be designated as intramembranous in a restricted sense, since it first takes place perichondrally and is accompanied by an incorporation of collagen fibers only in the locations mentioned above. The great majority of the skeleton of the trunk and extremities is preformed in cartilage; in particular, the ossification of the long bones is perichondral and endochondral. Since endochondral ossification plays a particularly important part in growth in length at the epiphyses, we shall now examine cartilaginous ossification in more detail. Special aspects of intramembranous ossification will be discussed when dealing with the periosteal involvement in circumferential growth.

The basic processes of bone formation in cartilage are generally exemplified by ossification of a long bone. Following the creation of a perichondral bone cylinder in the *diaphysis* and the formation of a medullary cavity by the resorption of cartilage, the articular ends of the bone consist of pure cartilaginous epiphyses. At the borders of the medullary cavity, typical endochondral ossification takes place and leads to formation of the primary cancellous bone trabeculae which are characteristic of the metaphysis of a long bone. At an age which is genetically determined and specific for each bone, centers of ossification appear within



a b c

Fig. 2a–c. *Photomicrographs for comparison of the proximal epiphyseal plates in tibiae of different species.* Nondecalcified microtome sections stained by the Goldner method. Magnification ×125.
a) Rat, approximately 80 g. Extremely narrow zone of resting cartilage. The columnar and hypertrophic cartilage zones contain many cells and are of approximately the same height.
b) Dog (beagle aged 7 months). Large area of resting cartilage (*1*). Clearly delineated cartilage columns with broad intercolumnar septa (*2*) which merge with equally broad calcified cartilage septa (*3*). Vascular canal containing capillaries supplied from the epiphysis (*4*).
c) Human aged 14 years (during growth). The resting cartilage begins at the upper margin and is at least as tall as the columnar and hypertrophic cartilage segment which is depicted. The axes of the cell columns run spirally. The volume of the matrix is greater than that of the cells

the cartilaginous epiphysis; they expand and gradually replace the cartilage until only the joint cartilage and the epiphyseal plate remain. The latter is a cartilaginous layer which completely separates the ossified epiphysis from the metaphysis and which is continuous with the articular cartilage around its circumference. Around its circumference, the epiphyseal cartilage is covered with a layer of perichondrium. A capillary network lies along the epiphyseal surface; it derives its blood supply from epiphyseal vessels and nourishes the epiphyseal cartilage. The epiphyseal vessels enter from the sides or pass through vascular canals from the metaphysis to the epiphysis. The dense capillary network covering the metaphyseal surface is supplied by metaphyseal arteries which either pierce the corticalis from the outside or derive their blood supply from the vascular system of the medullary cavity which, in turn, is supplied by the nutrient artery. During intracartilaginous ossification, the metaphyseal vessels play an important part in the invasion of the cartilage and in supplying the osteoblasts which synthesize the primary cancellous bone.

4 Structure and Function of Growth Cartilage

Epiphyseal plates from various mammals show the same basic microscopic structure (Fig. 2), but the proportions of the individual zones change during growth. The traditional classification of the zones is not based on unified criteria, and the mixing of histophysiological and structural variables leads unavoidably to blurring and overlapping of the borders. Macroscopically, the cartilaginous plate can first be divided into *epiphyseal* and *metaphyseal segments* (Fig. 3); the actual *ossification zone* is situated further down in the metaphysis. Bordering on the epiphysis is a zone of *resting cartilage* which may become very thick, but which

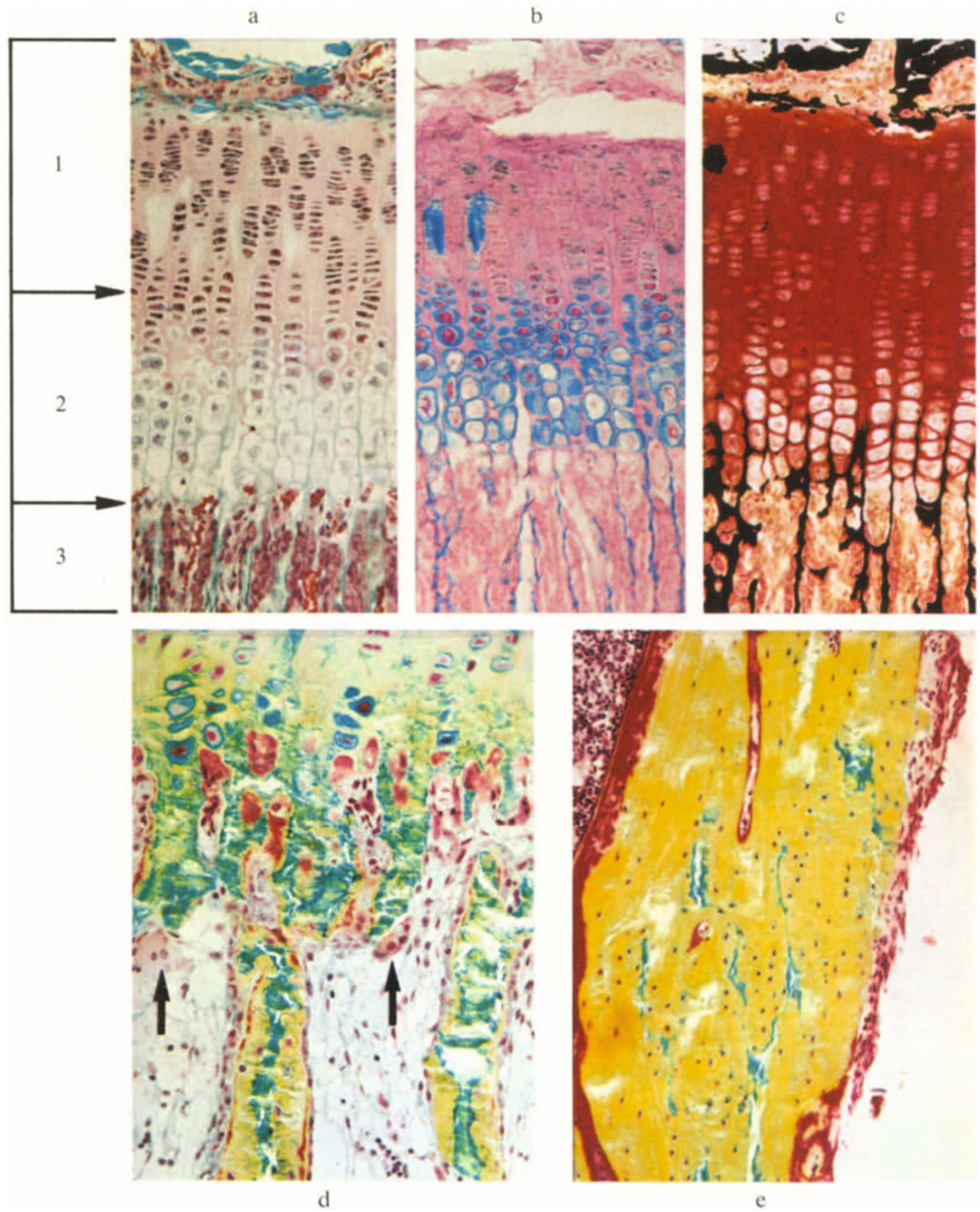


Fig. 3a–e. *Zoning in the proximal epiphysis of a rat tibia. Nondecalcified microtome section.* Magnification × 125. Epiphyseal segment (*1*) contains proliferative zone and columnar cartilage. Metaphyseal segment (*2*) contains hypertrophic cartilage and zone of temporary calcification (*3*) zone of vascular invasion and ossification.

a) Stained by the *Goldner* method.

b) PAS stain combined with alcian blue to demonstrate the proteoglycan capsules around the hypertrophic cartilage cells.

c) *Von Kossa* stain shows up calcium deposits (modified according to *Krutsay*; secondary staining with pyronine). Mineralized matrix appears black; noncalcified cartilage is metachromatic brown-red.

d) Zone of vascular invasion and ossification in the proximal epiphyseal plate of the tibia of a 14-year old male. Nondecalcified microtome section. Modified pentachrome staining by the method of *Olah et al.* (1978). The primary cancellous bone trabeculae contain calcified cartilage remnants (*blue-green*) on which mineralized bone (*yellow*) is deposited. The thin osteoid seams on the surface of the trabeculae (*red*) are covered with osteoblasts. At the border with the medullary cavity some of the calcified cartilage septa are being resorbed by multinucleate chondroclasts (*arrow*). Magnification × 160.

e) Segments from the metaphyseal cortex stained as in 3d. Magnification × 100. Calcified cartilage remnants are incorporated into the compact bone (*blue-green*). Osteoid (*red*) is seen covering the area of apposition along the endosteal surface of the medullary cavity (*left*). Periosteal surface (*right*) shows signs of resorption is frequently reduced to a few cells (Fig. 2). The cell replication in the proliferative zone, which is essential for growth, leads to the formation of isotypic cell groups which synthesize increasing amounts of matrix and thus give rise to the parallel rows of cells which are characteristic of *columnar cartilage*. Using autoradiography, *Kember* (1960) showed that the cartilage cells throughout the epiphyseal segment were capable of replication and that the ability to divide was not restricted to germinative zones at the tips of the cell columns. On the other hand, the cells in the metaphyseal segment can no longer divide and are simply passing through a phase of differentiation characterized by marked hypertrophy due to fluid uptake (Fig. 3). They swell up to form *hypertrophic cartilage cells* with partial loss of the longitudinal cartilaginous septa which separate them. In these intercolumnar septa just before the border with the metaphysis, mineralization of the cartilage matrix occurs which is typical of the *zone of provisional calcification* (Fig. 3c). This is a prerequisite for ingrowth of the metaphyseal vessels; the cartilage in this *calcified zone* is resorbed and the vessels irrupt into the spaces left by the hypertrophic chondrocytes. During this process, parts of the calcified longitudinal cartilaginous septa remain. In the metaphyseal region, their surfaces become covered with osteoblasts which lay down fibrous bone and thus form the primary trabeculae which are typical of the ossification zone (Fig. 3d).

It has already been pointed out that the relative sizes of the individual zones vary with the rate of growth, but that the proportions remain very constant for a given epiphysis at a given point in time. This means that the histogenetic processes which take place in epiphyseal cartilage, such as cell proliferation, matrix synthesis, cell differentiation, mineralization, cell death and resorption are precisely attuned to each other in their intensities. The complexity of the individual processes is discussed below; it implies the presence of a whole range of local and systemic control systems which are essential for coordinated growth, but whose individual mechanisms are still poorly understood.

4.1. Cell Proliferation and the Synthesis of Matrix

Cell proliferation is made possible by a pool of chondroblasts capable of division which extends throughout the columnar cartilage from the resting cartilage to the beginning of the hypertrophic cartilage. The interruption of matrix synthesis by cell division is only transient; certainly under the electron microscope, the chondroblasts show only slight variations in their cytoplasmic structure. The chondroblasts are characterized by an extremely well-developed endoplasmic reticulum with large numbers of ribosomes, an extensive Golgi apparatus, lysosomes, and scanty, relatively small mitochondria (Fig. 4). The glycogen content is low at the heads of the cell columns and increases markedly in the direction of the metaphysis. Lipid inclusions are absent. The extensively developed endoplasmic reticulum serves to synthesize collagen. The voluminous Golgi apparatus is involved in the synthesis of proteoglycans, a fact which can be confirmed by the incorporation of radioactive glucose or sulfur (S^{35}).

Since 1970, chemical investigation of the different types of collagen has shown that cartilaginous collagen is different from that found in bone, skin, or tendon. The latter organs contain Type I collagen with a tropocollagen molecule made up of three polypeptide chains which are twisted around each other; two of these chains are identical (alpha 1[I]) and the third has a different amino acid sequence (alpha 2). Type II collagen found in cartilage contains three identical chains whose structure differs from those described above (alpha 1 [II]). The Type II molecule is thought to be somewhat longer than Type I and its striations are less pronounced in contrast preparations under the electron microscope. The increased number of positive charges results in an increased affinity to the negatively charged glycosaminoglycans in the ground substance. These facts explain the much finer structure of the collagen fibrils under the electron microscope and the transverse striation which only becomes evident following extraction or enzymatic splitting of the proteoglycans (Fig. 5). The fibrils are apparently coated with proteoglycans which in turn form a 3-dimensional interfibrillary network; this is the structural basis of the ground substance which used to be described as amorphous and which is characterized by a very high water content (Fig. 5a). The proteoglycans make up aggregates of up to 4 µm in size which are arranged in rows along a hyaluronic acid backbone. More precise information about their macromolecular structure was recently provided by *Rosenberg et al.* (1974). Cartilage substance appears at first to be homogeneous, but morphological analysis has shown the existence of matrix compartments which add to and modify the conventional histological classifications. The cartilage cell is surrounded by an acid mucopolysaccharide capsule which can be demonstrated by contrast staining with alcian blue, ruthenium red, and other dyes (Figs. 3c, 4d). This capsule is surrounded in turn by a thick feltwork of collagen fibrils which, together with the glycoproteins, binds the cells together in columnar bundles. This matrix compartment

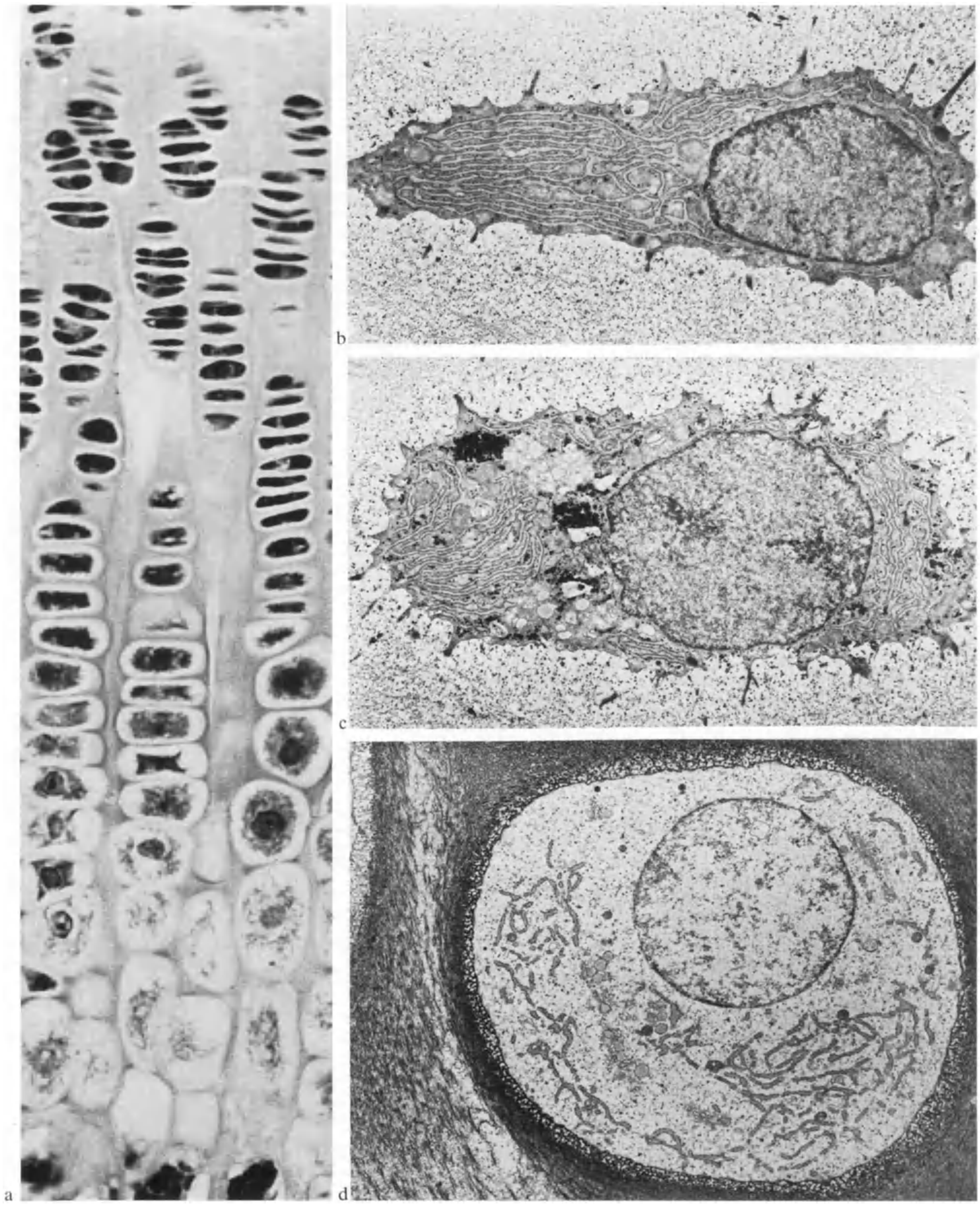
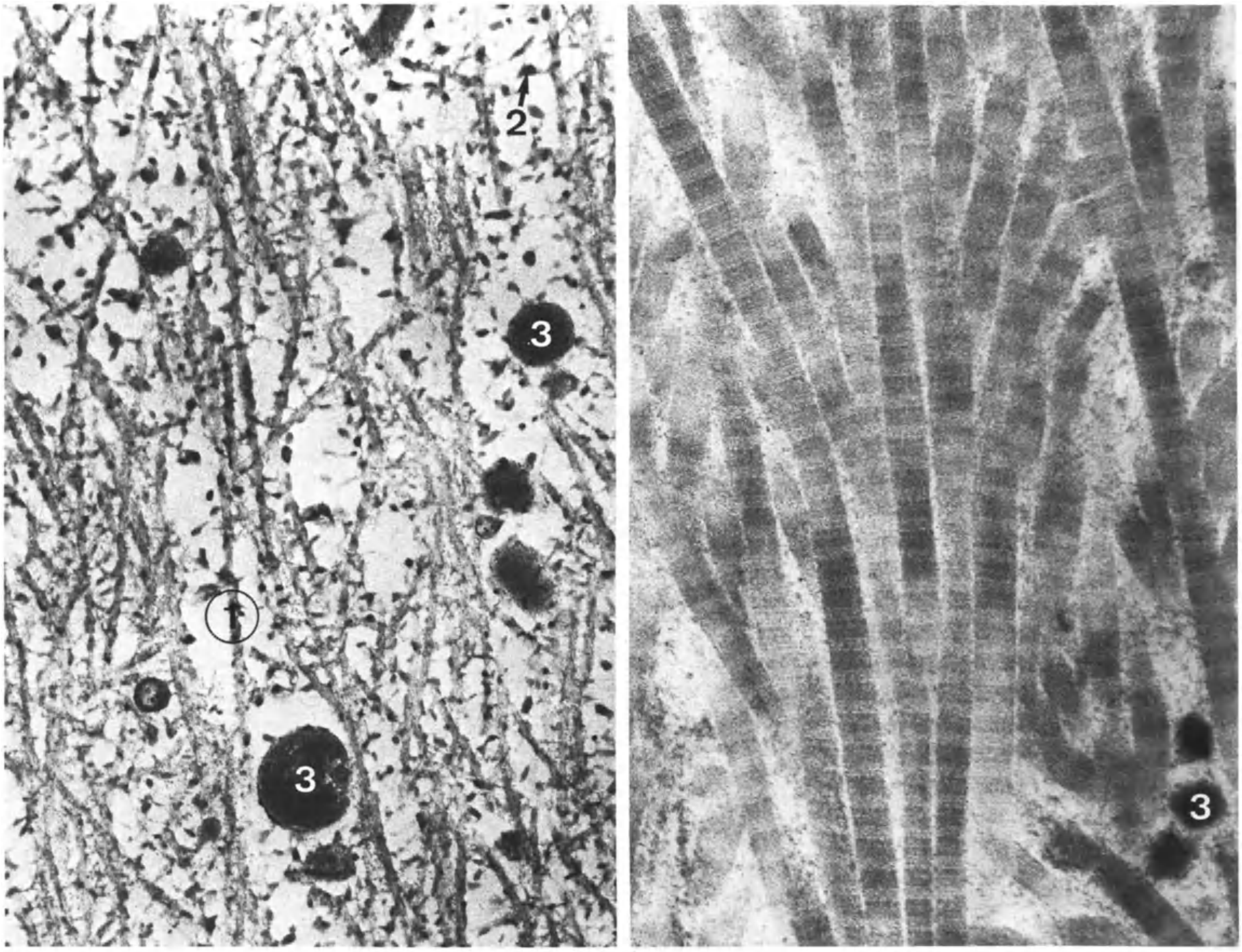


Fig. 4a–d. *Electronmicrographs of the cell types in the growth cartilage of the rat tibia.*

a) Light micrograph showing the positions of the adjacent cells.
b) Cell from the proliferative zone with abundant granular endoplasmic reticulum. Magnification ×9,000.
c) Cell from the middle of the columnar cartilage with glycogen deposits (*black granules*) and prominent Golgi apparatus (*left of nucleus*). Magnification ×7,500.
d) Hypertrophic cartilage cell. Proteoglycans are stained with ruthenium red. The strongly contrasted perilacunar matrix corresponds to the proteoglycan capsule stained with alcian blue in Fig. 3c. Magnification ×5,000



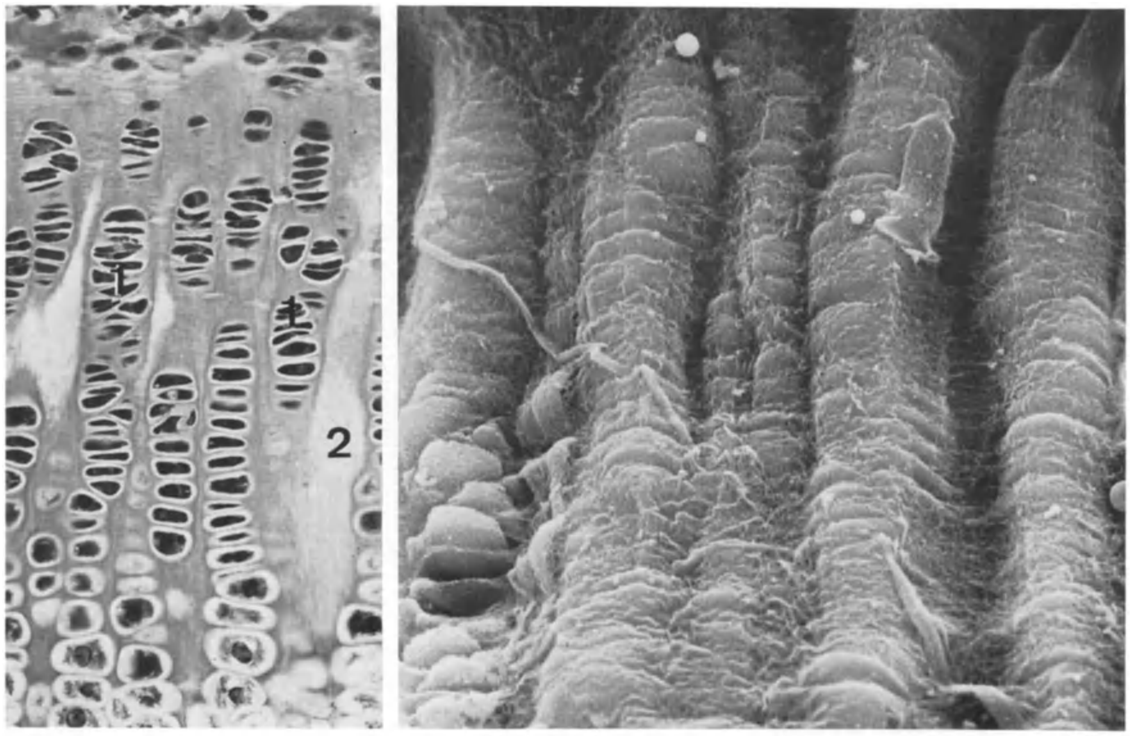
a b

Fig. 5a, b. *Electronmicroscopic comparison of cartilage and bone matrices. Magnification ×70,000.*

a) Interterritorial matrix of a rat tibia. Fine Type II collagen fibrils without recognizable periodicity (*1*) are partly associated with proteoglycans which form an interfibrillary network (*2*). (*3*) Matrix vesicle (see Mineralization).

b) Osteoid seam in a human iliac crest biopsy. Thick Type I collagen fibrils are seen with the characteristic 64 nm periodicity. There is little interfibrillary ground substance. (*3*) Matrix vesicle.
The collagen/proteoglycan ratio is 60%/40% in cartilage and 95%/5% in bone (expressed as dry weight of the organic matrix)

also contains the transverse septa which separate the cells from each other within the column. Together, the cell column and its matrix make up a *territory* (Fig. 6). The territories are separated by longitudinal intercolumnar septa known as the *interterritorial matrix*. This mainly contains longitudinally-oriented collagen fibrils which form bundles in places; these are responsible for the striation which is visible under light microscopy (Fig. 6a). Thus, three matrix components may be defined. They are: the *perilacunar matrix*, which is rich in glycoproteins and more or less corresponds to the classical cartilage capsule; the *territorial matrix* unites the cells which make up the chondron or cartilage column; the *interterritorial matrix*, which lies between the *territories*. The latter is traversed by fibril bundles and is partially mineralized in the zone bordering on the metaphysis. Recently, the existence of these compartments has been confirmed by scanning electron microscopy. By suitable preparative techniques, it is possible to split the epiphyseal cartilage longitudinally (Fig. 6b). In this manner, the individual cell columns can be separated from each other. They indeed turn out to be columnar structural units made up of a column of cells and the surrounding territorial matrix. The interterritorial matrix is easily split in a longitudinal direction and



a b

Fig. 6a, b. *Light micrograph (a, magnification* ×*250) and scanning electron micrograph (b, magnification* ×*1,230) of rat columnar cartilage.* (*1*) Cell columns with surrounding territorial matrix. (*2*) Interterritorial matrix. By splitting the epiphyseal plate longitudinally at the level of the interterritorial matrix, the cell columns can be individualized (specimen and photomicrography: *W. Herrmann*)

is seen to be a 3-dimensional honeycomb, the walls of which completely separate the columnar territorial compartments. In the epiphyseal segment, growth in length mainly results from cell division, which is equivalent to an increase in the number of building blocks within the column. This is complemented by the creation of the transverse interlacunar cartilage septa by matrix synthesis and, finally, by the increase in volume of the individual cells which regain their original size following division.

4.2 Formation of Hypertrophic Cartilage

On entering the metaphyseal segment, the cartilage cells lose their ability to divide and enter a maturation phase which features marked fluid uptake and rapid production of proteoglycans. The proteoglycans form a pericellular capsule which is several microns thick and can be stained with alcian blue and other dyes (Fig. 3c). The proteoglycan capsule is directly joined to the outer leaflet of the cell membrane on the one side and extends into the perilacunar matrix on the other side (Fig. 4d). Its water content probably assists the expansion of the lacunae. In the proliferative zone, the longitudinal diameter of the chondrocytes is 4–6 μm and this increases to 25–30 μm in the hypertrophic cartilage (Fig. 7). The increase in volume is mostly due to fluid uptake, and it is reasonable to suppose that this might be caused by a specific osmotic process. Until now, attempts to test this theory by the use of fixatives with graded osmolarities have been frustrated by the damage to and tearing of the cell membrane caused by changes in the proteoglycan capsule induced by the fixative (*Eggli, Herrmann* and *Schenk*, unpublished observation). This causes the cells to collapse, irrespective of the osmolarity of the solution. By adding certain dyes (ruthenium red, toluidine blue, alcian blue), however, it is possible to precipitate the proteoglycan in situ (Fig. 4d). The glycocalyx and the cell membrane remain undamaged and the cells in the lacunae approximately maintain their natural size. Morphometric comparison of the cell and matrix volumes in rats shows that 25% is occupied by cells and 75% by matrix in the proliferative zone, compared to a relationship of 60% to 40% in the hypertrophic cartilage. Thus, the cell volume has increased at the expense of the matrix volume. However, the decrease in matrix volume only takes place in the longitudinal intercolumnar cartilaginous septa and the thickness of the transverse interlacunar septa remains unchanged. Thus, the cell hypertrophy contributes fully to growth

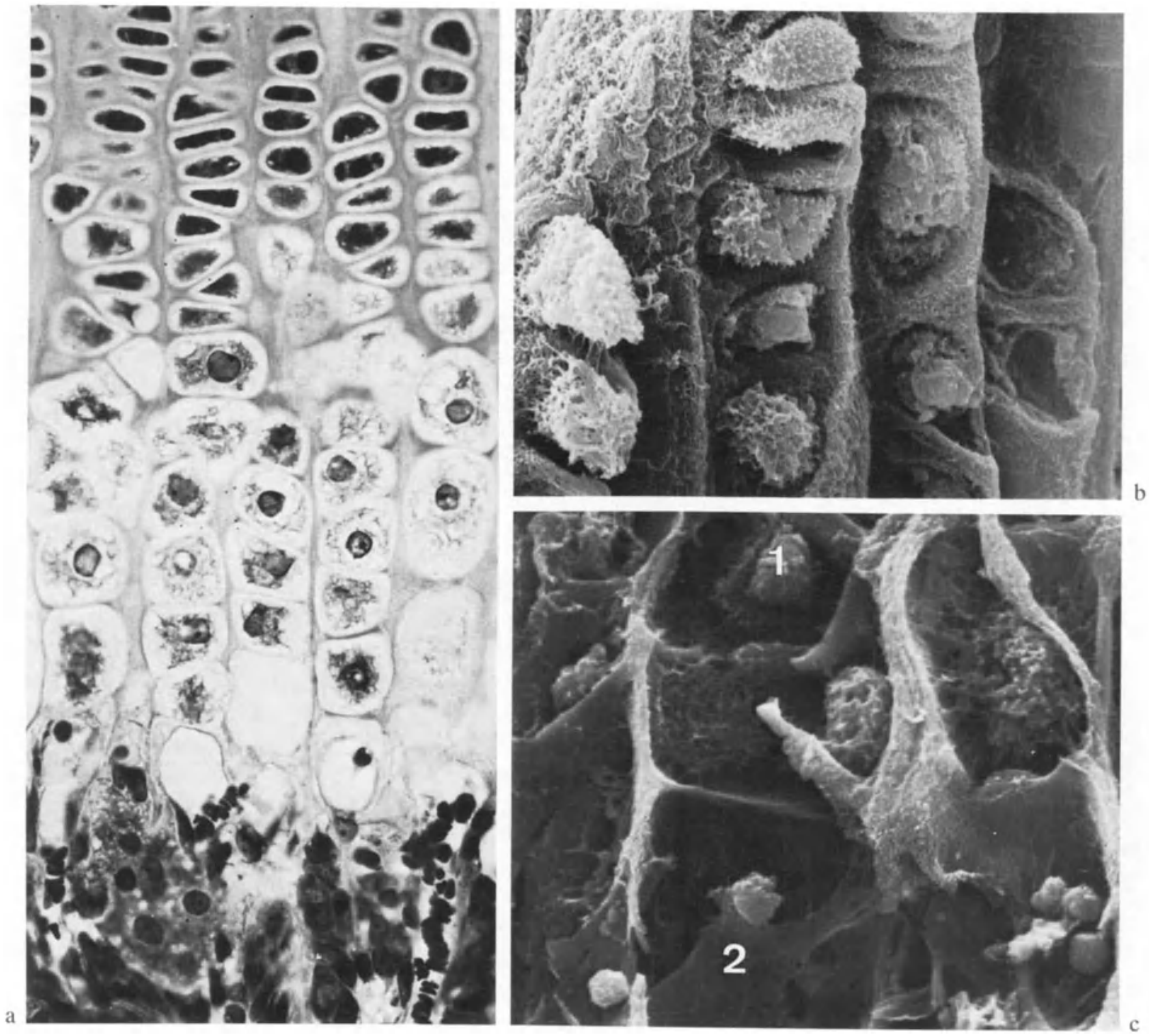


Fig. 7a–c. *Differentiation of hypertrophic cartilage.* The light micrographs (magnification ×400) can be compared to the corresponding scanning electron photomicrographs (magnifications ×2,300 and ×1,850). The volume of the cells increases at the expense of that of the interterritorial matrix. (*1*) Shrunken hypertrophic cartilage cell. (*2*) Endothelial cell of an ingrowing capillary

in length since the height of each structural unit increases from 5 µm to 25–30 µm, i.e., by a factor of 5–6.

4.3 Mineralization of Cartilage

As was shown by *Dodds* (1932), the mineralization of the cartilage is almost totally restricted to the longitudinal intercolumnar septa (*Schenk et al.,* 1967) (Fig. 8). Electron microscopic studies on the calcification zones have furnished interesting information about the initial mineralization processes (*Bonucci*, 1967, *Anderson*, 1968). The first apatite crystals to become visible in conventional electron microscope specimens always lie in direct contact with the so-called matrix vesicles. These are spherical structures with a diameter of up to 150 nm, surrounded by a membrane. At first their content is homogeneous and electron dense (Fig. 8c). Histochemical analysis of isolated vesicles has shown the presence of a whole range of enzymes, above all alkaline phosphatase and pyrophosphatase, which are also found bound to the cell membrane. This led to the assumption that the matrix vesicles were derived from the cell. There are various opinions as to the mode of action of the vesicles, some of them contradictory, but there is no reason to doubt that they are involved in mineralization, both in bone and in cartilage, and that their spatial distribution in the epiphyseal cartilage is responsible for the typical calcification pattern seen in that tissue. Following the appearance of the initial crystal aggregates, the calcification in the interfibrillary spaces progresses

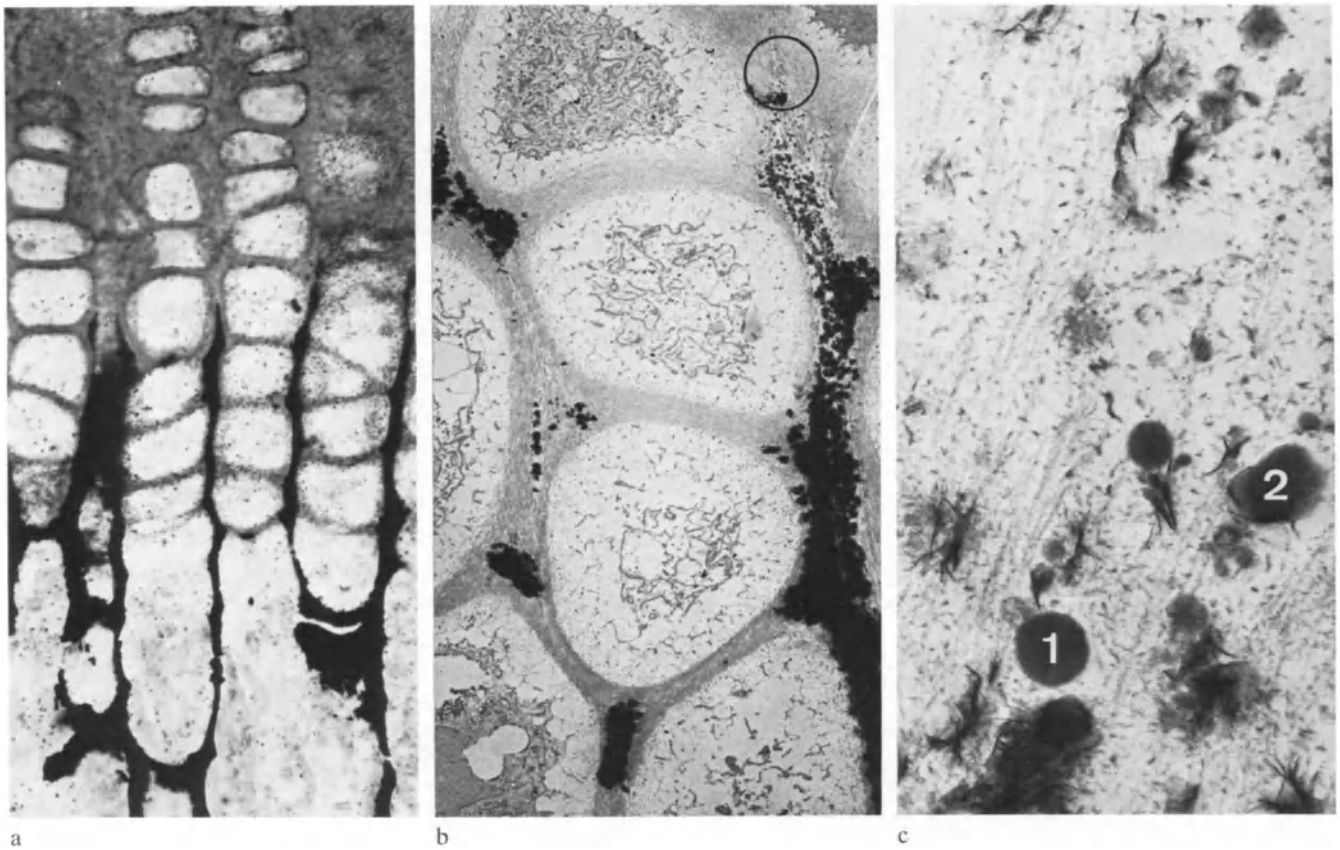


Fig. 8a–c. *Mineralization of the growth cartilage.*

a) The blackening of the *von Kossa* reaction shows the concentration of the mineral in the longitudinal intercolumnar cartilage septa. The cells are not stained (compare with Fig. 3c). Magnification ×500.

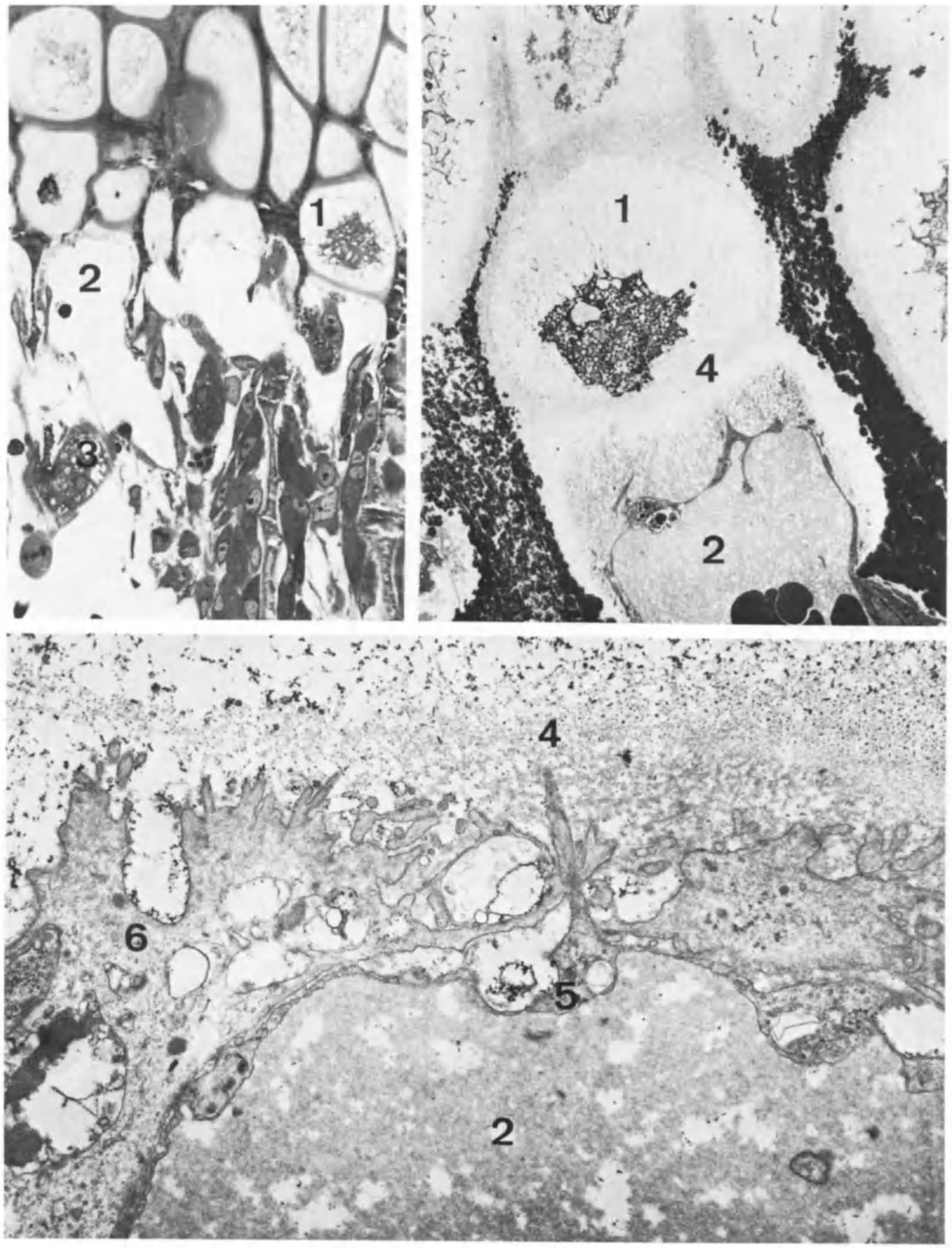
b) Mineralization zone in the electron photomicrograph. The *circle* indicates the position of the field shown in Fig. 8c. Magnification ×1,200.
c) Initial calcification zone with matrix vesicles (*1*). The first apatite crystals appear in contact with the membrane which surrounds the matrix vesicle (*2*). Magnification ×38,000

rapidly but, in contrast to bone, an association does not arise between apatite crystals and collagen. Furthermore, it should be noted that apatite deposition is restricted to the interterritorial matrix; the perilacunar matrix around the chondrocytes and the transverse septa remain free from calcium (Figs. 8b, 9d). The calcification of the interterritorial matrix results in stiffening of the honeycomb previously described, the walls of which enclose the hypertrophic cell columns. The only variations in this pattern seen in mammals are differences in the thickness of the calcified septa and in the number of cell columns enclosed in each honeycomb compartment (cf. Fig. 2).

4.4 Vascular Ingrowth and Resorption of Cartilage in the Zone of Vascular Invasion

The ingrowth of blood vessels along the metaphyseal surface of the epiphyseal cartilage is a remarkable phenomenon, not least of all because the cartilage itself is free of vessels and is normally inaccessible to proliferating capillaries. The mineralization pattern described allows the advancing capillaries access to the base of the individual cell columns which are separated from the metaphyseal intertrabecular spaces by nothing more than a nonmineralized cartilaginous septum. The walls of the intertrabecular spaces consist of solid calcified cartilage which protects the large-bore, extremely thin-walled capillary buds from mechanical stress (Fig. 9). Thus, the resorption processes in the invasion zone take place in both calcified and noncalcified cartilage, the processes being different in each case (*Schenk et al.*, 1967).

The *dissolution of the nonmineralized transverse septa* takes place with the active participation of the vessel walls. The wide-bore capillary buds possess an extremely thin fenestrated endothelium which may contain fine pores (*Zinkernagel et al.*, 1972). Their external surface is only partially covered with accompanying perivascular cells. A basal lamina is absent or consists



a b c

Fig. 9a–c. *Chondrolysis in the invasion zone of the epiphyseal plate of a rat tibia.*

a) Semi-thin section. Magnification ×400. (*1*) Lacunae of the last disintegrating chondrocytes. (*2*) The cartilage is being resorbed by capillaries which have been cleared by perfusion. (*3*) Calcified cartilage is being resorbed by a chondroclast.

b) Electron photomicrograph. Magnification ×1,350. The capillary (with erythrocytes) is not yet fully expanded and its wall is not yet in contact with the remaining transverse cartilage septum (*4*).

c) Dissolution of a nonmineralized transverse septum by infiltration with cytoplasmic processes which originate partially from endothelium (*5*) and partially from accompanying macrophages (*6*). Magnification ×10,600 of fragments occupying the interstitial space between the endothelium and the pericytes. The capillary wall is almost always in direct contact with the surrounding cartilage except in newly opened lacunae in which the ingrowing vessels first have to develop (Figs. 9a, b). Along the surface of contact with the nonmineralized transverse septa at the base of the cell columns, there are morphological signs of intense cell activity in the form of fine cytoplasmic processes which resemble pseudopodia and infiltrate the cartilage (Fig. 9c). These processes belong mainly to the perivascular cells, but also partly to the endothelial cells themselves. In their immediate vicinity in the cytoplasm, primary lysosomes, phagolysosomes, and microtubules are commonly found. Thus, these cells exhibit the characteristics of macrophages and are probably derived from monocytes which leave the vessels in this region.

From a morphological point of view, there is no doubt that the capillary wall plays an active part in the resorption of the nonmineralized cartilage septa. Furthermore, the cartilage cells themselves undergo structural changes which can be construed as evidence of their involvement in chondrolysis. Thus, the chondrocytes adjacent to the base exhibit contraction of their cell bodies prior to invasion of their lacunae by blood vessels; there is an increase in cytoplasmic density, rupture of the cell membrane, and rupture of the membrane system within the cytoplasm (Fig. 9). These features are particulary obvious in specimens which have been fixed by one of the methods described on p. 11 in which the natural shape of the hypertrophic chondrocytes is retained. There is always the possibility that the structural appearance described is influenced by fixation, but nevertheless, one may assume that the disintegrating cells release lysosomal enzymes which take part in the degradation of matrix constituents. In this manner, the nonmineralized cartilage septa are prepared for resorption by the vascular elements which are erupting from the metaphysis. As part of this concept, it is also assumed that the chondrocytes themselves disintegrate and can no longer act as osteoblast precursors.

Thus, the cartilage cells pass through a cycle which begins with cell proliferation and matrix synthesis. This is followed by a phase of differentiation and cell hypertrophy, and the cycle ends with the lysis of the chondrocytes. This chain of events is probably accompanied by a mechanism which synchronizes cartilage growth and destruction in order to ensure normal growth in length. The time course and rates of the individual processes are exemplified by the proximal tibial metaphyses of 80–100 g rats shown in the accompanying illustrations. Growth rates of 400–500 μm per day were found, which correspond to the appearance of 5–8 lacunae per day in each cell column and an appropriate rate of cell division in the proliferative zone.

Descriptions of the cartilage breakdown in the invasion zone frequently begin with the chondroclast. This is a multinucleate giant cell which is identical to the osteoclast in structure and function except that it resorbs calcified cartilage instead of bone. In the invasion zone, its activity is restricted to the dissolution of some of the longitudinal mineralized cartilage septa; in cross section, there is a reduction in the number of calcified cartilaginous septa which are available for the synthesis of the primary cancellous bone trabeculae (Figs. 3d, 9a). In this manner, the width of the intertrabecular spaces increases to three times that of the cartilage cell columns. Spatially, this corresponds to an expansion of the relatively narrow cylindrical columnar cell compartments to form wide labyrinthine tunnels separated by walls composed of calcified cartilage upon which the osteoblasts deposit bone. The thinning out of the calcified cartilage septa also clears the way for the proliferation of numerous hairpin-shaped vascular loops. These give rise to the aforementioned saccular capillary sprouts which grow into the epiphysis. In the ossification zone, the capillary loops supply the osteoblasts on the surface of the trabeculae and also supply the adjoining primary bone marrow. The phases of ossification are described in the introductory section on the histogenesis of bone (p. 3).

5 Regulation and Disturbances of Epiphyseal Growth

It would be reasonable to expect that complex and interrelated processes of differentiation of the type described be subject to physiological control mechanisms at the cellular and tissue levels, and that they would respond to perturbation with characteristic reaction patterns. A system of this type must also contain compensatory mechanisms which counteract temporary local and systemic disturbances. The ability of a fractured bone to correct angular deformity by increasing the rate of growth on one side is an example of such regulation (p. 47). The results of various types of damage to the epiphysis itself are described later (p. 50). The experimental and clinical observations on the influence of hormones and vitamins on various processes in the epiphysis are summarized in Table 1. A discussion of the genetic disturbances of epiphyseal function and the numerous congenital growth disorders would be beyond the scope of this book.

Table 1. Physiology and pharmacology of endochondral ossification

Activity	Stimulation	Inhibition
Cell proliferation	Growth hormone Thyroxin (indirect) Androgens?	ACTH Corticosteroids Estrogens?
Matrix production		
Collagen		Corticosteroids Vitamin C deficiency
Proteoglycans		Vitamin C deficiency Vitamin D deficiency
Mineralization of cartilage and bone	Vitamin D metabolites?	Vitamin D deficiency Diphosphonate (EHDP)
Resorption of non-calcified cartilage	Vitamin A excess (lysosomes!)	Vitamin A deficiency Vitamin D deficiency
Osteoid production	Estrogens (birds, mouse)	Corticosteroids Vitamin C deficiency Vitamin A excess
Bone resorption	Parathormone	Diphosphonate Calcitonin? Estrogens (birds, mouse)

6 Participation of Articular Cartilage in Epiphyseal Growth

With the appearance of the center of ossification in the cartilaginous epiphysis, the cartilage of the epiphyseal plate becomes separated from the articular cartilage with the exception of a transition zone around the margin. The latter largely remains covered with perichondrium. The perichondrium is a source of appositional growth which increases the circumference of the epiphyseal plate. It is also the source of blood vessels which pass into the cartilage through vascular canals to supply the epiphyseal bone. In the initial stages, the center of ossification extends radially in all directions until the thickness of the epiphyseal plate and articular cartilage is more or less uniform. During part of this phase, the epiphyseal plate has a bipolar structure, i.e., endochondral ossification takes place on its epiphyseal and metaphyseal surfaces. Meanwhile, the proliferative zone is supplying both surfaces with cells. Growth continues to take place in the articular cartilage as long as the articular end of the bone increases in circumference. During this period, the proliferative zone is close to, but not directly in contact with, the joint surface. While growth is taking place, the articular cartilage has a remarkable capacity for remodelling: by localized changes in the growth rate, the joint surfaces adapt to each other so that perfectly congruent sliding movement takes place between the surfaces within the physiological range of movement. The basic shape of the articular end of the bone is genetically determined, but there is no doubt that additional fine adjustment occurs in the manner described.

7 Growth and Modelling of Metaphyseal Bone

Within the metaphysis, the primary cancellous bone formed by endochondral ossification is gradually replaced by a trabecular framework of lamellar bone. Meanwhile, on the surface of the cortex, resorption and apposition take place so as to change the shape of the bone. Circumferential growth of a diaphysis basically implies appositional bone formation by the periosteum together with osteoclastic resorption by the endosteum so as to enlarge the medullary cavity. This changes at the junction between the cylindrical shaft and the more rounded metaphysis which ends in the epiphyseal plate. The activity of the epiphyseal plate manifests itself as a cylindrical accretion zone which undergoes continuous remodelling in such a way that the metaphysis retains its conical shape despite the increase in length (Fig. 10). The shape of the bone is determined by the distribution of the apposition and resorption zones over the external periosteal and internal endosteal cortex surfaces (Figs. 3e, 10b). The metaphyseal growth pattern also results in the incorporation of outlying cancellous trabeculae into the internal cortex. Primary cancellous trabeculae which are embedded in the cortex can still be identified by appropriate techniques which highlight the calcified cartilage (Fig. 3e). Knowledge of the distribution of the synthesis and resorption zones in the cortex throws light on the cause of local variations in the blood supply and may also be relevant in the assessment of the healing of metaphyseal fractures.

Similar considerations apply to the border of the metaphyseal cortex where it adjoins the epiphysis. Externally, the periosteum joins the perichondrium which surrounds the circumference of the epiphyseal plate. During growth, the border of the metaphyseal cortex advances in the direction of the joint and at the same time the perichondrium undergoes functional metamorphosis, changing into periosteum at the junction between the two tissues. Furthermore, the lines of insertion of the joint capsule and ligaments undergo continuous displacement. Thus, localized injury may give rise to selective changes in bone growth, e.g.,

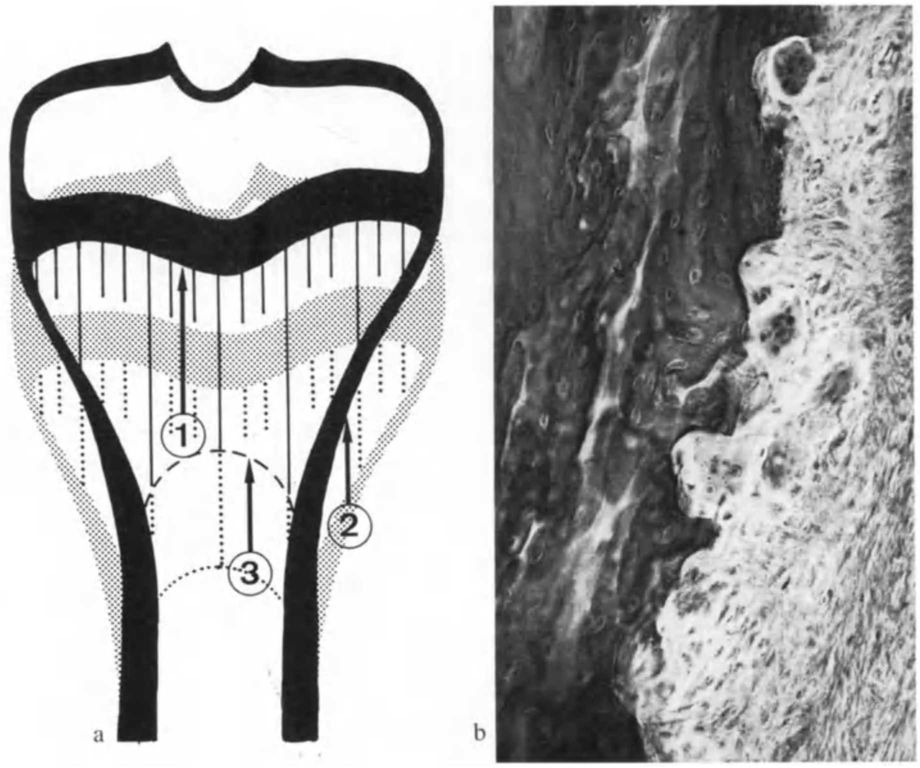


Fig. 10a, b. a) Shaping of the metaphysis by remodelling during longitudinal growth. Dotted area = initial shape; *black* = final shape. The resorption processes take place (*1*) at the metaphyseal surface of the growth cartilage, mediated by chondroclasts (cf. Figs. 3d and 9a); (*2*) at the periosteal surface of the cortex, mediated by osteoclasts; (*3*) in the metaphyseal cancellous bone during expansion of the medullary cavity. At the same time, bone apposition takes place at the endosteal surface of the cortex (cf. Fig. 3e).
b) Subperiosteal accumulation of osteoclasts over the outer surface of the metaphyseal cortex. Magnification ×175

injury at the site of insertion of a ligament may stimulate periosteal callus formation which extends to the perichondrium and ends by crossing the epiphyseal plate, thus leading to unilateral arrest of growth (p. 54).

It is clear from the aforementioned concepts and examples that even the diagramatically simple, circumferential growth of a long bone is associated with complex interrelated remodelling processes which require a precise control mechanism. Countless clinical

8 Modifications of the Growth Pattern in the Diaphysis

Even in the shafts of some of the long bones, shaping of the bone is accompanied by localized differences in remodelling along the periosteal and endosteal surfaces. Thus, harmonic growth of a bone which is bowed in a forward direction, such as the femur, requires a change in the radius of curvature; this is achieved by a phenomenon known as drifting (Fig. 11). The shaft of the bone is displaced in such a way that its longitudinal axis describes an arc of a circle of increased radius. A cross section at the middle of the shaft shows a ridge of periosteal apposition in the ventral cortex and an endosteal resorption zone on the side of the medullary cavity. In the dorsal cortex, the opposite occurs: endosteal bone deposition is accompanied by resorption along the periosteal surface. Fine coordination of the growth rates in these different zones finally results in a cortex whose shape and thickness are typical of a cross section at this level.

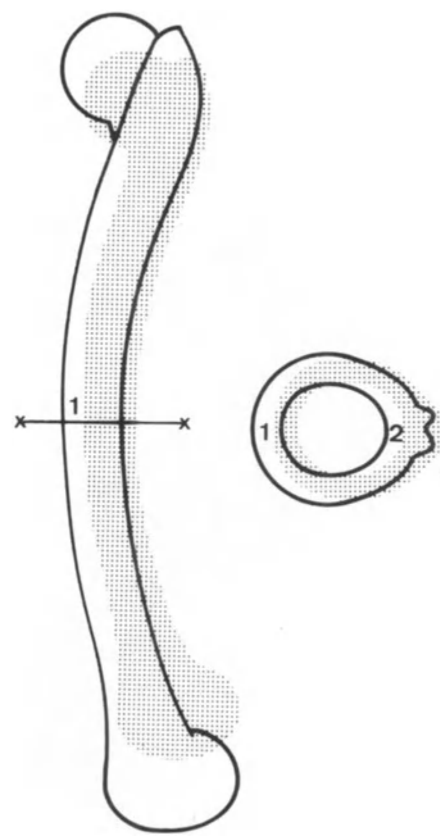


Fig. 11. *Cortical drift during growth and modelling of a curved long bone, e.g., the femur. Dotted area* = growth stage; *black outline* = final shape. The scale of the cross section is three times that of the profile. (*1*) Zone of periosteal apposition. (*2*) Zone of endosteal apposition. (Adapted from *Enlow*, 1963; taken from *Schenk*, 1976)

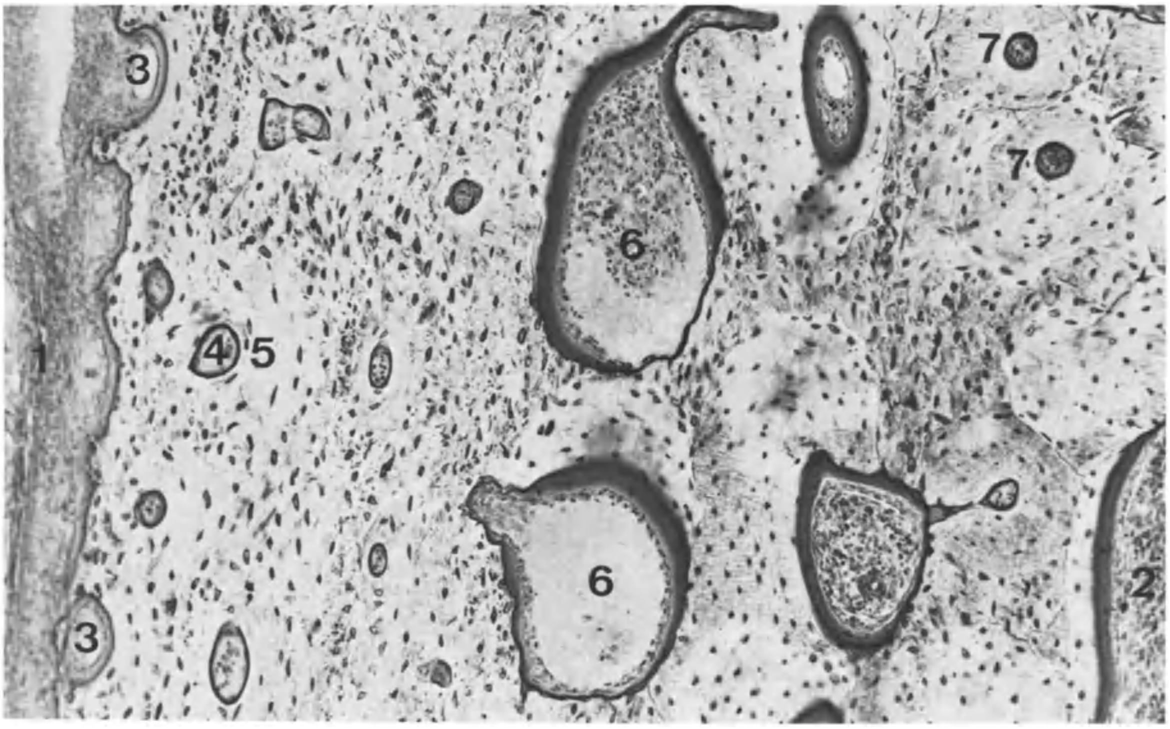


Fig. 12. *Cross section of the rib cortex of an 8-year old boy*. Nondecalcified ground specimen stained with basic fuchsin. Magnification ×75. (*1*) Periosteum. (*2*) Medullary cavity. (*3*) Primary vascular canals at the formation stage. (*4*) Primary osteon canal. (*5*) Wall of the primary osteon. (*6*) Resorption canals with incipient formation of secondary osteons. (*7*) Fully formed secondary osteons. (Taken from *Schenk*, 1976)

and experimental observations have shown that in the growing skeleton this control system plays a part in correcting pathological changes. As long as growth continues for an adequate period, the bone is able to reduce or even abolish angular deformity by asymmetric resorption and apposition.

9 Influence of the Growth Pattern on Vascularization of the Long Bones

An adequate capillary blood supply is essential, not only for bone formation, but also for nutrition of the mature bone. An important factor here is the association between the osteocytes and calcium homeostasis. However, the high density of the completely mineralized matrix almost totally prevents diffusion through the intercellular substance. The exchange of metabolites is restricted to the network of canaliculi and lacunae and to the osteocytes. The latter are situated in the lacunae and are in direct cytoplasmic contact with each other via junctions between cell processes. Intracytoplasmic transport can take place over the gap junctions at the points of contact between the processes (*Holtrop* and *Weinger*, 1972). This is complemented by extracellular flow in the lacunae and canaliculi which can also be demonstrated by electron microscopy (*Doty* and *Schofield*, 1972). However, the range of both modes of transport is restricted to approximately 100 μm. This range plays a part in determining the architecture of the cancellous bone and the internal structure of the compact bone. It is the reason why the thickness of the plates and trabeculae in the cancellous bone is restricted to approximately 200 μm. Furthermore, it causes compact bone to be divided into small units, the osteons, with central Haversian canals containing vessels which communicate with those in the periosteum and medullary cavity via the Volkmann canals. During growth, two types of cortical vessel are encountered. The first generation of primary osteons contains vessels which are incorporated into the bone during appositional growth and which remain connected to the vessels on the surface of the appositional zone (Fig. 12). The associated areas of the cortex are supplied with vessels derived from their tissue of origin, i.e., from the periosteum or endosteum, in a manner corresponding to the local pattern of apposition. However, this vascular pattern changes when the primary osteons are replaced by secondary osteons. Their formation commences with the appearance of wide resorption cavities, the great majority of which pass into the cortex from the medullary cavity and then run parallel to the longitudinal axis of the bone. New bone lamellae are laid down concentrically in these resorption channels, thus forming the typical *Haversian* systems which are separated from the remaining lamellae of the compact bone by cement lines and which should be considered as both mechanical and trophic units. The blood supply of this and all subsequent generations of osteons is derived from the medullary vascular system, irrespective of the origin of the cortex zone in question. The physiological process of renewal is known as *Haversian* remodelling, and its rate depends on the age of the individual as well as a variety of hormonal and other factors. During growth, the development of the secondary osteons in humans between the 7th and 12th years of age is noticeably increased, and a cross section of the bone shows areas containing wide resorption channels of apparently simultaneous origin and growing osteons (Fig. 12). During this transition phase, the vascular supply of the cortex is dependent on the substrate of origin of the tissue in question and also on the branches of the medullary blood vessels in the secondary osteons. Particularly in the metaphysis, where the shaping of the bone is accompanied by a complex pattern of apposition zones, it is not always easy to determine the source of the major blood supply of a particular area during a particular phase of growth. The same applies to the diaphysis, where harmonic remodelling is determined by the asymmetric distribution of the periosteal and endosteal apposition zones (p. 17). Even in these zones, the Haversian remodelling which follows completion of longitudinal growth leads to a more uniform pattern of distribution of the intracortical vessels. In the adult skeleton, the latter are mainly derived from the medullary vascular system, which plays the most important part in revascularization and reconstruction following fracture.

10 References

Anderson, H. C.: Vesicles associated with calcification in the matrix of epiphyseal cartilage. J. Cell Biol. **41**, 59 (1969).

Bonucci, E.: Fine structure of early cartilage calcification. J. Ultrastruct. Res. **20**, 33 (1967).

Dodds, G. S.: Osteoclasts and cartilage removal in endochondral ossification of certain mammals. Amer. J. Anat. **50**, 97 (1932).

Doty, S. B., Schofield, B. H.: Metabolic and structural changes within osteocytes of rat bone. In: Talmage, R. V., Munson, P. L. (Eds.): Calcium, Parathyroid hormone and the Calcitonins P. 353–364. Amsterdam: Excerpta Medica 1972.

Enlow, D. H.: Principles of bone remodeling. Springfield/I11.: Ch. C. Thomas 1963.

Friedenstein, A. J., I. I. Piatetzky-Shapiro, K. V. Petrakova: Osteogenesis in transplants of bone marrow cells. J. Embryol. exp. Morph. **16**, 381 (1966).

Frost, H. M.: Bone remodelling dynamics. Springfield/I11.: Ch. C. Thomas 1963.

Holtrop, M. E., Weinger, J. M.: Ultrastructural evidence for a transport system in bone. In: Talmage, M. V., Munson. P. L. (Eds.): Calcium, Parathyroid hormone and the Calcitonins, p. 365–374. Amsterdam: Excerpta Medica 1972.

Kember, N. F.: Cell division in endochondral ossification. A study of cell proliferation in rat bones by the method of tritiated thymidine autoradiography. J. Bone Jt Surg. **42B**, 824 (1960).

Krompecher, S.: Die Knochenbildung. Jena: Gustav Fischer 1937.

Rosenberg, L., Hellmann, W., Kleinschmidt, A.: Electron microscopic studies of proteoglycan aggregates from bovine articular cartilage. J. biol. Chem. **250**, 1877 (1975).

Schenk, R. K., Spiro, D., Wiener, J.: Cartilage resorption in the tibial epiphyseal plate of growing rats. J. Cell Biol. **34**, 275 (1967).

Schenk, R. K.: Besonderheiten des kindlichen Skelets im Hinblick auf die Frakturheilung. Langenbecks Arch. Chir. **342** (Kongressbericht 1976) 269 (1976).

Trueta, J.: The role of vessels in osteogenesis. J. Bone Jt Surg. **45B**, 402 (1963).

Zinkernagel, R., Riede, U. N., Schenk, R. K.: Ultrastrukturelle Untersuchungen der juxtaepiphysären Capillaren. Experientia Basel **28**, 1205 (1972).

Fracture Healing in the Growing Bone and in the Mature Skeleton

B.G. WEBER

CONTENTS

1 Introduction

It is clear from the chapter by *Schenk* that the skeleton grows in the following manner: The *epiphyseal plates* determine the *length* of the bone; the *periosteum* is responsible for *circumferential* growth; and the final size of the *articular ends* of the bone is set by the *epiphyses*. The skeleton is the site of proliferative activity throughout growth.

The mature skeleton is in a relatively quiescent state. It no longer grows, but nevertheless, it remains active. Synthesis is accompanied by resorption, and this turnover leads to continuous renewal of the bone structure with gradual replacement of the Haversian systems.

A fracture in a child involves a tissue which differs significantly from that of the adult. The young *growing bone* is much more capable of reaction and adaptation, but is also *vulnerable* in a manner which is not encountered in the adult bone. In a child, a fracture can accelerate or slow growth. Thus, *disturbances of growth* can occur, creating problems which are superimposed on those of the fracture itself and are specific to the growing skeleton.

These disadvantages of growth are balanced by advantages. The remarkable healing capacity of the young bone, which is inversely proportional to the age of the patient (*Rettig*), allows childrens' fractures to unite extremely rapidly, frequently with complete correction of angular deformity.

The following section contains a concise description of fracture healing in the adult and in the child. The two processes are compared and their specific features are highlighted so as to show the problems which may be associated with a fracture in a child and the circumstances under which they may be expected to occur.

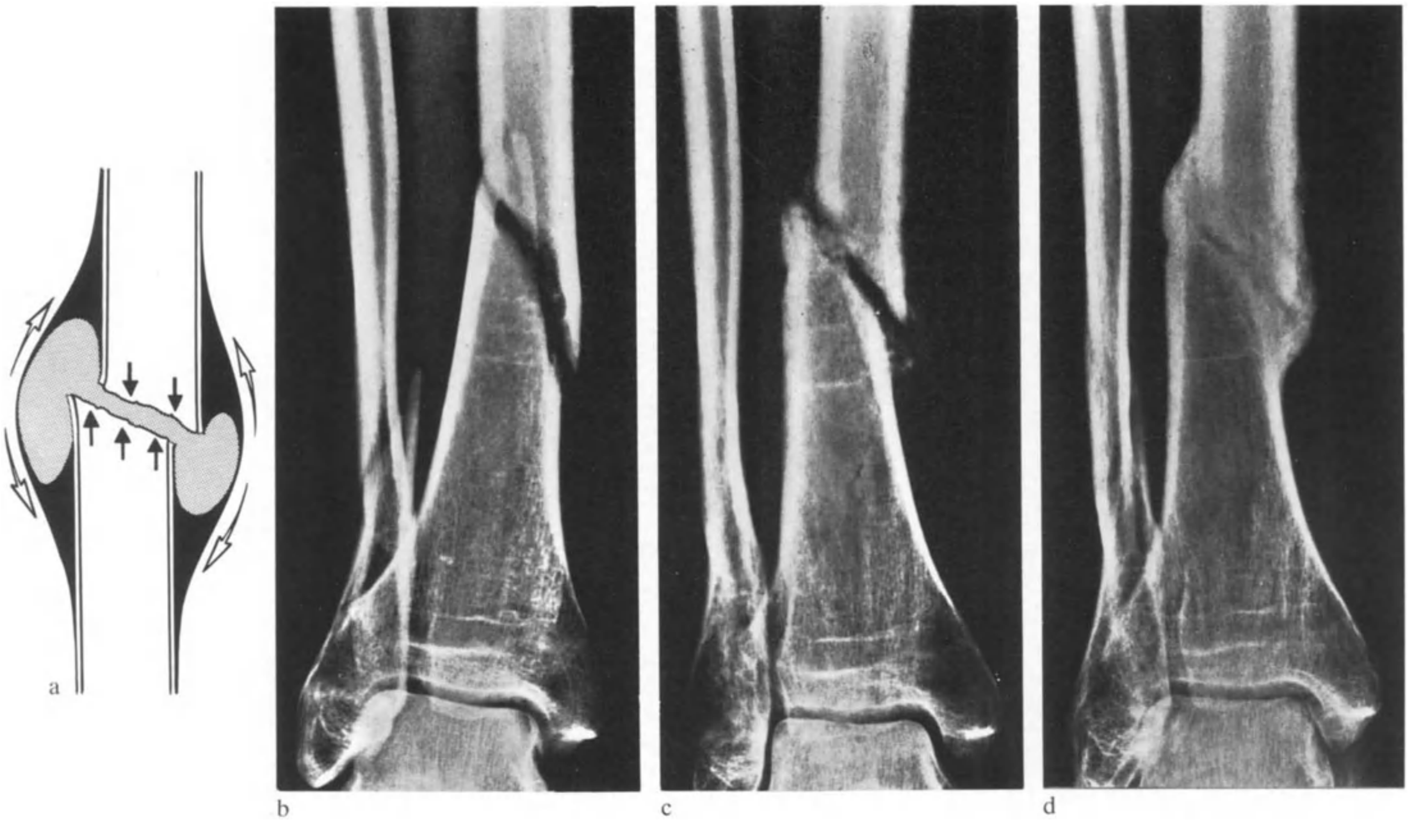


Fig. 1a–d. *Indirect fracture healing.*

a) Diagrammatic illustration. Connective tissue cuff resists traction, and interfragmentary granulation tissue resists compression. Fibrous cartilage then forms. In the absence of interfragmentary movement, mineralization occurs and the cartilage is converted into fibrous bone which is then replaced by lamellar bone.
b) Z.H., ♂, aged 42 years, No. 123820. The fresh fracture.
c) 4 months later: Incipient mineralization is clearly visible.
d) 8 months following the accident: The fracture has healed and the fibrous bone is being converted into lamellar bone

2 Healing of Shaft Fractures in the Adult

Fracture healing which is accompanied by radiographically visible callus formation is known as *indirect healing;* in the absence of callus, it is referred to as *direct healing*. The terms *secondary healing* and *primary healing*, respectively, are synonymous (*Danis, Küntscher, Willenegger, Perren, Schenk*).

2.1 Indirect Fracture Healing

Indirect healing is a characteristic result of the nonoperative treatment of fractures. It has been best investigated and described by *Pauwels* (Fig. 1).

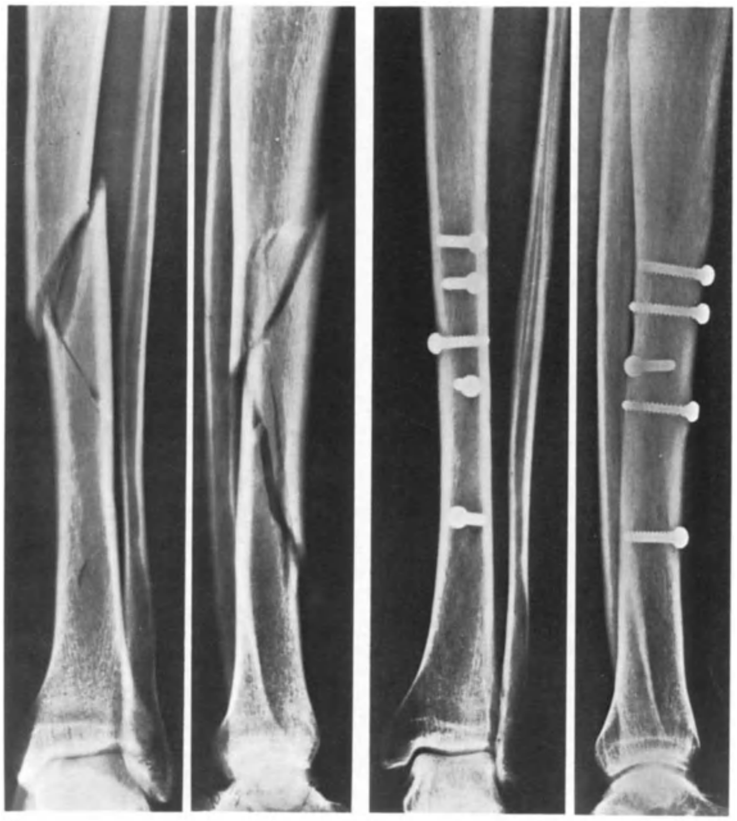
The decisive mechanism of fracture healing by callus formation is the synthesis of an immobile framework which initially joins the fragments and reduces movement between them. This framework first consists of a high-tensile connective tissue cuff and interfragmentary granulation tissue which resists compression; it is replaced by fibrous cartilage and, when the fragments are finally immobilized, calcification occurs. Mineralization follows disintegration of the cartilage by chondroclasts, blood vessels, and accompanying cells. Osteoid is laid down and is then converted into woven bone which, in turn, changes to lamellar bone.

Conversion of connective tissue to bone via an intermediate cartilage stage always takes place when initial stability has to be established between the ends of the bones. However, if the initial movement between the ends of the bones is eliminated, a different type of bone healing occurs.

2.2 Direct Fracture Healing

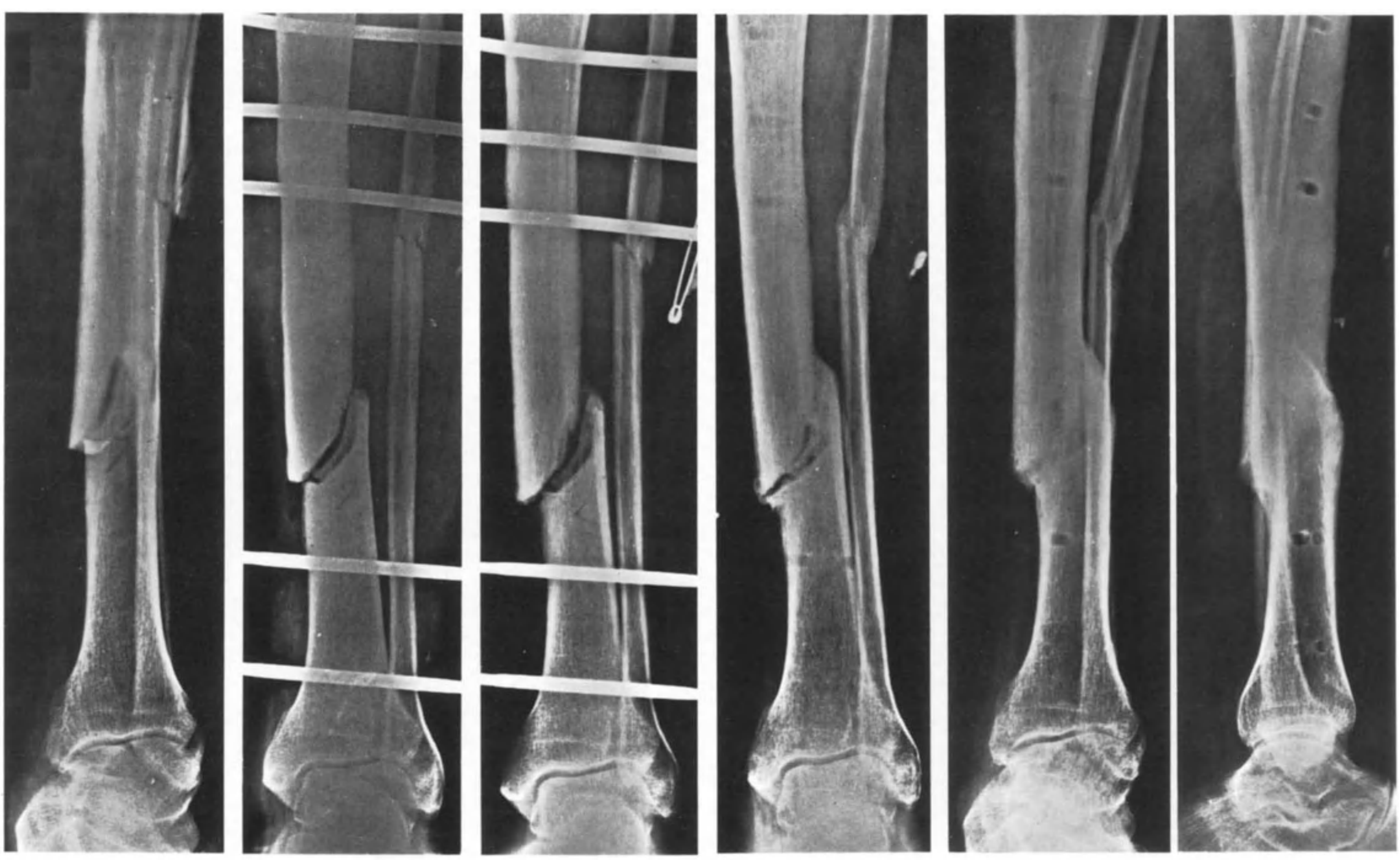
Direct fracture healing follows stable internal fixation. It also occurs in a partial fracture or bone fissure, which is stabilized by the adjacent intact bone.

A fracture which is immediately and completely stabilized can be directly bridged by blood vessels and bone and does not require an initial immobilizing framework of the type described by *Pauwels*. Union takes place directly in the form of contact or gap healing (see below) (*Willenegger, Perren, Schenk*).



a b

Fig. 2a, b. *Direct bone healing: Contact healing*. T.J., ♂, aged 24 years, No. 78709.
a) The fresh fracture.
b) 1 year following stable internal fixation with lag screws. There is no callus reaction. The fracture line is invisible. Direct angiogenic bone union has occurred



a b c d e

Fig. 3a–e. *Direct bone healing: gap healing*. S.H., ♂, aged 64 years, No. 160244.
a) Open fracture of the lower leg with reduction of the arterial blood supply.
b) Indirect fixation with external fixation clamps and without exposure of the fracture. Débridement of the soft tissues was carried out.
c) 1 month following the accident. There is no sign of fixation callus, but bone union is commencing in the gap.
d) 3 months after the accident. Direct fracture healing, i.e., gap healing, is almost complete.
e) 7 months after the accident. Fracture healing is complete

Fig. 4a–d. *The law of Roux and Pauwels*. Maximum strength is attained with the minimum amount of bone. F.W., ♂, aged 79 years, No. 127689.
a) Comminuted fracture of the tibia with poor skin covering and precarious blood supply. The fracture was treated with a cast.
b) 2 months later. Indirect fracture healing is progressing rapidly.
c) 3 months later. The fracture has healed and weight bearing is possible.
d) $4^1/_2$ years later. Following resynthesis of the lamellar bone, the callus becomes redundant and is largely resorbed

At the internal points of contact of the cortex, groups of osteoclasts cross the fracture gap and are followed by capillaries from the existing *Haversian* systems. Along these vessels, new osteons are created which plug the fracture gap. Synthesis and resorption take place simultaneously without shortening of the ends of the bone. This is known as *contact healing* (Fig. 2).

At various points, gaps exist between the cortices, i.e., there is no contact. Under stable conditions, such as those furnished by adequate internal fixation, these gaps become directly filled with bone. This is known as *gap healing* (Fig. 3).

2.3 Functional Adaptation of the Bone Following Fracture

Towards the end of bone union, increased loading becomes possible and is accompanied by remodelling and adaptation processes whose nature depends on the type of fracture healing.

2.3.1 Adaptation Following Indirect Fracture Healing

On reinstigation of normal loading, the excess material in the primary fixation callus is gradually resorbed. *Roux* and *Pauwels* described this process as *functional adaptation;* its aim is to reduce the amount of bone to the minimum which is necessary to fulfill the structural requirements (Fig. 4). A similar process is stimulated by angular deformity (*Wolff's* Transformation Law) (Fig. 5); the articular ends of a fractured and malunited bone remain misaligned with each other, but the angulation of the shaft at the site of the fracture appears to decrease with time. Bone apposition takes place on the concave side of the angulation and is accompanied by resorption on the convex side. This functional adaptation of the internal architecture of the bent bone increases its compression strength, but cannot correct the misalignment of the articular ends. Assymetrical loading of the joints results and leads to osteoarthrosis (Figs. 6 and 7). Osteotomy is necessary to correct the angulation and the assymetrical load distribution (Fig. 8).

Fig. 5. *Wolff's law of transformation.* Functional adaptation of a curved bone without change in the spatial relationship of the bone ends, i.e., synthesis of bone on the concave side of the curved diaphysis and resorption on the convex side. B.K., ♀, aged 51 years, No. 83781.
Open fracture of the leg 20 years previously, followed by development of an infected pseudarthrotic gap in the tibia. The infection subsequently healed, but the pseudarthrotic gap remained. The weight bearing function of the tibia was assumed by the fibula, which underwent corresponding remodelling. Bone synthesis was concentrated on the concave side with resorption on the convex side. The axes of the joints are still misaligned

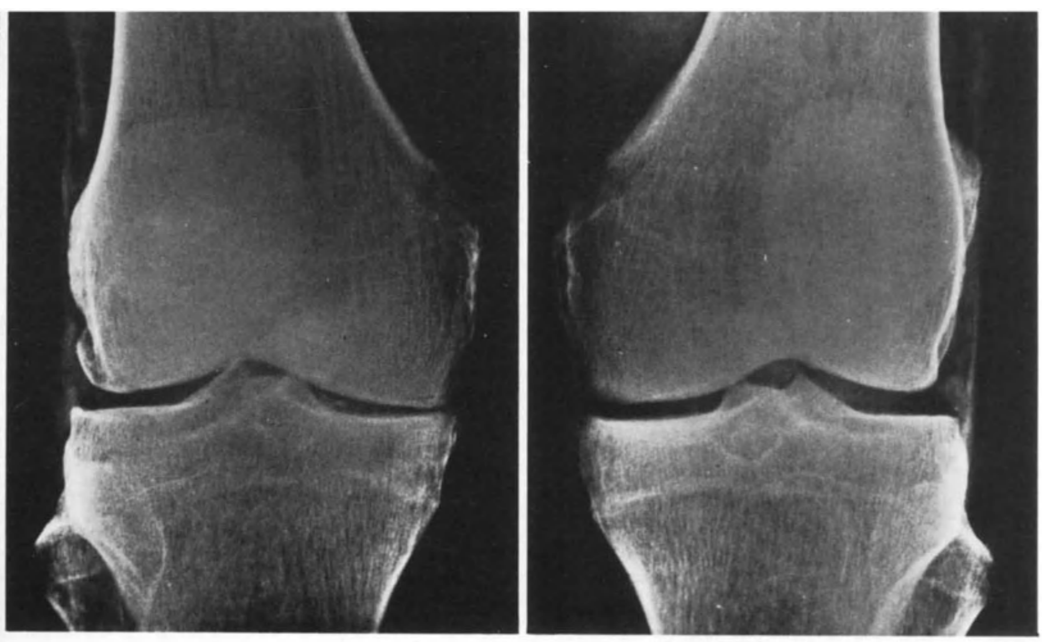
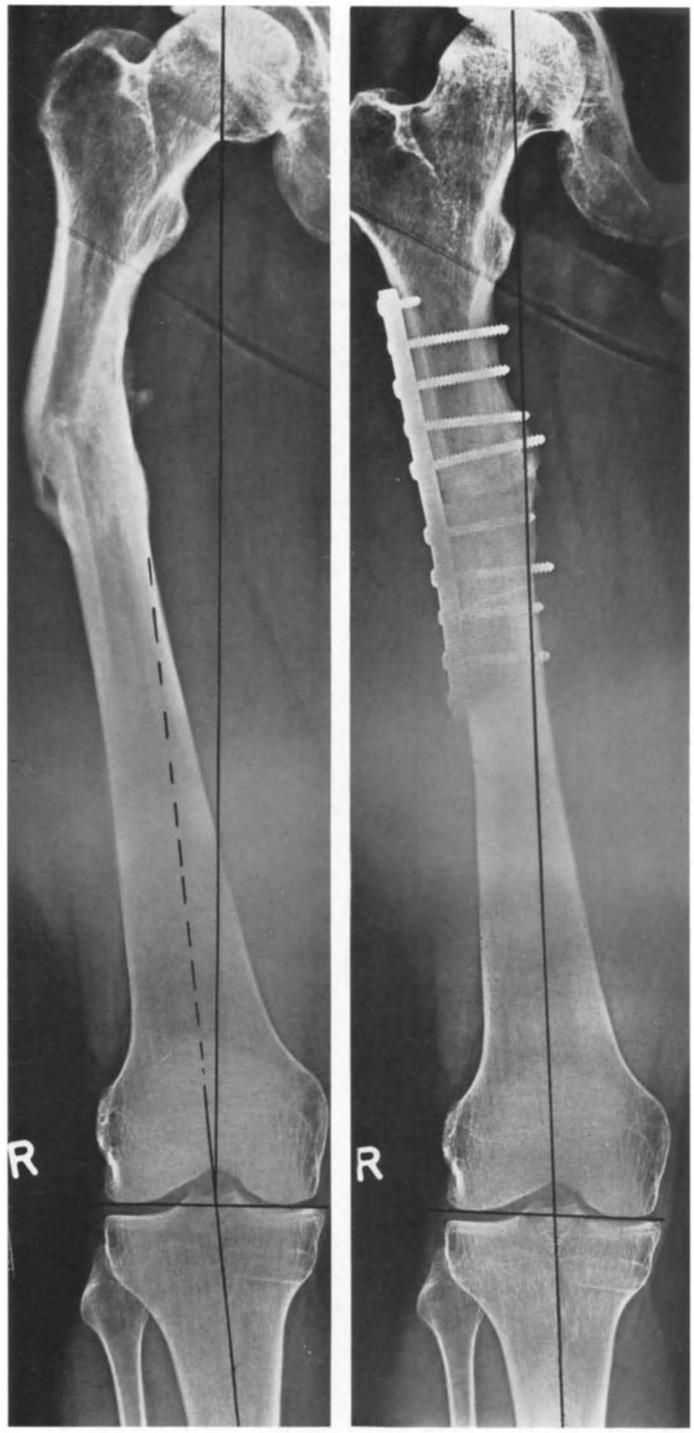


Fig. 6. *Joint deformity leads to osteoarthrosis.* K.H., ♂, aged 73 years, No. 152096. A fracture of the leg sustained 35 years ago healed with varus deformity of 13°. Subsequently, varus osteoarthrosis of the knee joint developed

Fig. 7. *Angular deformity and osteoarthrosis*. V.D., ♂, aged 46 years, No. 100064.
Accident 28 years ago. The fracture of the shaft of the femur has healed with varus deformity. Subsequently, coxa vara and varus osteoarthrosis of the knee joint developed



a b

Fig. 8a, b. *Angular deformity and corrective osteotomy*. R.G., ♂, aged 24 years, No. 86347.
a) 2 years following fracture of the shaft of the femur. There is varus deformity with incipient medial overloading of the knee joint.
b) 4 months following corrective osteotomy. The axes are correctly aligned and the load distributions in the hip and knee joint are normal

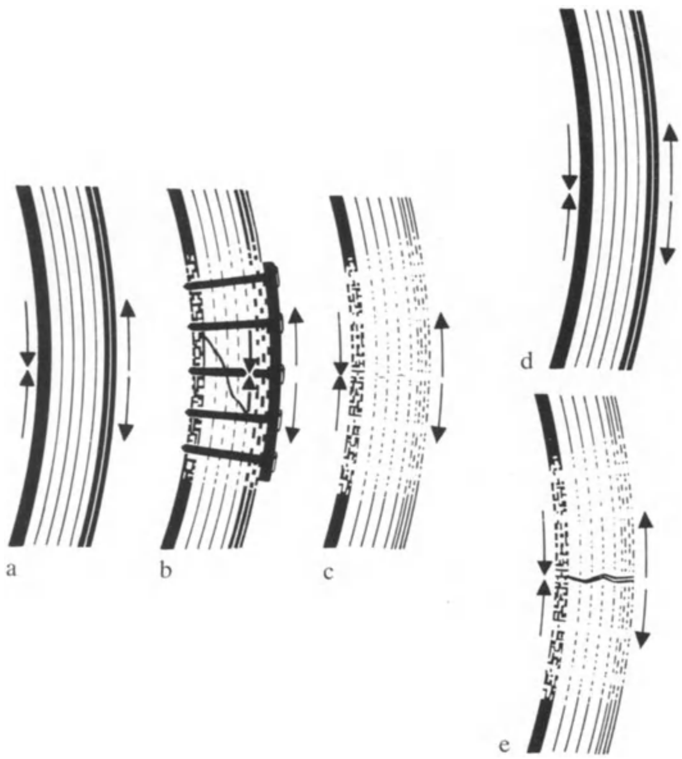


Fig. 9a–e. *Adaptation of the bone following direct fracture healing subsequent to plate fixation.*
a) Normal structure of the bone, with resistance to compression on the concave side and resistance to tension on the convex side.
b) Compression osteosynthesis with assumption of the tensile and compressive loads by the plate and screws. The bone adapts to the reduced stress by reducing its density, thus saving material both on the compression side and on the tension side. Stress protection by the plate has occurred.
c) Following removal of the implant, the strength of the bone no longer suffices to resist the normal tension and compression forces. There are now two possibilities:
d) Functional adaptation occurs once more, and the structure of the bone changes so as to recover adequate tensile and compressive strength.
e) As a result of the decrease in density of the bone, the latter is no longer able to withstand the loads placed upon it, and fatigue fracture results

2.3.2 Adaptation Following Direct Fracture Healing

Indirect healing can be said to involve the creation of excess bone. This excess is resorbed during remodelling of the primary fixation callus. In one sense, the opposite occurs following direct bone healing; it is most pronounced following plate fixation. Here, the internal fixation material partly assumes the load applied to the bone. The bone responds to the reduced biomechanical demands made upon it by saving material, i.e., the stress protection leads to bone resorption. Removal of the implant abolishes the stress protection and is therefore followed by a phase during which the bone structure is relatively weak. Normal loading then stimulates the remodelling processes and the bone recovers its original strength. During the phase of relative weakness following removal of the implant and prior to the restoration of normal bone density and strength, a fatigue fracture may occur (Fig. 9).

2.4 Disturbances of Fracture Healing

The borderlines between normal healing, delayed healing, and nonunion or pseudarthrosis are not clear-cut. The pathophysiology of abnormal healing varies according to the previous treatment of the fracture and the blood supply and vitality of the fragments (*Weber* and *Cech*).

Disturbances of indirect fracture healing are accompanied by good or even excellent vascularization of the bone ends. Bone ends which are in contact with each other hypertrophy ("elephant foot") and those which are separated (e.g., by interposition) atrophy and become rounded.

Disturbances of direct fracture healing show greater variety. If an internal fixation loosens and the bone ends remain viable, cloudy "irritation" callus forms. Under suitable circumstances, this cloudy callus may save the situation by stabilizing the fracture sufficiently to allow indirect healing. If this does not occur, the callus persists and the result of the inadequate fixation is a well-vascularized pseudarthrosis.

If the fragments are no longer viable, spontaneous healing with the aid of callus cannot take place and a nonreactive pseudarthrosis forms.

Thus, there are three possible causes of pseudarthrosis, i.e.,

a) *Inadequate immobilization.* Inadequate splinting during nonoperative treatment prevents the synthesis of an immobilizing framework and its conversion to bone. Hypertrophic pseudarthrosis results, with a layer of fibrous cartilage covering both bone ends.

Insufficiently stable internal fixation stimulates the formation of cloudy callus if the fragments are still viable, i.e., the bone attempts to build a stabilizing framework in response to failure of the internal fixation.

b) *Inadequate reduction of the fracture.* Separation of the bone ends by distraction or by interposition of soft tissues prevents union following operative or nonoperative treatment and may even lead to resorption of the bone ends.

In both cases, stable contact between the bone ends suffices to induce union of the fracture.

c) *Necrosis of the fragments.* The most frequent causes of necrosis are aggressive surgery, i.e., excessive

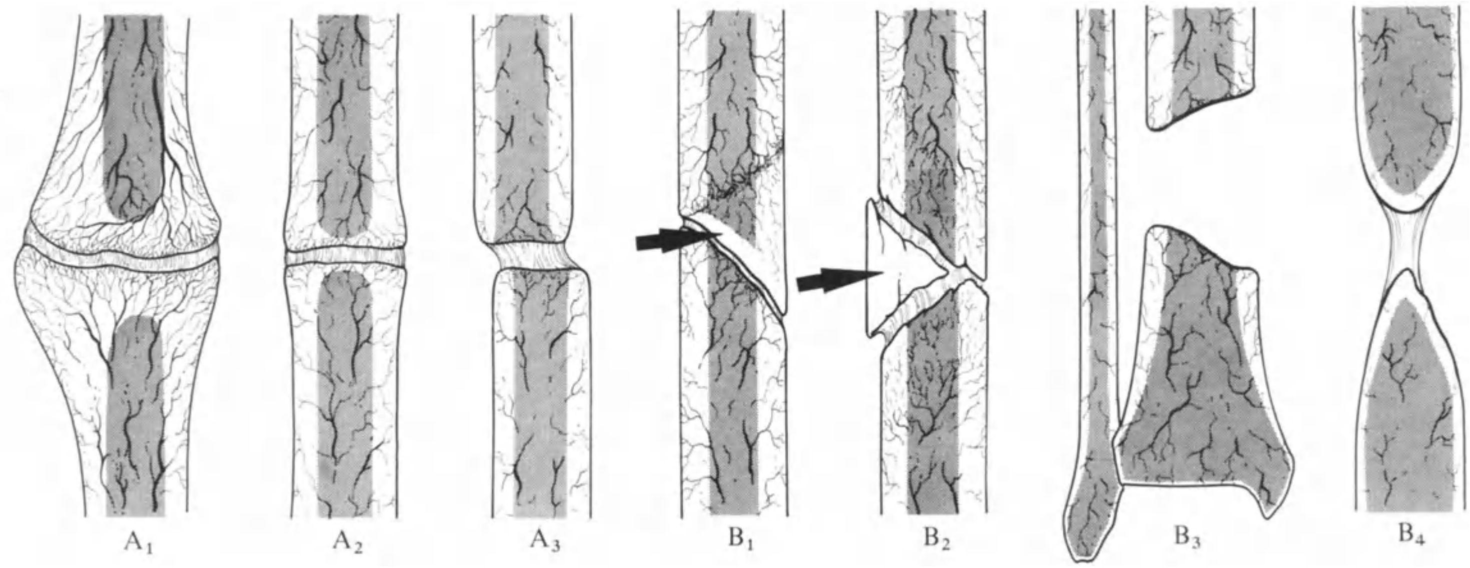


Fig. 10. *Classification of pseudarthroses.*
A: Biologically active pseudarthroses:
A_1 – hypertrophic, hypervascularized pseudarthrosis (elephant's foot); A_2 – slightly hypertrophic pseudarthrosis (horse's hoof); A_3 – oligotrophic pseudarthrosis without callus.
B: Nonactive pseudarthroses:
B_1 – butterfly fragment pseudarthrosis with necrosis of the butterfly fragment; B_2 – pseudarthrosis in a comminuted fracture with complete necrosis of the fragments: B_3 – gap pseudarthrosis; B_4 – atrophic pseudarthrosis with absence of biological activity

removal of periosteum, and infection of the fracture. The fragments must be viable and stable for healing to occur. In the absence of infection, fragments whose viability is questionable may be saved by the stabilization offered by internal fixation. If infection is present, the sequester must be excised and replaced by viable cancellous bone.

2.5 Classification of the Pseudarthroses (Fig. 10)

Pathophysiologically, pseudarthroses are divided into those with *viable, active fragments* and those with *nonviable fragments or bone gaps.* The first type requires mechanical stability in order to heal. The second type requires stability and, in addition, biological stimulation in the form of freshening of the bone ends, cancellous bone plasty, or both.

3 Healing of Shaft Fractures in the Growing Bone

As in adults, fractures in children and young persons may heal with or without callus.

3.1 Indirect Fracture Healing

Callus formation, consolidation, and remodelling of the callus take place much more rapidly in the child than in the adult. The callus is more extensive and is completely resorbed (Fig. 11). The quality of healing of shaft fractures is inversely proportional to the age of the child and directly proportional to the axial alignment of the bones at the time of union. An older child may be left with residual signs of the fracture, especially if extensive dislocation and deformity were present or if the fracture occurred shortly before cessation of growth.

The radiographic signs of the original fracture, the callus, and any deformity disappear more or less completely as the bone increases in circumference (Fig. 12).

3.2 Direct Fracture Healing

The radiological signs of healing of an internally-fixed fracture in a child differ somewhat from those seen in the adult. Periosteal bone apposition almost always occurs and, in some cases, may rapidly bury the implant. This callus is not to be confused with that associated with "irritation"; it is consistent with absolutely stable internal fixation. The increased periosteal

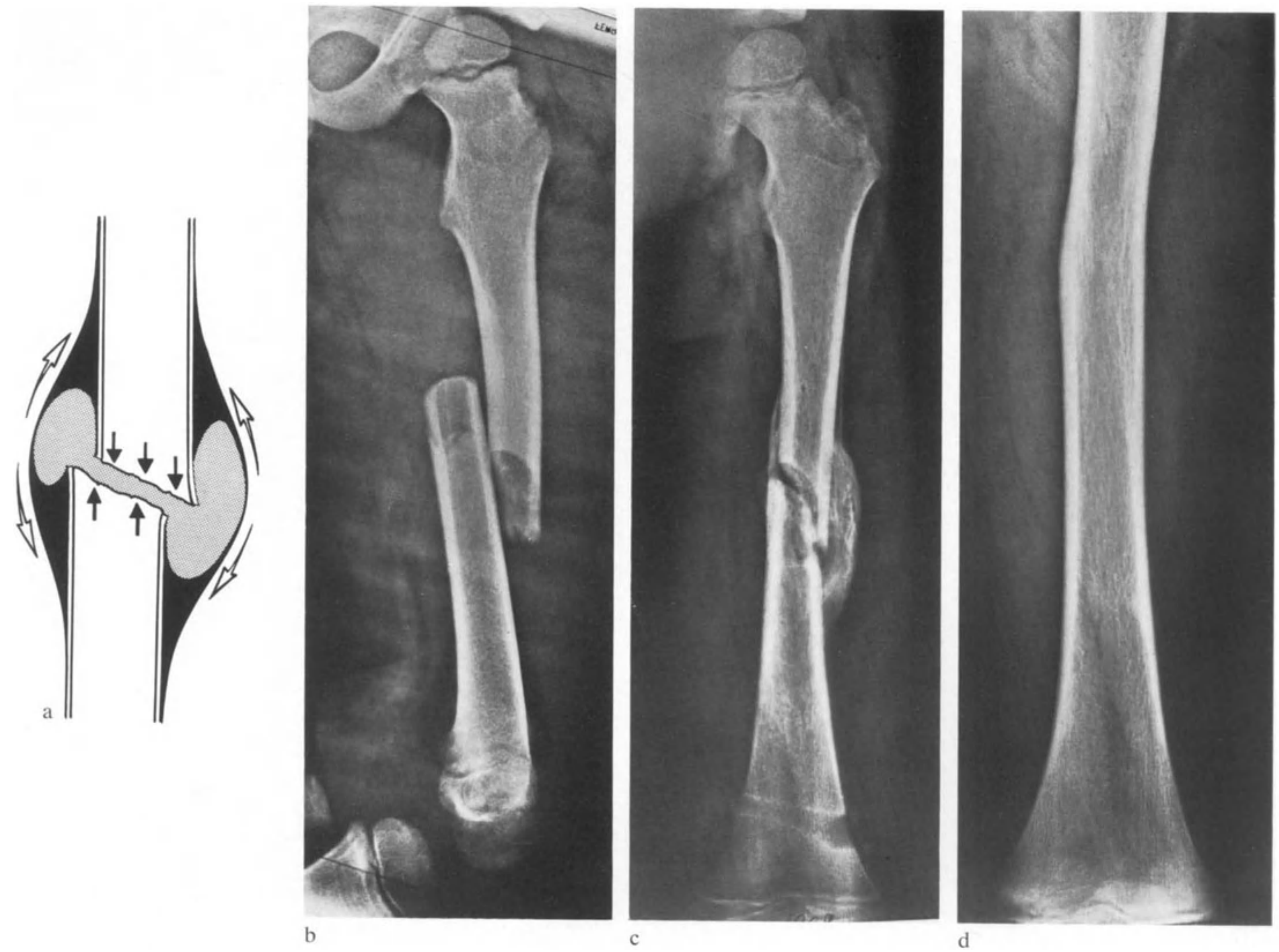


Fig. 11a–d. *Indirect fracture healing in the child.*

a) The principles are the same as in the adult: callus formation, consolidation, and remodelling. However, the process is significantly faster.

b) B.R. ♂, aged 5 years, No. 82249. Femoral fracture.
c) Treatment by skeletal traction. 2 months later, a large callus cuff has formed.
d) 5 years after the accident, there is complete structural and functional adaptation of the bone

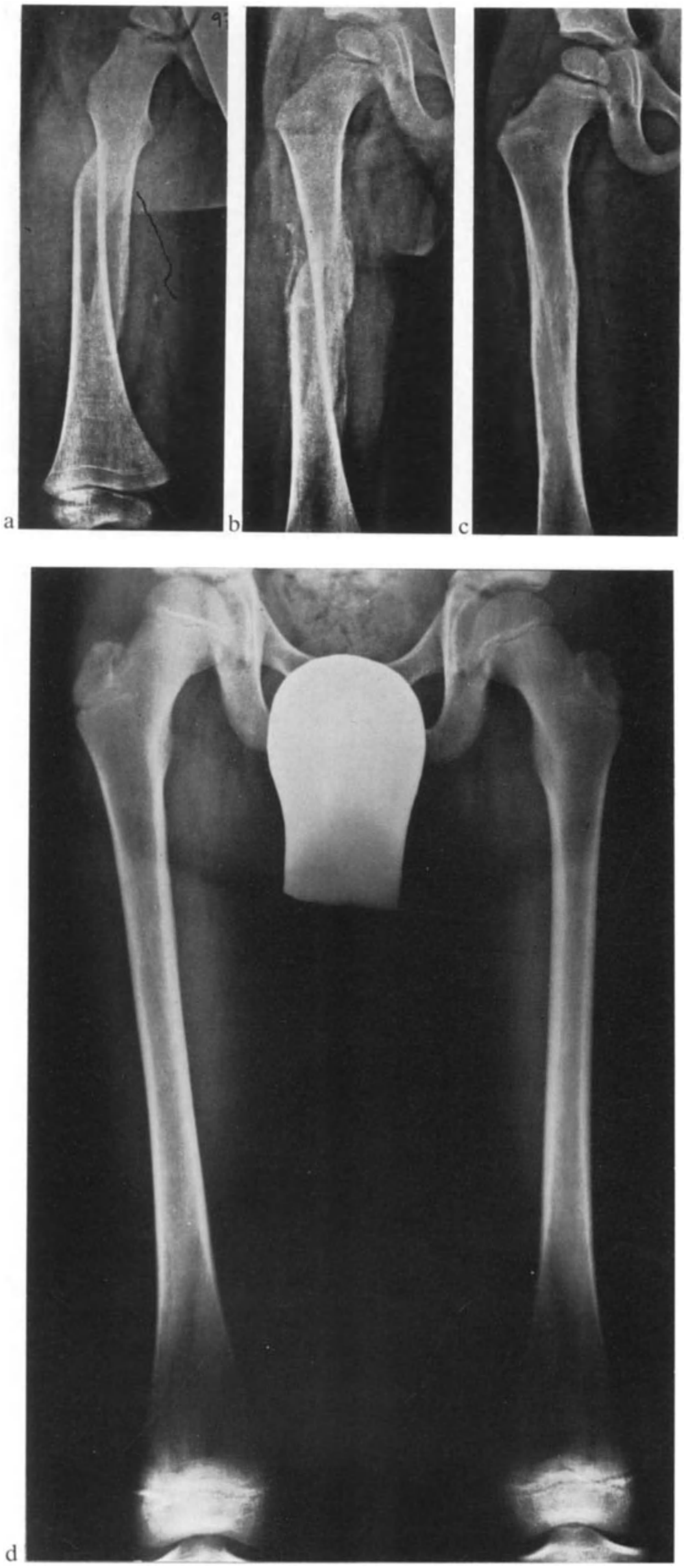


Fig. 12a–d. *Bone remodelling by growth in length and circumference following a fracture in a small child.* G.R., ♂, aged 3 years, No. 97217.
a) Mid-diaphyseal fracture of the femur. Treated by traction.
b) Following removal of the traction.
c) 8 months following the accident. The fracture has become almost invisible.
d) $6^{1}/_{2}$ years after the accident. There are neither radiological nor clinical signs of the fracture, apart from slight lengthening of the leg

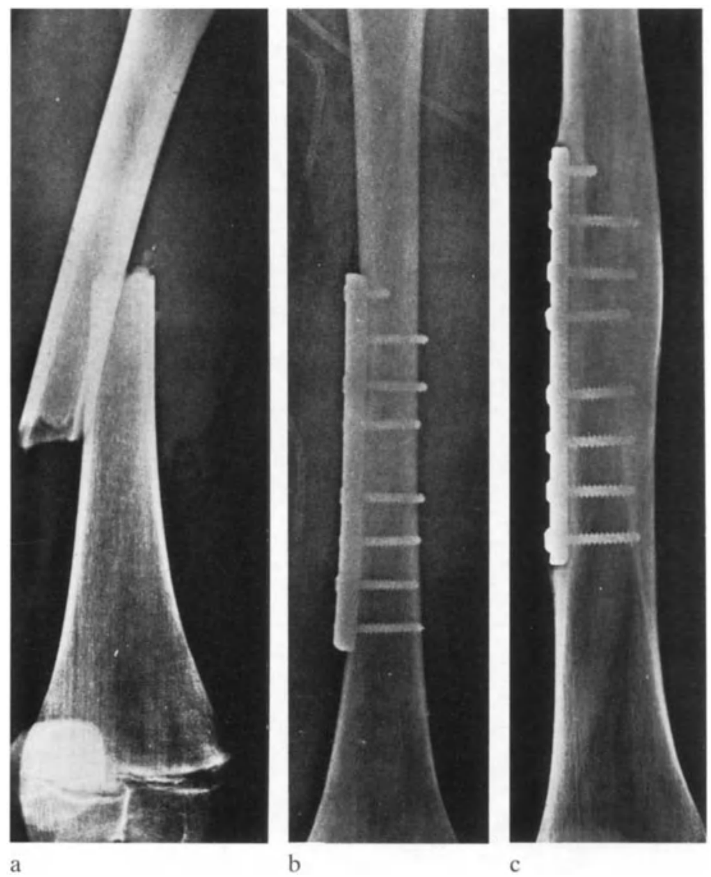


Fig. 13a–c. *Direct bone healing with additional splinting by the periosteal callus cuff.* P.A., ♀, aged 12 years, No. 155021.
a) Diaphyseal fracture of the femur.
b) Plate fixation with anatomically precise reduction and a reliable degree of stability.
c) 13 months following the accident. Marked callus cuff formation as a result of accelerated periosteal bone formation

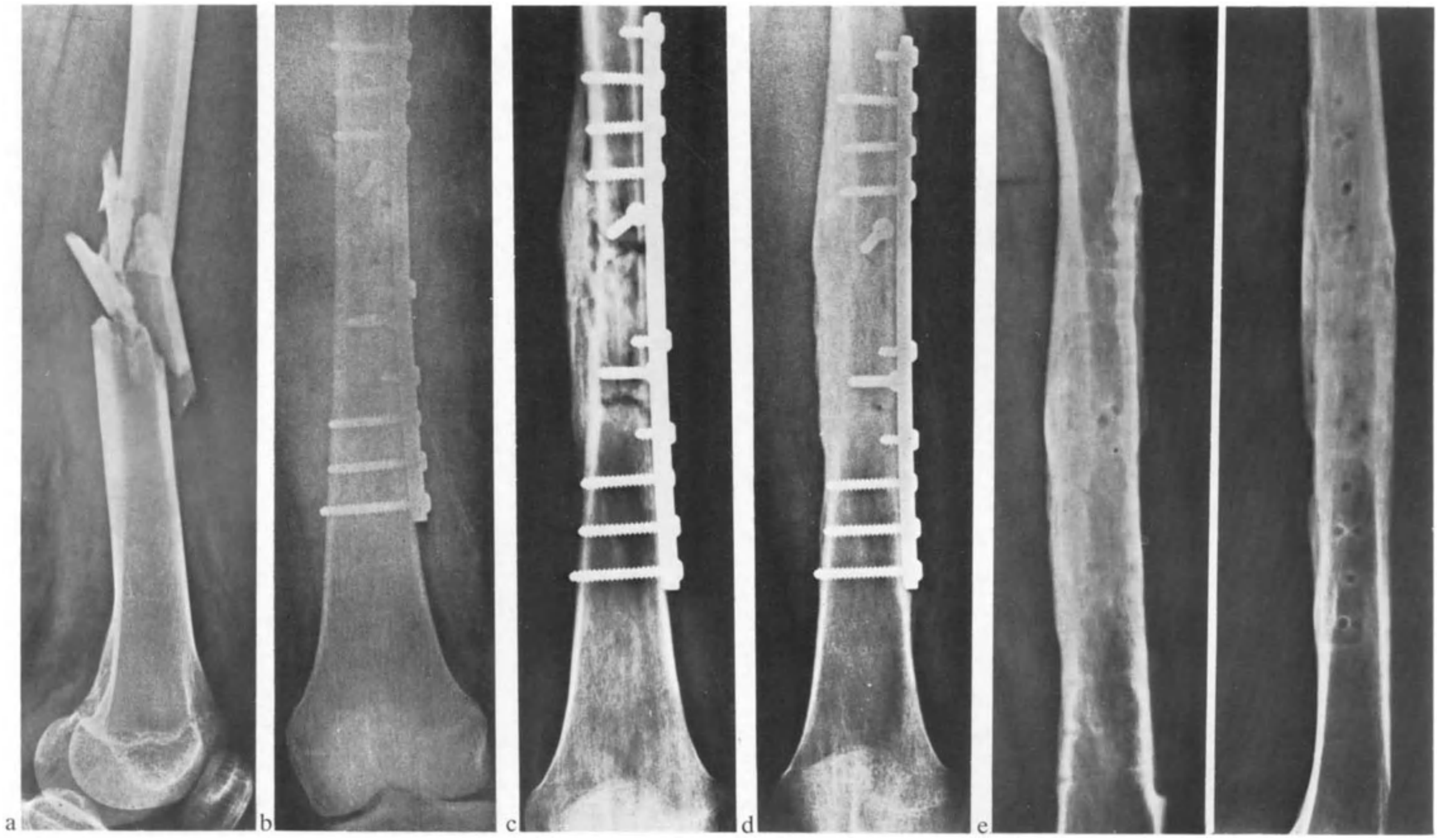


Fig. 14a–e. *Re-incorporation of devitalized fragments.* S.J., ♀, aged 16 years. No. 121790.

a) Comminuted fracture of the shaft of the femur.
b) Internal fixation with a long straight plate. The middle fragments are partially devitalized.
c) 4 months later. Fracture healing is mainly occurring by periosteal callus formation.
d) 1 year after the accident. The devitalized middle fragment has been revitalized and fully incorporated.
e) 2 years after the accident, following removal of the implant. Fracture healing is complete, with restructuring of the bone as an expression of functional adaptation to the normal load placed on it

bone formation during fracture healing and the increase in the circumference of the bone result in a combination of direct and "indirect" union, i.e., consolidation of the cortex takes place directly by Haversian remodelling, with additional splinting by periosteal callus (Fig. 13).

Composite fracture healing of this type is generally less pronounced with increasing age. The older the child, the more direct is the fracture healing which accompanies stable internal fixation. During fracture healing in the child, devitalized fragments recover their viability remarkably quickly and are incorporated into the bone and remodelled. This is a consequence of the extremely vigorous activity of the growing skeleton in the child and particularly that of the periosteum (Fig. 14).

3.3 Functional Adaptation of the Bone Following Fracture

During growth, the capacity for *functional adaptation* of a healed *fracture of the shaft* is inversely proportional to the age of the patient. In the infant and in the young child, the radiographic signs of a fracture disappear completely, even if angular deformity was present. The *growth in circumference* conceals the callus and any angulation (Fig. 15). In the older child, the fracture is remodelled according to the principle of "direct self-determination of the most appropriate bone structure" (*Roux*); its shape and structure gradually change in such a way as to minimize the amount of bone which is needed to withstand the loads imposed (*Pauwels*), i.e., the bone undergoes functional adaptation (*Wolff's* Transformation Law).

If angulation causes tilting of the epiphyseal plates, the latter undergo *compensatory changes in longitudinal growth* so as to restore normal alignment (*Pauwels*).

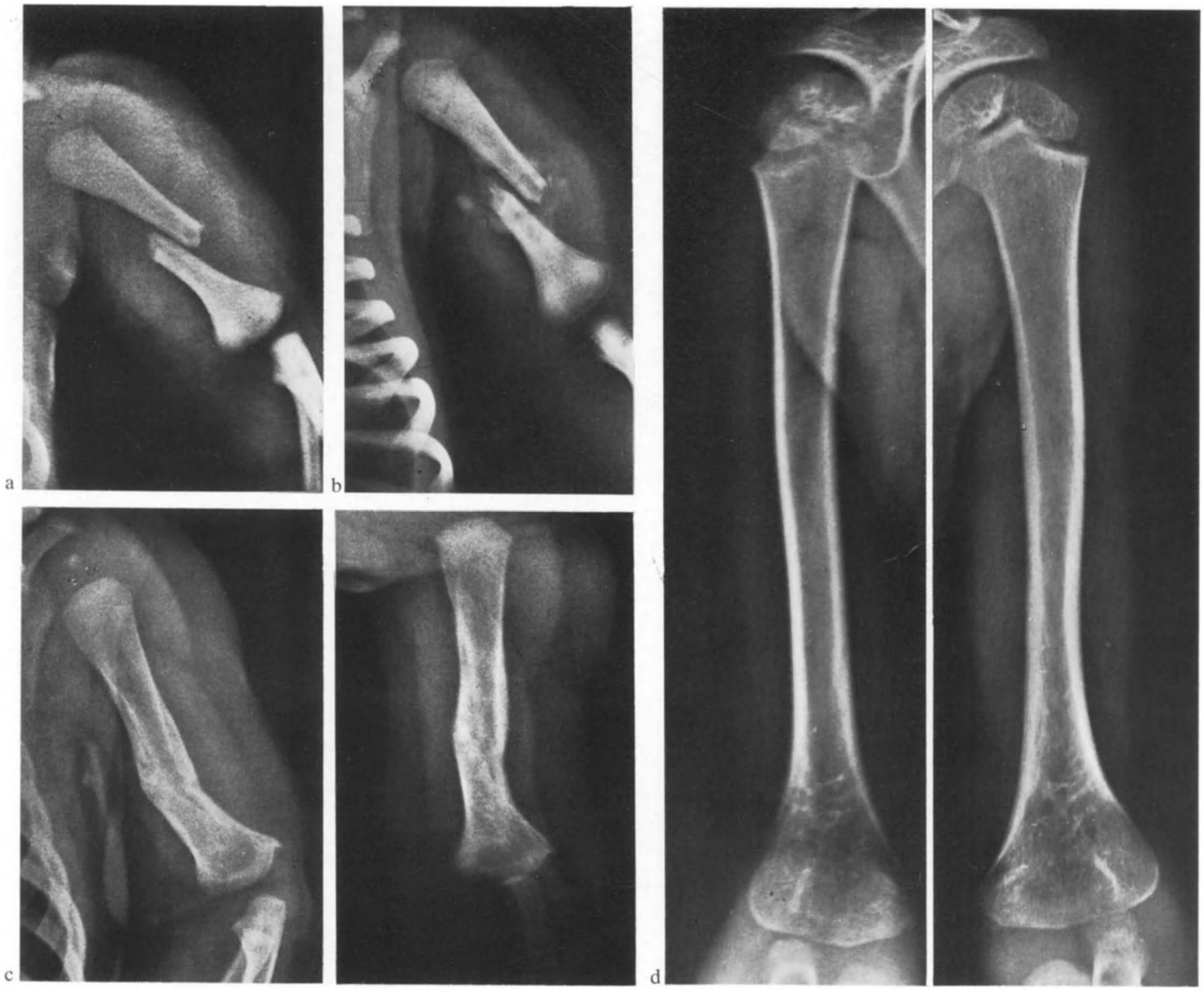


Fig. 15a–d. *Functional adaptation of a healed diaphyseal fracture in a newborn child.* S.A., ♀, newborn, No. 132112.
a) Fracture of the humerus following freeing of the arm during breech delivery.
b) 12 days after birth. Fracture healing is advanced, with formation of a large callus cuff.
c) 2 months later. Complete fracture healing with angular deformity and shortening.
d) $5^1/_2$ years after birth. Symmetrical axes with almost no difference in length of the bones. The deformity has been corrected by circumferential and longitudinal growth

a

b

Fig. 16a, b. *Fatigue fracture following prolonged immobilization.* S.J., ♀, aged 2 years, No. 168512.
a) Bilateral congenital dislocation of the hip treated by traction and application of a hip spica for 2 months. On mobilization, bilateral supracondylar fractures occurred spontaneously as a result of bone atrophy due to inactivity. b) Following reduction and immobilization in a bilateral above-knee cast and subsequent remobilization, uneventful healing with correct axial alignment and remineralization occurred

Bone atrophy which results from prolonged immobilization is reversed very rapidly when functional loading is resumed. However, a *fatigue fracture* may result if a severe load is placed on the bone before this latter has recovered its normal strength. It follows that a child should be protected from severe mechanical stresses immediately following a prolonged period of immobilization. Even the growing skeleton requires time to recover its normal strength (Fig. 16).

3.4 Disturbances of Fracture Healing

Disturbances of *indirect fracture healing* in the child hardly ever lead to pseudarthrosis. Probably the only exception is latent congenital pseudarthrosis of the tibia, i.e., fracture at the site of congenital angulation of the tibia; here, the predisposition to pseudoarthrosis can be said to have been present before the fracture occurred (Fig. 17).

Of more than 1000 fractures of the tibia and lower leg, we know of only one which had not united within 3 months (Fig. 18). We have no unequivocal explanation for the delay in healing and assume that spontaneous union would have subsequently occurred.

Disturbances of healing occur more frequently in the opposite sense, if excessive callus formation can be described as a disturbance of healing. However, following consolidation of the fracture, even the palpable and radiographically enormous callus masses which sometimes form are rapidly resorbed, leaving no problems.

Fig. 17. *Congenital crus varum and fracture of the tibia.* V.R., ♀, aged 7 years, No. 108785.
Tibial fracture 6 weeks ago with failure of bone union. This is a so-called congenital pseudarthrosis of the tibia with fracture of a congenital crus curvatum

a b c

Fig. 18a–c. *Disturbance of indirect fracture healing*. V.R., ♀, aged 9 years, No. 158344.
a) Oblique fracture of the tibia. Treatment with a circular cast.
b) 3 months later. Union has failed to occur. Delayed internal fixation with a plate.
c) 4 months following internal fixation. Rapid and reliable healing

Fig. 19a–c. *Excessive longitudinal growth following internal fixation.* W.C., ♀, aged 11 years, No. 125841.
a) Open, distal fracture of the leg. Internal fixation with a small dorsal plate. Débridement of the soft tissues.
b) 4 months following the accident. Reliable, uneventful healing of bone and soft tissues has occurred.
c) 3 years following the accident. There is a 1.5 cm increase in leg length

Direct bone healing under the protection of stable internal fixation seldom presents problems. A stably fixed fracture in a child heals as directly and easily as that in an adult. The additional apposition of bone seen in children is physiological and should not be interpreted as a sign of derangement of direct healing, e.g., due to inadequate mechanical stability.

An undesirable phenomenon which may complicate direct healing following internal fixation is *excessive longitudinal growth*. Acceleration of growth is particularly marked after osteosynthesis, particularly after medullary nailing. The explanation may well be analogous to that proposed by *Trueta* to account for excessive longitudinal growth accompanying chronic osteomyelitis: restriction of the medullary blood flow by screws and nails may stimulate collateral hyperemia in the vicinity of the epiphyseal plate and thus accelerate longitudinal growth (Fig. 19).

Pseudarthrosis, infection, and *infected pseudarthrosis* are uncommon, but serious complications. They are usually the result of inappropriate use of internal fixation or poor surgical technique (or both) (Fig. 20).

In contrast to the situation in the adult, bone union is almost certain to occur in the child if the treatment is more or less correct. As has already been pointed out, the problems associated with fracture healing in the growing bone lie elsewhere.

a b c

d

Fig. 20a–d. *Incorrect indication for internal fixation.* B.R., ♂, aged 7 years, No. AK 4958.
a) Fracture of the leg with shortening.
b) Treatment by adaptation osteosynthesis with subperiosteal cerclage wiring and a full-leg cast with bed rest.
c) 3 months later. Fracture healing has failed to occur and there is infection of the bone with fistula formation.
d) 5 months following the accident. As a result of internal fixation in a case in which it was not indicated, a pseudarthrosis has occurred with the additional complication of infection

4 Problems Associated with Fracture of the Epiphyseal Plate

4.1 Anatomy and Physiology of the Epiphysis

Throughout the literature, fractures in or in the vicinity of the epiphyseal plate are considered to be more serious than those in the diaphysis (*Rang*).

The *anatomically normal epiphyseal plate* forms a clear-cut zone (Fig. 21). The epiphysis, the metaphysis, and, in the majority of cases, the diaphysis each have their own blood supplies. Blood vessels do not penetrate the epiphyseal plate.

A normal blood supply is a prerequisite of normal growth. The effects of interruption of the blood supply on the epiphyseal plate vary according to the vessel damaged:

a) Damage to the epiphyseal vessels results in permanent disturbance of growth. Typically, there is ne-

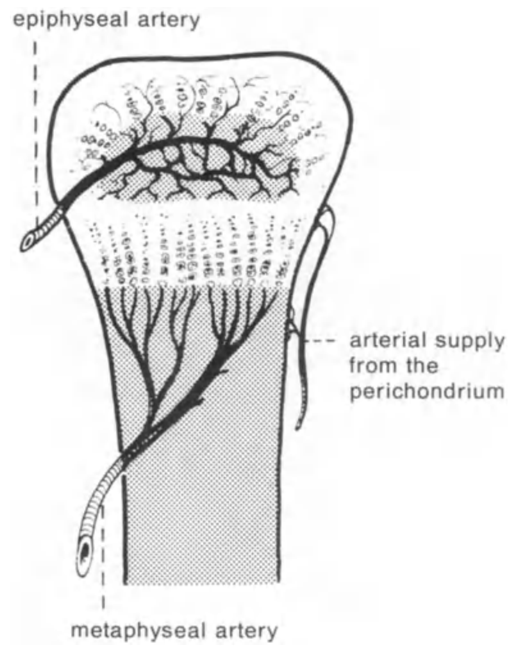


Fig. 21. The blood supply of the epiphyseal plate

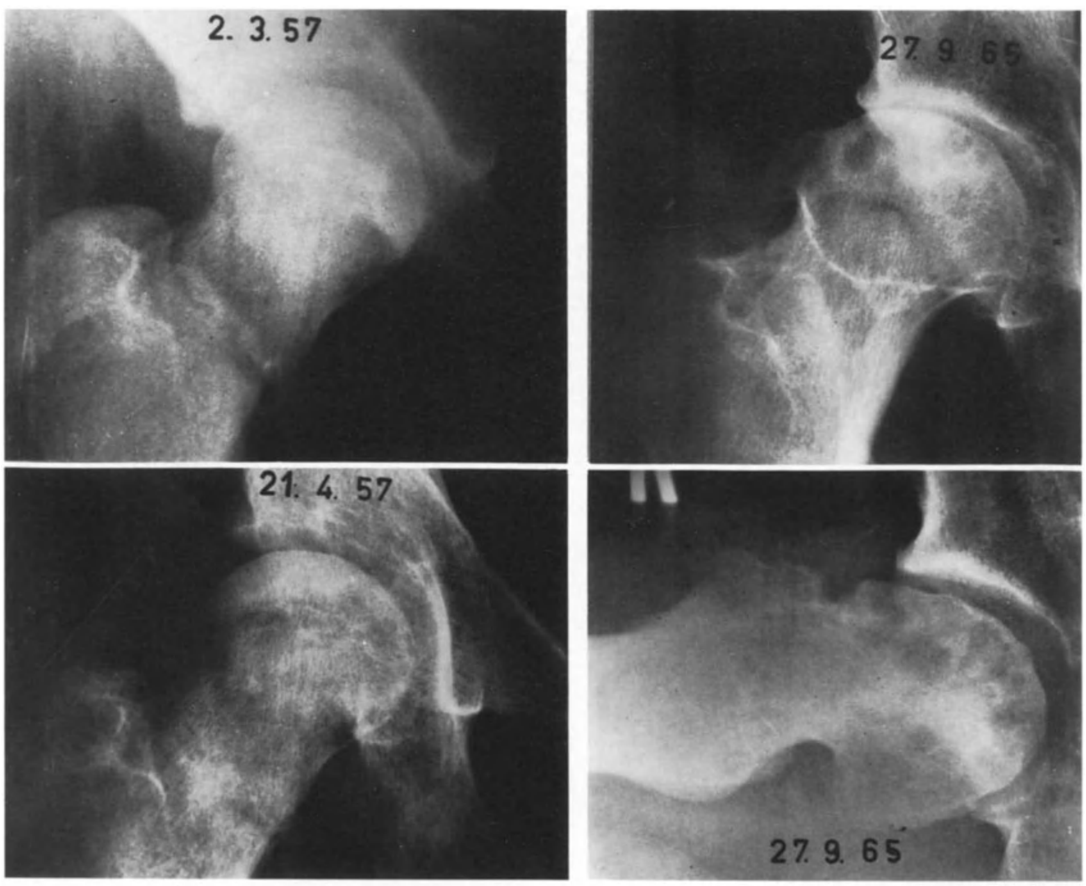
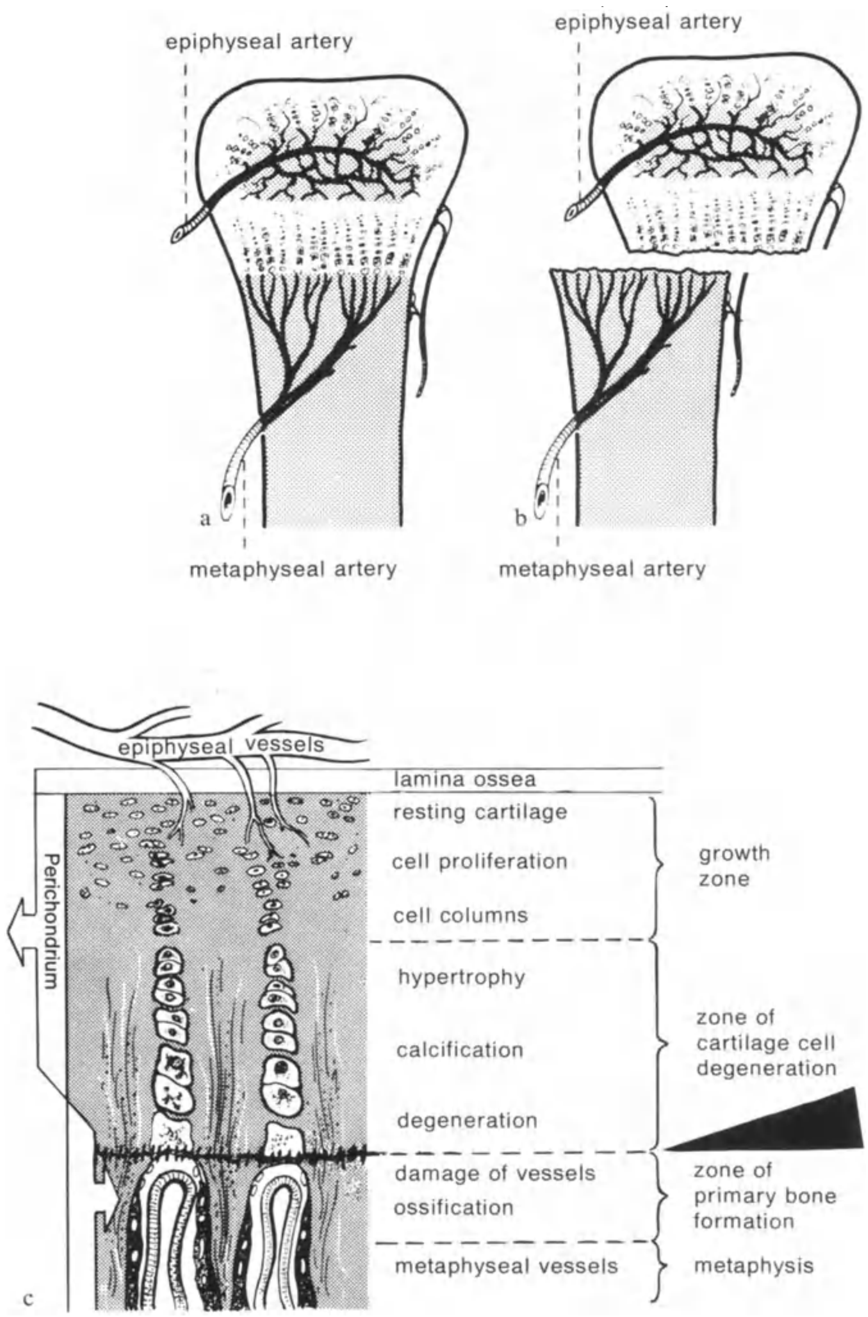


Fig. 22a, b. *Necrosis of the epiphyseal center of ossification following damage to the blood supply*. C.R., ♂, aged 16 years, FK.
a) Fracture of the base of the femoral neck, with uneventful fracture healing in traction and a hip spica.
b) $8^1/_2$ years following the accident. Severe deformity of the head of the femur with cyst formation as a result of avascular posttraumatic necrosis

Fig. 23a–d. *Transient disturbance of the metaphyseal circulation, resulting in temporary slowing of growth.* K.W., ♂, aged 11 years, No. 141398.
a) Severe comminuted metaphyseal fracture of the leg with displacement of the epiphysis.
b) 2 months following emergency treatment, including open reduction and fixation with *Kirschner* wires and a lag screw. Fracture healing is problem-free, but there is a region of apparently increased bone density in the metaphysis, which is a sign of partial bone necrosis (disuse osteoporosis occurs in the biologically active bone surrounding the necrotic area and leads to an decrease in its radiodensity; the necrotic bone does not undergo resorption and its radiodensity therefore remains unchanged).
c) 2 years after the accident. Growth in the epiphyseal plate has continued, but is definitely slower than that on the intact side.
d) $2^1/_2$ years following the accident. Growth is now normal

Fig. 24a–c. *Excessive growth as a result of collateral hyperemia in the region of the epiphyseal plate following fracture of the diaphysis.* E.E., ♀, aged 5 years, No. 115358.
a) Transverse diaphyseal fracture of the femur. Treatment with the traction device.
b) Uneventful, indirect fracture healing with formation of a callus cuff.
c) Follow-up $4^1/_2$ years following the accident. Longitudinal growth increased by 1.5 cm

Fig. 25a–c. *Epiphysis, epiphyseal plate, and separation of the epiphysis.*
a) Normal anatomy of the epiphysis and epiphyseal plate.
b) Separation occurs in the region of primary endochondral ossification and in that of the degenerating cartilage cells. Thus, only the arterial supply from the perichondrium is interrupted, and the metaphyseal and epiphyseal arteries remain intact.
c) The fracture occurs between the zone of primary bone formation and that of degeneration of the cartilage cells. The growth zone is not damaged and the germinative layer remains intact.



crosis of the center of the epiphysis with deformation of the articular surface (Fig. 22).

b) Damage to the metaphyseal vessels results in slowing of growth which is usually transient (Fig. 23).

c) Damage to the perichondrial vessels has no adverse effects.

d) Damage to the diaphyseal blood supply induces collateral hyperemia in the epiphysis. The rate of longitudinal growth increases and remains raised until the normal blood supply is restored to the diaphysis (Fig. 24).

Injuries to the epiphysis itself are divided into two basic types, known as *separation* and *fracture*.

Experimental or traumatic *separation* takes place in the layer of degenerating cartilage cells and in the zone of primary endochondral ossification (*Bergenfeld, Morscher, Rampoldi* and *Boni*) (Fig. 25). Although the mechanical strength of the epiphyseal plate is less than that of the bone, fracture of the adjacent bone is more common than pure separation. The extremely tough perichondrium protects the epiphyseal plate from the bending, torsion, and compression to which it is usually subjected when a child has an accident, so that a metaphyseal or diaphyseal fracture is more likely to occur. Pure separation only occurs if the epiphyseal plate is subjected to *shear forces*, which the perichondrium is less able to resist.

A particularly important feature of separation is its location along the *metaphyseal border of the cartilage* without direct involvement of the epiphyseal

Fig. 26

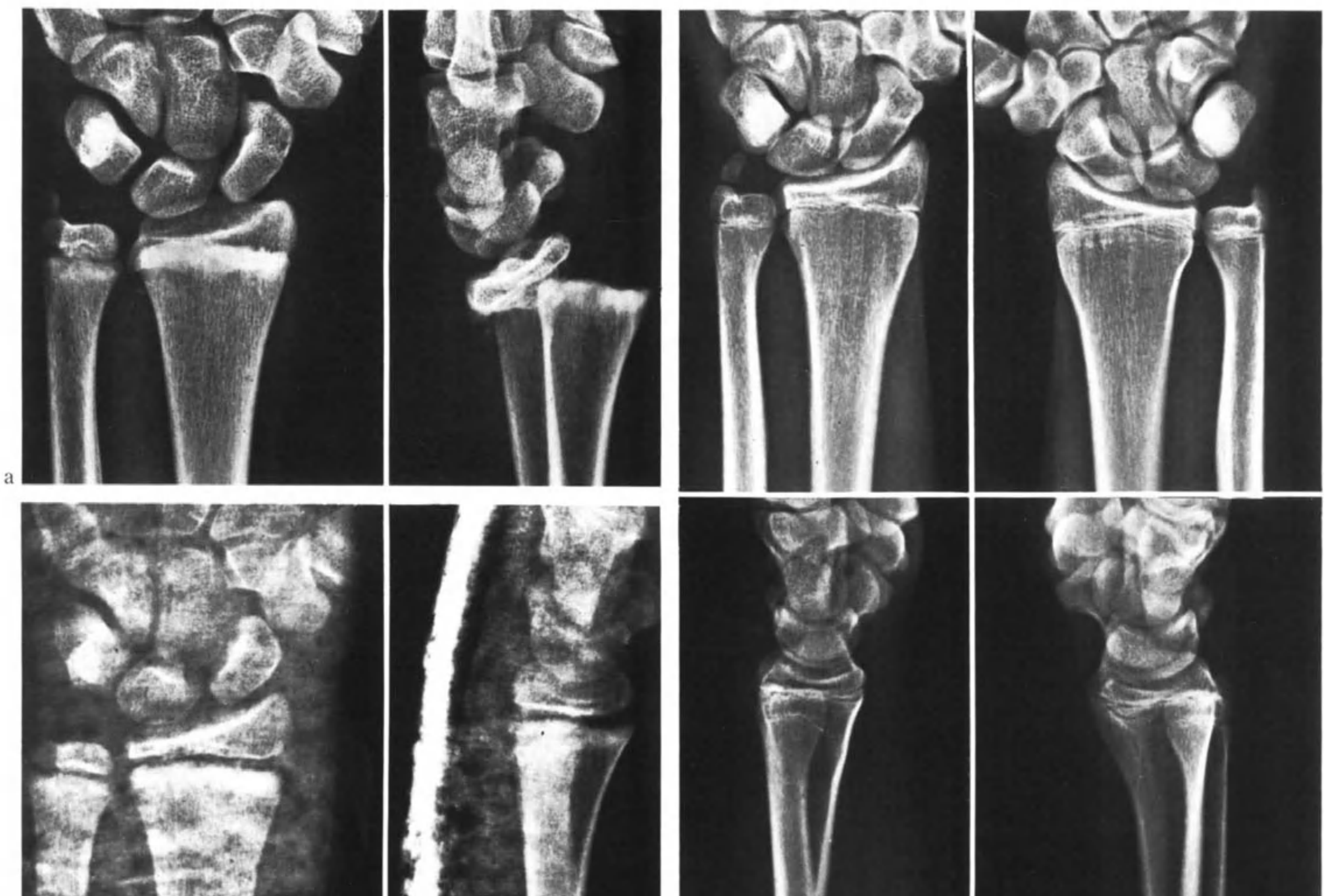


Fig. 27

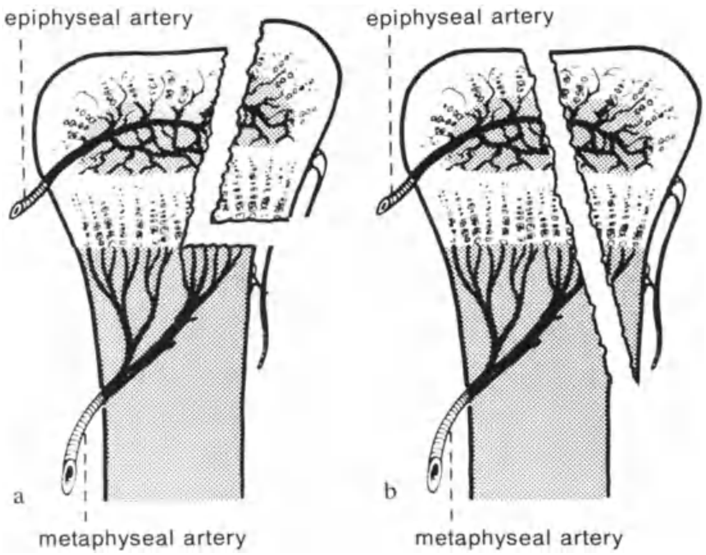


Fig. 28a, b. *Pathological anatomy of true fracture of the epiphysis. Two alternative forms.*
a) Fracture of the epiphysis and separation in the region of primary bone formation.
b) Fracture which traverses the epiphysis and metaphysis. In both cases, the germinative layer of the epiphyseal plate is injured

plate. The very vulnerable germinative zone of the growth cartilage remains undamaged. Vascular injury rarely occurs and, when it does so, is restricted to the metaphyseal blood supply, which is then restored via anastomoses with the diaphyseal vessels. These biological features explain why abnormal growth rarely occurs following separation and is restricted to special cases (Figs. 26, 27).

True *fracture of the epiphysis* is fundamentally different, both in an anatomic and in a pathological sense (Fig. 28). It is produced by a combination of axial compression and bending. The fracture starts at the articular surface and always passes through the epiphyseal plate. Proximal to the latter, it either runs laterally in the plane along which separation occurs or it continues into the metaphysis. The epiphyseal and metaphyseal blood supplies may remain intact or may also be injured.

In contrast to separation, fracture of the epiphyseal plate involves injury to the germinative layer and the prognosis is therefore worse. Furthermore, the fracture very often runs into the articular surface and thus causes joint incongruence.

4.2 Classification of Epiphyseal Injuries

The classification which is most useful to the clinician is that which simplifies his choice of the most appropriate treatment (Fig. 29).

Epiphyseal injuries are divided into the following types:

a) Loosening of the epiphyseal plate with or without dislocation.

b) Partial separation of the epiphysis together with a metaphyseal fragment (*Aitken* Type I injury).

c) Fracture of the epiphysis with extension of the fracture line through the epiphyseal plate and then

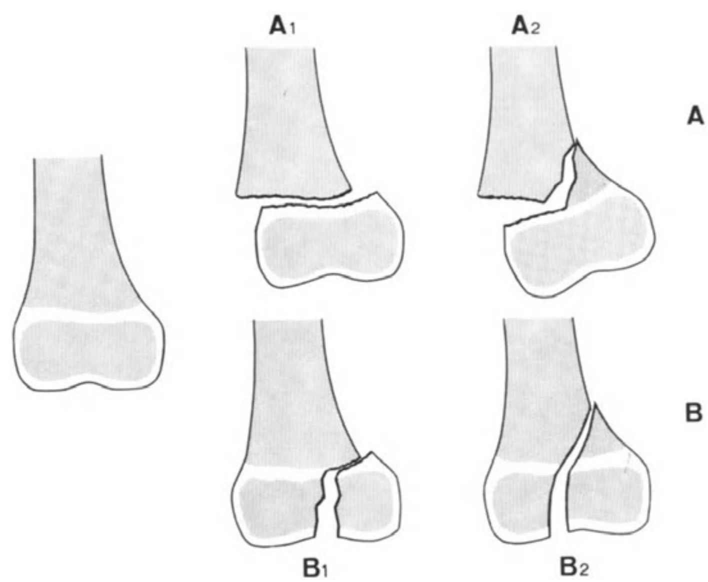


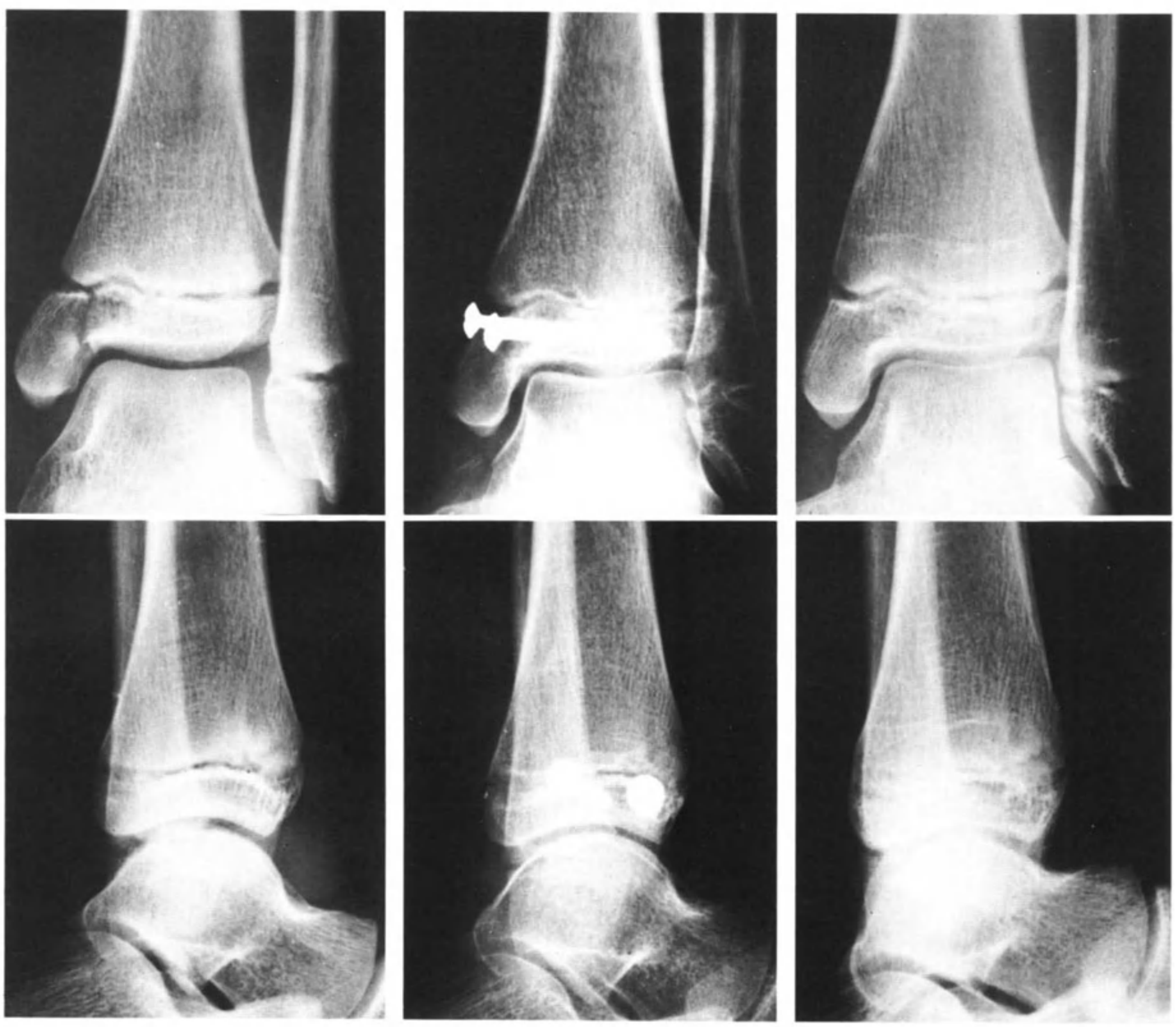
Fig. 29. *Prognostic classification of injuries to the epiphyseal plate.*
A: Good prognosis. A_1 – Simple loosening or separation of the epiphyseal plate; A_2 – separation of the epiphyseal plate with an attached metaphyseal fragment (*Aitken* Type I fracture).
B: Doubtful prognosis; B_1 fracture passes through the epiphysis and epiphyseal plate, and then passes laterally so as to constitute a partial separation (*Aitken* Type II fracture); B_2 fracture passes through the epiphysis and the epiphyseal plate, and includes a fragment of the metaphysis (*Aitken* Type III fracture)

←

Fig. 26a–c. *Separation of the epiphysis at the distal end of the tibia without damage to the epiphyseal plate.* W.E., ♀, aged 8 years, No. 70672
a) Separation of the distal tibial epiphysis.
b) Closed reduction and cast fixation.
c) $6^3/_4$ years following the accident. The fracture has healed with no sequelae. The growth rate is slightly increased, but there are no serious disturbances of growth

Fig. 27a–c. *Separation of the distal radial epiphysis.* A.P., ♂, aged 11 years, No. 147757.
a) Separation of the distal epiphysis of the radius with fracture of the styloid process of the ulna.
b) Closed reduction and cast fixation.
c) 3 years following the accident. There is symmetrical growth with an insignificant pseudarthrosis of the styloid process of the ulna

a b
Fig. 30



a b c
Fig. 31

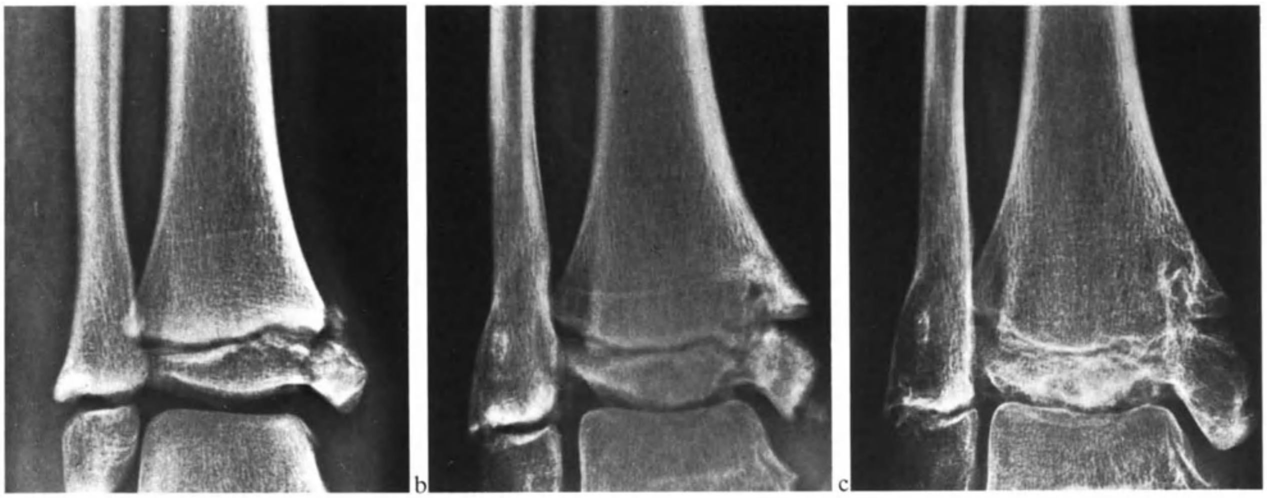


Fig. 30a, b. *Partial epiphyseal closure due to transection of the epiphyseal plate by a bone bridge*. S.M., ♂, aged 13 years, No. 65702.
a) Fracture of the medial malleolus which transects the epiphyseal plate (*Aitken* Type II fracture). Nonoperative treatment by immobilization with a cast for 7 weeks.
b) 2 years and 3 months following the accident. Severe club foot deformity as a result of fusion of the medial part of the epiphyseal plate due to the fracture, with continuation of normal growth in the lateral part of the epiphyseal plate. The severe deformity is apparent on comparison with the opposite side

Fig. 31a–c. *Normal healing following fracture of the epiphyseal plate*. T.E., ♀, aged 10 years, No. 118871.
a) *Aitken* Type II fracture of the epiphyseal plate of the medial malleolus. Treatment: "Watertight" reduction, followed by lag screw fixation of the epiphyseal fragment.
b) 8 weeks following the accident. The fracture has healed.
c) 1 year following the accident. Growth is normal and the epiphyseal plate is normal; there is no fusion of the epiphysis

Fig. 32a–d. *Abnormal growth caused by epiphyseal fusion and disturbance of the circulation.* H.S., ♂, aged 8 years, No. 140420.
a) Fracture dislocation with separation of the lateral malleolar epiphysis. Impaction of the tibial epiphysis on the medial side. *Aitken* Type III fracture of the medial malleolus. Nonoperative treatment with cast fixation for 8 weeks.
b) 11 months following the accident. There is a curious increase in the density of the distal tibial epiphysis. Callus crosses the epiphyseal plate in the region of the medial malleolus.
c) 18 months after the accident. Definite signs of aseptic necrosis are seen in the central part of the distal tibial epiphysis (the radiodensity of the necrotic area is greater than that of the surrounding osteoporotic bone). Fusion of the distal tibial epiphysis has occurred on the medial side.
d) 3 years following the accident. Severe posttraumatic deformity is seen, with marked aseptic bone necrosis in the central part of the distal tibial epiphysis and corresponding changes in the ankle joint. This is a result of posttraumatic fusion of the epiphysis combined with disturbance of the epiphyseal blood supply

along the interface between the latter and the metaphysis (*Aitken* Type II injury).

d) Fracture of the epiphysis with extension of the fracture line through the epiphyseal plate and into the metaphysis (*Aitken* Type III injury).

In order that the classification be more easily memorized, we have grouped the type a) and b) epiphyseal separations together in the *Aitken* Type I category. In both cases, the epiphyseal plate and the vulnerable germinative layer have escaped injury so that serious disturbances of growth are unlikely.

On the other hand, the type c) and type d) injuries (*Aitken* II and III) are true fractures of the epiphyseal plate which include the epiphysis, the growth cartilage, and the germinative layer. Abnormal growth is therefore to be expected and the outlook is more serious.

The *Aitken* classification which we have adopted does not include the so-called crush injury which is described in the classification of *Salter* and *Harris*. This is caused by crushing of the epiphyseal plate by axial compression. In our opinion, this type of injury is extremely rare. It can hardly be caused by indirect force and is more likely to be the result of direct trauma. From time to time we see examples of abnormal growth which have allegedly been caused by crush injury but which, in our opinion, have resulted from partial closure of the epiphysis due to nonoperative (i.e., inadequate) treatment (Fig. 30). If our treatment is followed by normal growth, then true crush injury cannot have been present (Fig. 31). The arterial blood supply to the epiphysis may also be damaged, thus providing a further explanation for subsequent abnormal growth. Finally, premature closure of, and interruption of the blood supply to the epiphysis may both occur and combine to disturb growth (Fig. 32).

4.3 Prognosis of Epiphyseal Injuries

When *pure separation* or *fracture separation* with inclusion of a metaphyseal fragment occur, the cleft does not pass through the epiphysis. It lies in the zones of cartilage cell degeneration and primary ossification on the metaphyseal side of the epiphyseal plate. Thus, the vulnerable germinative layer remains intact. The prognosis is good as long as approximate reduction is possible and the epiphyseal blood supply is not interrupted.

Fractures of the epiphyseal plate which cross the germinative cell layer are much more serious. They are very likely to be followed by abnormal growth if incorrectly treated (*Bishop, Blount, Carothers* and *Crenshaw, Ehalt, Gall, Giuliani, Goff, Salter* and *Harris, Titze, Weber, Witt, Witt* and *Mittelmeier*). In some cases, even correct treatment cannot prevent abnormal growth (*Lehner* and *Dubas, Witt*). It is said to be impossible to prevent deformity if the epiphyseal plate has been crushed (*Aitken*), particularly since the epiphyseal blood supply is very often compromised by injuries of this nature (*Morscher, Morscher* and *Taillard, Steinert*). Thus, abnormal growth can be predicted on the day of the accident if the injury is sufficiently severe (*Carothers* and *Crenshaw, Salter* and *Harris, Weber*).

The mechanism of injury can be deduced from the pathological anatomy seen in the roentgenogram. The prognosis is predictable and depends on the following factors:

1. The mechanism of the injury.
2. The severity of the epiphyseal injury.
3. The remaining prospective epiphyseal growth.

The anatomy and prognosis of the injury vary according to the trauma mechanism. Thus, separation of the epiphysis is caused by shear forces and is harmless in comparison to compression fracture and other special forms of injury, such as traction and avulsion fracture which cross the epiphyseal plate.

Thus, the type of damage suffered by the epiphyseal plate has a significant influence on its subsequent function. Countless animal experiments and observations in humans have shown that irritation, whatever its cause, can increase or decrease the activity of the epiphyseal plate in agreement with the basic biological law of *Arndt-Schulz*, which states that activity is increased by slight irritation and is proportionally inhibited by greater degrees of irritation.

4.4 Compensatory Capacity of the Epiphyseal Plate

4.4.1 General Aspects. Stimulation of the Epiphyseal Plate

Slight irritation is defined as that which stimulates growth. The epiphyseal plate reacts to an increase in the blood supply by accelerating its growth (Fig. 33). Examples of irritating stimuli are: inflammation (Fig. 34); pathological fracture secondary to a benign fibrocystic tumor of the metaphysis (*Goff*); foreign material in the vicinity of the epiphyseal plate (iron, copper, ivory); traumatic intramedullary displacement of the blood flow with subsequent increase in the flow in and around the junction between the epiphysis and the metaphysis (*traumatic hyperemia*) (*Trueta, Weber*); osteotomies; and removal of the periosteum (*Morscher* and *Taillard, Ollier*). All these stim-

Fig. 33. *Increased longitudinal growth due to increased blood supply to the epiphyseal plates.* M.B., ♂, 5 years, No. 117546. Klippel-Trénaunay syndrome

Fig. 34. *Accelerated longitudinal growth as a result of chronic inflammation.* B.M., ♂, aged 53 years, No. 164874. Hematogenic osteomyelitis of the left leg occurred at the age of 8 years, with recurrent fistula formation up to the age of 51 years. 1.5 cm difference in leg length

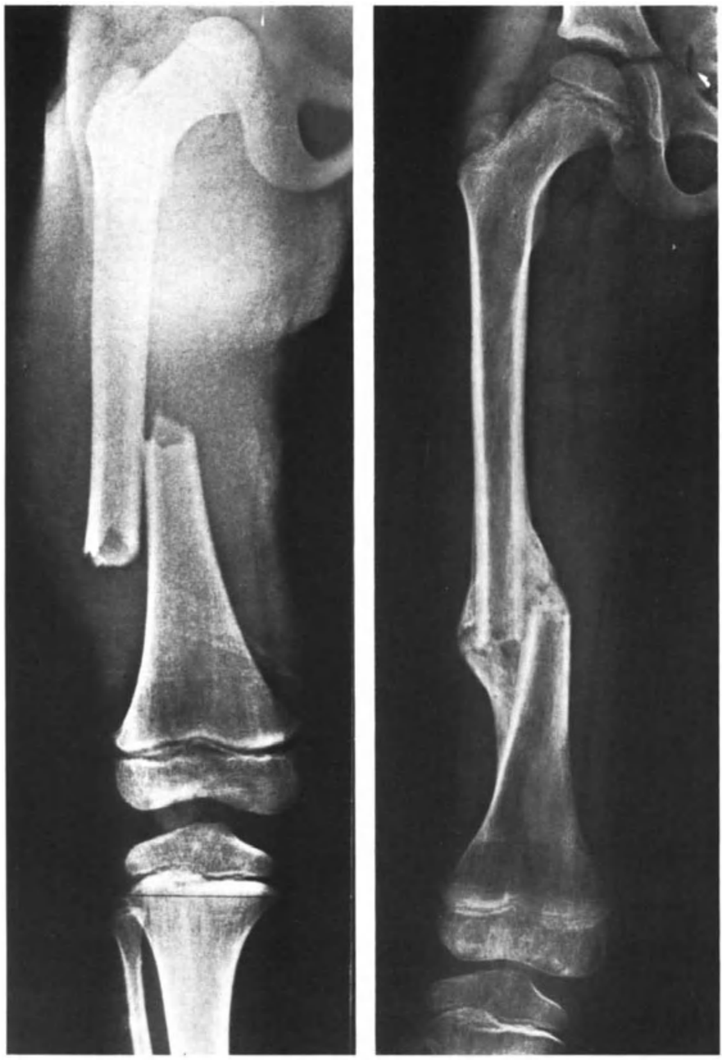


Fig. 35a–c. *Functional adaptation by remodelling and perpendicular realignment of the bone as a result of compensatory epiphyseal growth.* M.M., ♂, aged 8 years, No. 119095.
a) Diaphyseal fracture of the femur. Treatment by traction.
b) 4 months after the accident. There is 1 cm of leg shortening, slight valgus, and massive callus.
c) 4 years after the accident. Functional adaptation has occurred. The callus has been resorbed, the valgus angulation is no longer present, and the condylar planes of the knee are symmetrical, i.e., the posttraumatic valgus has been corrected by differential longitudinal growth

uli have the same basic effect: they *accelerate growth.* In this manner, the shortening of a fractured bone is compensated for (*Blount, Goff*). The subsequent function of the epiphyseal plate is determined not only by the type of irritation, but also by its duration and localization.

Compression has the followed effects on the growing skeleton:

1. It stimulates circumferential growth of the diaphysis. Axial compression leads to an increase in strength of the bone which is proportional to the load. Apposition exceeds resorption and there is a net gain in bone mass. Asymmetrical distribution of pressure leads to an increase in the strength of the bone on the side which is subjected to the greater load. The trabeculae on that side become thicker than those on the opposite side which is under tension, but the remodelling does not change the axes of the bone (*Pauwels*). Thus apparent straightening undergone by a fracture which has healed at an angle can be regarded as a reaction of the bone to the loads imposed upon it (*Wolff's* Transformation Law).

2. *Epiphyseal growth* is inhibited by nonphysiological pressure (*Arkin* and *Katz*). Increases in pressure along an axis parallel to the direction of growth inhibit or stop longitudinal growth; the latter is accelerated by tension or decreases in pressure (*Gelbke, Hueter, Volkmann*). *Blount's* epiphyseal staples make use of

Fig. 36a, b. *Folded-in periosteum obstructs reduction.* L.B., ♂, aged 14 years, No. 96406.
a) The line superimposed on the roentgenogram shows the torn periosteum which has slipped into the gap and prevents anatomically precise reduction of the epiphyseal separation. There is slight valgus deformity.
b) 3 years after the accident. The periosteal scar is still clearly visible. Closure and ossification of the epiphysis occurred shortly after the accident, and spontaneous correction of the valgus deformity therefore failed to occur

this phenomenon; they exert inhibitory compression on the proliferative cell zone of the epiphyseal cartilage.

4.4.2 Straightening by Asymmetrical Growth of the Epiphyseal Plate

If an epiphyseal plate is subjected to asymmetrical pressure which remains below a certain limit, it responds by asymmetrical longitudinal growth. This asymmetrical growth continues until the resultant of the compression force acts at right angles to the epiphyseal plate and passes through its center, i.e., until the compression is evenly distributed over the plate (*Pauwels*). Thus, in contrast to circumferential growth, asymmetrical growth in the epiphyseal plate changes the alignment of the bone so as to gradually decrease the bending stress. This leads to a saving in bone mass (*Pauwels*), and the bone can be said to be optimizing its structure in response to the functional stresses imposed upon it (*Roux*) (Fig. 35).

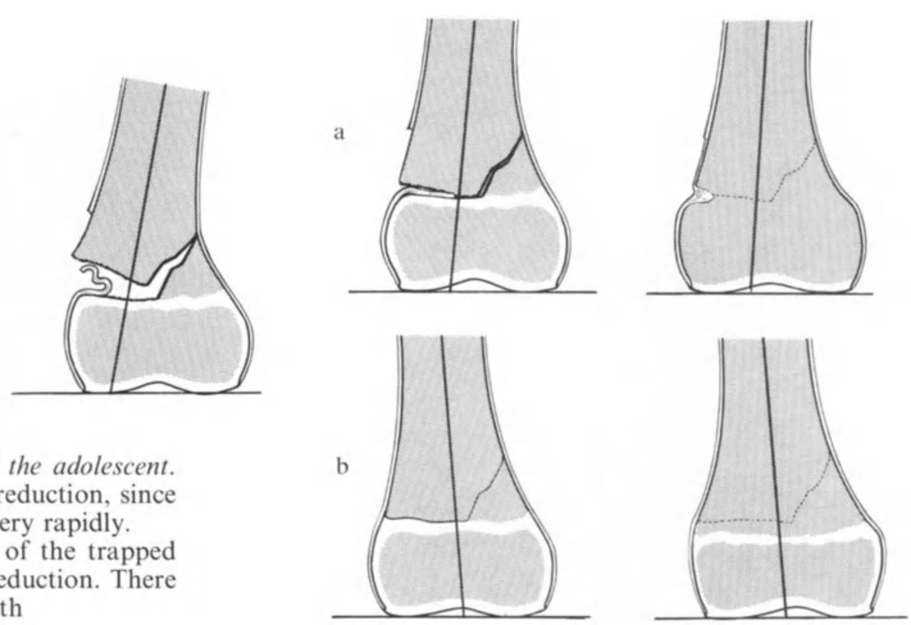


Fig. 37a, b. *Folding-in of the periosteum in the adolescent.*
a) Any deformity remains following closed reduction, since ossification of the epiphyseal plate occurs very rapidly.
b) Exposure of the fracture and extraction of the trapped periosteal flap allows anatomically precise reduction. There is no deformity following cessation of growth

Shortly before the end of the growth phase in the older child, the bone is no longer able to correct even small angular deformities. Before the epiphysis can be releveled by corrective longitudinal growth, the epiphyseal plate matures and ossifies. A characteristic example is that provided by separation of the epiphysis with interposition of the periosteum, which peels off the metaphysis and slips into the gap, thus preventing perfect reduction (Fig. 36). In older children, surgery may be necessary in order to remove such obstacles to reduction, since fracture healing might otherwise be followed by lifelong angular deformity (Fig. 37).

Functional correction by differential longitudinal growth is thus a reaction to bending loads imposed on the *epiphyseal cartilage*, whereas *functional adaptation by circumferential growth* occurs in response to bending loads imposed on the *shaft* of the bone.

4.4.3 Premature Closure of the Epiphyseal Plate

A harmless form of premature epiphyseal closure is seen following a fracture separation which occurs approximately 1 year before cessation of growth. The closure appears to be accelerated by the hyperemia which accompanies fracture healing. However, no measurable difference in leg length results, since longitudinal growth in the epiphyseal plate on the opposite side has practically ended at the time of injury (Fig. 38).

A prognostically more serious type of epiphyseal closure with subsequent growth disturbance is that caused by severe infection of the metaphysis or even of the epiphysis. The infection may be hematogenous or iatrogenic, and in this context the reader is warned about the use of *Kirschner* wires for applying traction (Fig. 39).

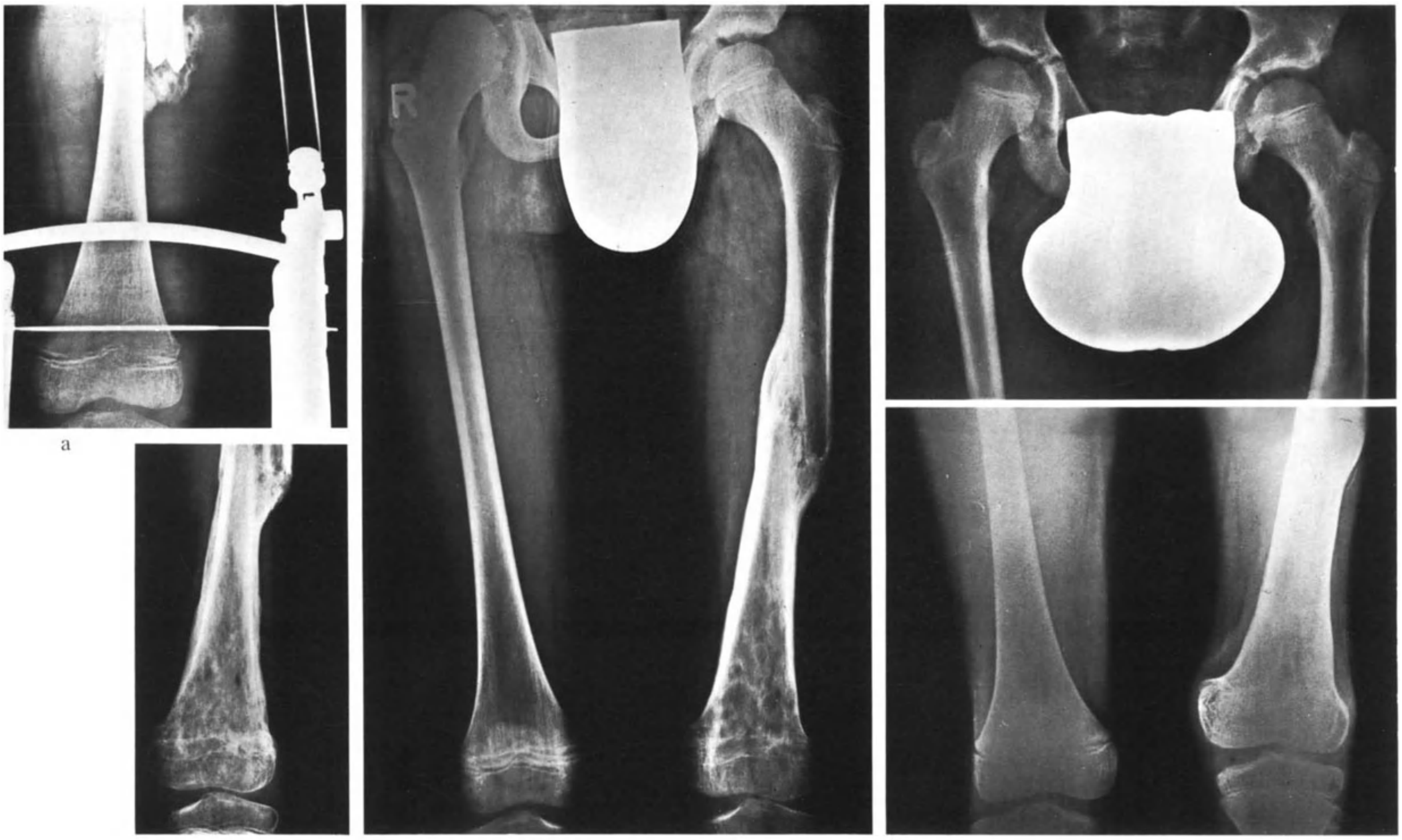
The incorrect use of radiation for the treatment of telangiectatic nevi may seriously damage the epiphyseal plate. Shortening and progressive angular deformity may result, presenting the surgeon with one of the most difficult orthopedic problems he is ever likely to encounter (Fig. 40).

a

b

c

Fig. 38a–c. *Premature epiphyseal closure*. E.D., ♀, aged 12 years, No. 75565.
a) Epiphyseal separation and metaphyseal fracture with severe dislocation. Treatment: Open reduction with removal of the trapped periosteal flap; screw fixation of the metaphysis.
b) 6 weeks after the accident. Correct healing of the fracture.
c) 9 months later. Healing with correct alignment and no abnormal growth. However, premature epiphyseal closure has occurred as a result of excessive stimulation of the epiphyseal plate by the hyperemia which accompanied fracture healing. Fusion has not occurred on the opposite side



▲ Fig. 39 a–d. *Premature epiphyseal closure caused by infection.* A.P., ♂, aged 11 years, No. 147757.
a) Diaphyseal fracture of the femur treated by traction applied to a supracondylar *Kirschner* wire. Fracture healing was satisfactory, but infection developed around the *Kirschner* wire.
b) 4 months later. The infection was followed by septicemia with very serious systemic complications. Antibiotics were given in extremely high doses. Osteomyelitis was followed by destruction of the distal femoral epiphyseal plate. Perfusion drainage resulted in healing of the osteomyelitis.
c) 8 months following the accident. Complete fusion of the distal femoral epiphysis. 23 mm difference in leg length.
d) 2 years after the accident. Severely abnormal growth, resulting in 3.5 cm difference in leg length. This difference in leg length is not final since growth is continuing on the intact side. Incipient deformation of the femoral part of the knee joint is seen

Fig. 40. *Radiation damage to the epiphyseal plate.* M.M., ♀, aged 5 years, No. 125055. ▶
A hemangioma in the vicinity of the lateral part of the knee joint was treated with X-rays! 1 year later there was severe valgus deformity of the knee as a result of radiation damage to the lateral part of the epiphyseal plate of the distal femur and to the epiphyseal plates of the proximal tibia and fibula. Subsequently, repeated osteotomies were necessary to lengthen the leg and to correct the angular deformity

a b

Fig. 41 a, b. *Growth spurt and growth lines.* H.R., ♂, aged 13 years, No. 116324.
a) Partial separation of the distal tibial epiphysis with fracture of the metaphysis (*Aitken* Type I). Treatment with a plaster cast.
b) 20 months after the accident. Growth is symmetrical, but there is a definite increase in length caused by a transient growth spurt, which is shown by the *Harris* line

4.4.4 Transient Acceleration of Growth

Separation or fracture separation of the epiphyseal plate in the younger child long before normal closure of the epiphysis very often causes transient acceleration of growth. The extent of the additional growth is apparent from the difference in the spacing of the growth lines, i.e., the *Harris* lines, in the metaphysis (Fig. 41).

4.4.5 Asymmetrical Stimulation of Growth in the Epiphyseal Plate

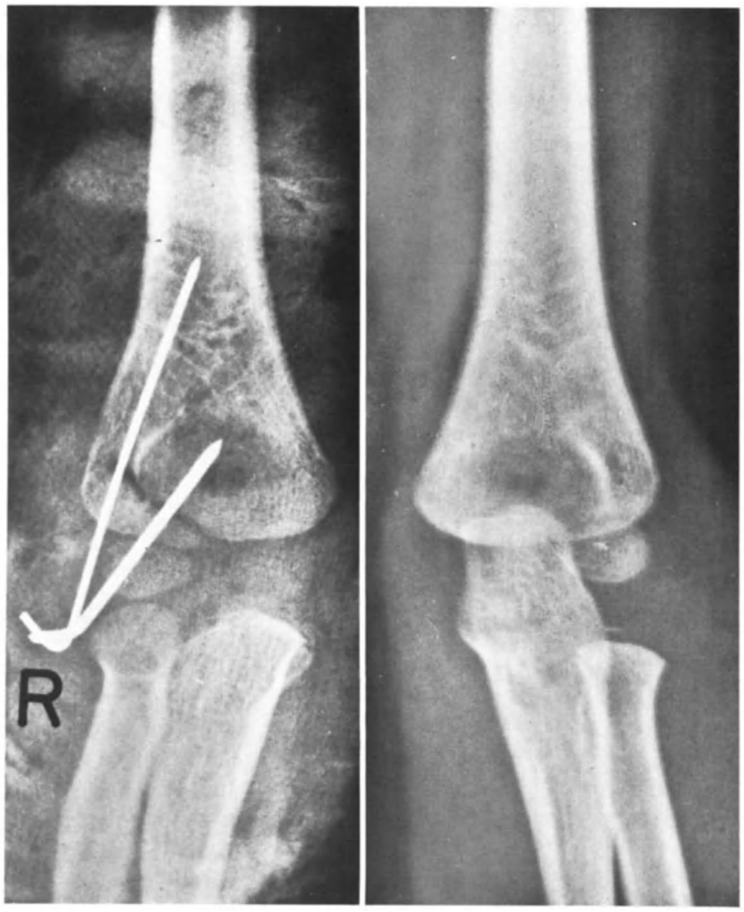
This particular reaction typically occurs following fracture of the lateral condyle of the humerus (Fig. 42). Varus angulation of the elbow almost always occurs instead of physiological valgus. The deformity is presumably caused by accelerated growth which results from fracture of the distal part of the lateral humerus.

4.4.6 Closure of the Epiphyseal Plate as a Result of Fracture

The *strongest stimulus* to closure is that which results from injury to the epiphyseal plate with *creation of a gap*. Damage to the whole plate causes shortening without angulation. It is usually impossible to decide which proportions of the injury are due to the accident and the reduction of the fracture, respectively. In the case shown in Fig. 43, separation led to premature closure of the dorsal segment of the epiphyseal plate. Shortening and angulation resulted. The original injury may have been of the crush type.

In our series of cases, premature or asymmetrical epiphyseal closure very rarely followed separation or fracture separation of the epiphyseal plate.

The important factor which causes premature closure of the epiphysis following fracture is the presence of *Aitken* Type II or III injury, i.e., a fracture which directly traverses the epiphyseal plate. The subsequent



a

b

Fig. 42a, b. *Unilateral stimulation of the epiphyseal plate.* M.C., ♀, aged 9 years, No. 93627.
a) Distal fracture of the humerus with avulsion of the lateral condyle (*Aitken* Type III fracture). Comparative roentgenograms following open, anatomically precise reduction and internal fixation with *Kirschner* wires.
b) 5 years after the accident: asymmetrical development of the distal humeral epiphysis has occurred. The fracture on the lateral side has caused increased stimulation which is restricted to the region of the head of the radius. Varus angulation of the elbow has resulted

a b c d

Fig. 43a–d

Fig. 43a–e. *Premature spontaneous epiphyseal fusion.* N.M., ♀, aged 12 years, No. 85220.
a) Partial epiphyseal separation with metaphyseal fracture of the distal femur on the right side. Treated by closed reduction and fixation with a plaster cast.
b) 1 month following reduction. The fragments are correctly aligned.
c) 11 months following the accident. The anterior part of the distal femoral epiphyseal plate is normal, but there are definite signs of fusion of the dorsal part of the plate.
d) 29 months following the accident. Severe antecurvature of the knee is present as a result of complete cessation of growth in the dorsal part of the epiphyseal plate.
e) Treatment: osteotomy with slight overcorrection of the deformity

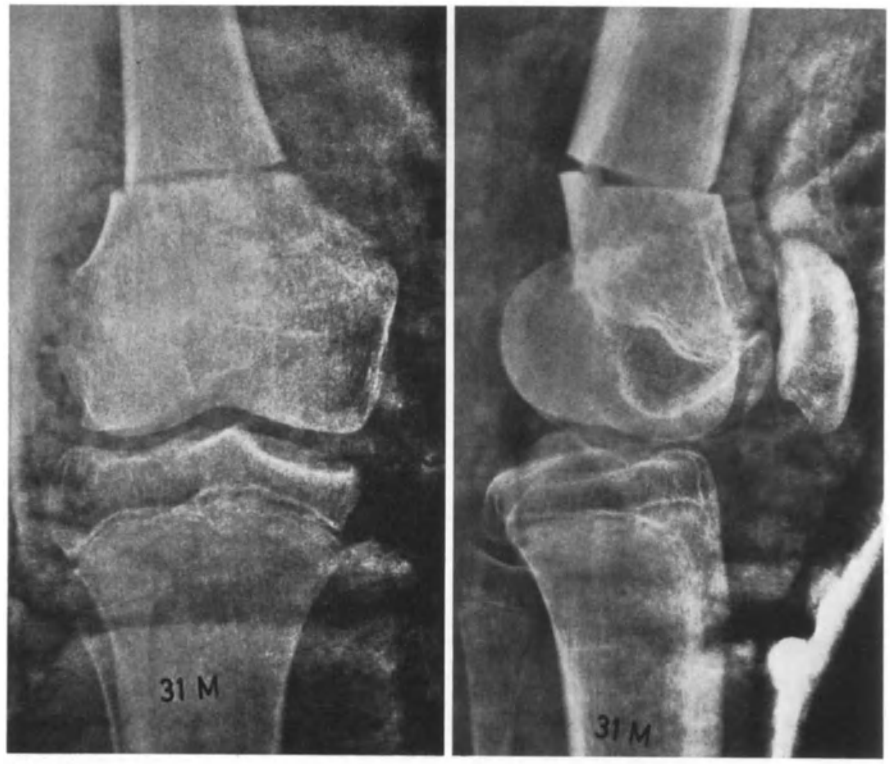


Fig. 43e

a

b

c

Fig. 44a–c. *Skewed growth following damage to the epiphyseal plate.* B.R., ♂, aged 13 years, No. 42701.
a) Injury to the lateral collateral ligament with avulsion of a proximally situated bone fragment from the distal femur. Treatment by immobilization with a plaster cylinder.
b) 5 months after the accident. A callus bridge has formed, resulting in lateral epiphyseal fusion, and asymmetrical growth is already apparent.
c) $2^1/_2$ years after the accident. Severe valgus deformity of the knee joint as a result of cessation of growth on the lateral side with slowing of growth on the medial side. Apart from the severe deformity, marked shortening of the leg is to be expected

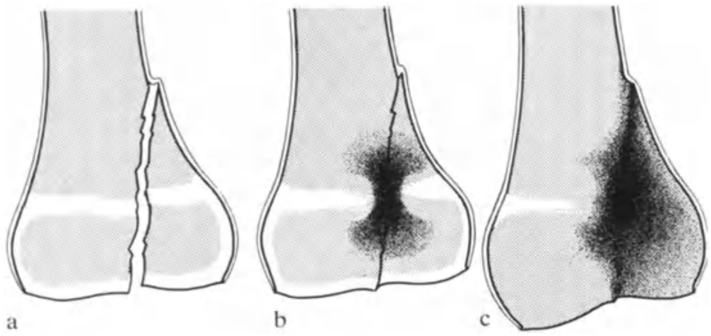


Fig. 45a–c. *Healing of a fracture which transects the epiphyseal plate.*
a) Dislocation of the germinative layer of the growth cartilage.
b) Formation of a callus bridge between the metaphysis and the epiphysis, with destruction of the germinative cartilage layer in this region.
c) Partial epiphyseal fusion. At first, normal growth continues in the intact part of the epiphyseal plate; gradually, asymmetrical growth sets in and is accompanied by a reduction in the longitudinal growth rate

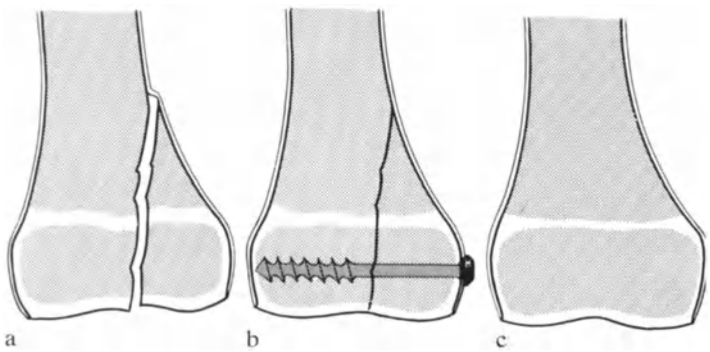
deformity is independent of the size of the fragment. It is proportional to the amount of growth remaining, and is thus inversely proportional to the age of the child. Progressive *angular deformity* and *shortening* occur concurrently. The *angulation* commences not later than 1 month following injury. It becomes obvious 6–8 months later and reaches a maximum after a period of months or years (Fig. 44). Disturbances of growth following asymmetrical, *Aitken* Types II and III injury to the epiphyseal plate can be explained as follows (Fig. 45). Following incomplete reduction of the fracture, a gap remains which extends from the epiphysis to the metaphyseal side of the growth cartilage and this gap becomes filled with callus. The resulting bridge between the epiphysis and the metaphysis constitutes a discontinuity of the epiphyseal plate within which growth cannot occur. Localized closure of the epiphysis thus occurs. If, as in the majority of cases, the closure lies near the edge of the epiphyseal plate, growth continues on the opposite side and the epiphysis becomes tilted relative to the shaft of the bone.

We have also seen premature closure of the epiphysis following fracture of the acetabulum in a child. Acetabular dysplasia results, with subsequent disproportion of the femoral head and acetabulum (Fig. 46).

4.4.7 Fracture Healing Following Internal Fixation of *Aitken* Type II and III Fractures

It follows from the considerations in the previous section that normal growth might be expected if the formation of a callus bridge between the epiphysis and the metaphysis could be prevented. Fractures of this type should therefore be treated according to the principle shown in Fig. 47. By precise reduction followed by suitable internal fixation, the fracture is closed so

Fig. 46a–c. *Premature epiphyseal fusion in the acetabulum.* K.V., ♀, aged 6 years, No. 51633.
a) Road traffic accident. Fracture of the pelvis with dislocation in the region of the triradiate cartilage of the acetabulum. Treatment: bed rest.
b) 3 years after the accident. There are clear signs of epiphyseal fusion in the region of the triradiate cartilage. The tear drop is displaced laterally.
c) 8 years after the accident. There is dysplasia of the left acetabulum with joint incongruence

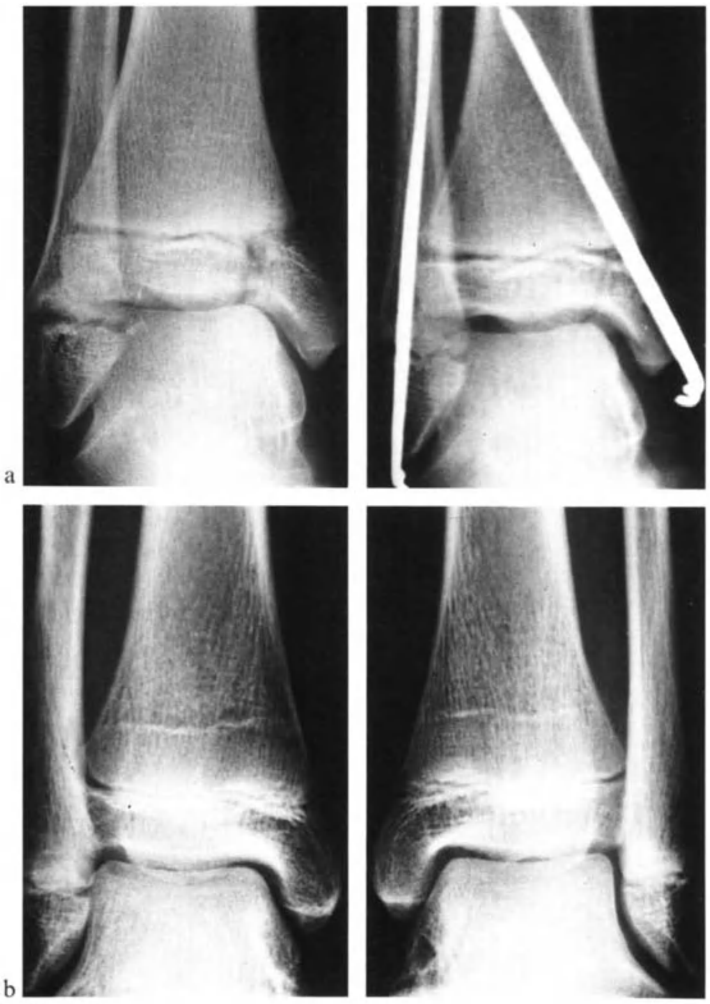


a b c

Fig. 47a–c. *Principle of treatment of Aitken fracture types II and III.*
a) Site of the fracture.
b) The fracture gap is eliminated by lag screw fixation of the fragments. This "watertight" reduction obliterates the channel along which a callus bridge might otherwise form between the epiphysis and metaphysis.
c) Growth is normal following healing of the fracture, since localized epiphyseal fusion cannot occur

that there is no longer a gap within which callus can form. Care should be taken to prevent damage to the epiphysis or the epiphyseal plate during the operation. Implant material which traverses the epiphyseal plate should be kept to a minimum and restricted to *Kirschner* wires; these should lie as near as possible to 90° to the epiphyseal plate. Growth is not disturbed by *Kirschner* wires or by the small holes in the epiphyseal plate which remain when they are removed (Fig. 48). The epiphyseal plate should never be pierced by screws (Fig. 49). They slow growth and thus cause tilting of the epiphysis (*Wagner*) (Fig. 50). This effect is made use of in the *Blount* epiphyseal stapling procedure.

a

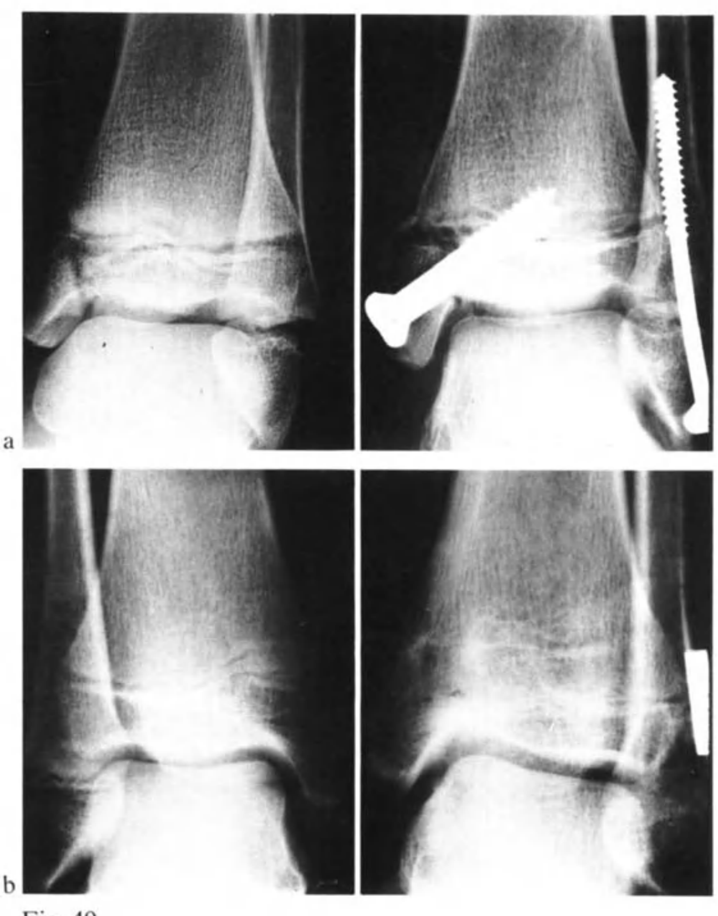


b

Fig. 48

Fig. 48a, b. *Permissible fixation by an implant which crosses the epiphyseal plate.* Z.U., ♂, aged 13 years. No. 110286.
a) *Aitken* Type II fracture of the medial malleolus with separation of the distal epiphysis of the fibula.
b) Treatment: Open, anatomically precise reduction followed by *Kirschner* wire fixation. At follow-up 1 year and 9 months later, growth is normal, there is no damage to the epiphyseal plates, and recovery is complete. The *Kirschner* wires are placed at as near to 90° to the epiphyseal plate as possible, so as to minimize the injury to the latter and thus prevent growth disturbances

a



b

Fig. 49

Fig. 49a, b. *Incorrect internal fixation.* S.M., ♂, aged 13 years, No. 65702.
a) *Aitken* Type II fracture of the medial malleolus with separation of the distal epiphysis of the fibula. Treatment: Incorrect use of screws which pass obliquely through the epiphyseal plate. Screw fixation of the fibula.
b) Logical result: Severely abnormal growth as a result of localized fusion of the epiphysis

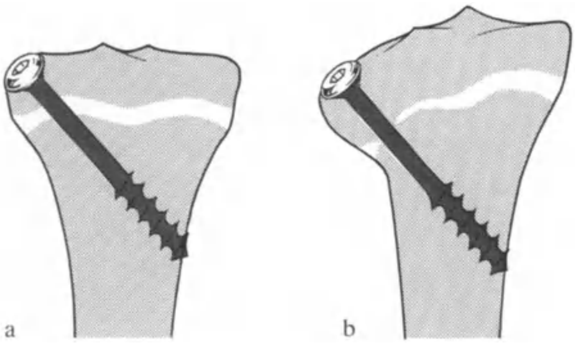


Fig. 50a, b. *Skew growth following screw fixation.*
a) One-sided screw fixation of an epiphyseal plate will cause slow growth.
b) Asymmetrical growth caused by "stapling" of one-half of the epiphyseal plate

The basic principles of treatment of epiphyseal injuries can thus be deduced from the foregoing description of bone growth and its response to injury. These principles are reiterated in the following chapters on individual types of trauma.

In summary, the epiphyseal plate may react to trauma in one of the following ways:

1. Excessive longitudinal growth is caused by the localized collateral hyperemia which accompanies fracture of the diaphysis. It may also follow injury to the epiphysis or epiphyseal plate if the germinative layer remains intact.

2. Compensatory longitudinal growth corrects angular deformity.

3. Premature total epiphyseal closure as a result of damage to the epiphyseal plate shortly before cessation of growth does not cause a measurable difference in bone length.

4. Premature total epiphyseal closure as a result of severe damage to the germinative layer leads to *shortening* of the bone.

5. Partial closure of an epiphysis results in asymmetrical growth, *angular deformity*, and *shortening*.

6. Asymmetrical stimulation of an epiphyseal plate causes asymmetrical growth with progressive tilting of the epiphysis relative to the metaphysis. Shortening does not occur.

7. Normal growth may even follow severe *Aitken* Type II and III injuries to the epiphyseal plate if the formation of a callus bridge between the epiphysis and the metaphysis is prevented by precise reduction and fixation: "watertight reduction" (*Wagner*).

5 Summary

Diaphyseal fractures in children heal well and rapidly, whether they be treated by closed reduction or by surgery. With the exception of torsional deformity, most degrees of angular misalignment are corrected by subsequent growth. Closed treatment is therefore indicated in the majority of cases. The necessity for precise reduction and fixation increases with the age of the child. The likelihood of spontaneous correction of malunion is proportional to the time interval between the accident and normal cessation of growth, i.e., it is proportional to the growth reserve.

Separation of an epiphysis requires reduction with more or less correct axial alignment. Subsequent growth is normal and can even correct residual axial deformity. However, immediately before normal cessation of growth, the ability of the bone to correct malunion is restricted, so precise alignment should be aimed for when reducing a fracture at this time.

True fractures of the epiphyseal plate which are incorrectly treated very often cause premature asymmetrical closure of the epiphysis. This leads to progressive retardation of longitudinal growth and serious angular deformity.

The following facts should be taken account of when treating fractures in children.

1. Bone union occurs rapidly and easily. Malunion is corrected spontaneously in the majority of cases.

2. True fractures of the epiphyseal plate which transect the growth cartilage have an exceedingly poor prognosis if incorrectly treated. Precise reduction and internal fixation are the only means of preventing angular deformity in such cases.

6 References

Aitken, A. P.: The end results of the fractured distal tibial epiphysis. J. Bone Jt. Surg. **18**, 3, 685 (1936).
Arkin, A. M., Katz, J. F.: The effect of pressure on epiphyseal growth. J. Bone Jt. Surg. **38 A**, 1056 (1956).
Bergenfeldt, E.: Beiträge zur Kenntnis der traumatischen Epiphysenlösung an den langen Röhrenknochen der Extremitäten. Acta chir. scand **58** (1933).
Bishop, P. A.: Fractures and epiphyseal separation fractures of the ankle. Amer. J. Roentgenol. **28**, 40 (1932).
Blount, W. P.: Baltimore: Fractures in Children. Williams and Wilkins 1954.
Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.
Carothers, Ch. O., Crenshaw, A. H.: Clinical significance of a classification of epiphyseal injuries at the ankle. Amer. J. Surg. **89**, 879 (1955).
Danis, R.: Technique de l'ostéosynthèse. Paris: Masson 1932.

Danis, R.: Théorie et pratique de l'ostéosynthèse. Paris: Desoer, Liège, Masson 1949.
Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1960.
Gelbke, H.: Tierexperimentelle Untersuchungen zur Frage des epiphysären Längenwachstums des Knochens unter Druck. Langenbecks Arch. Chir. **265**, 133 (1950).
Gall, F.: Nachuntersuchungen von Epiphysenfugenbrüchen. Langenbecks Arch. Chir. **265**, 133 (1950).
Giuliani, K.: Spätzustände nach traumatisch-mechanischen Schädigungen der Epiphyse am distalen Tibiaende. Arch. orthop. Unfall-Chir. **45**, 386 (1952).
Goff, C. W: Surgical treatment of unequal extremities. Springfield Ill.: Ch. C. Thomas 1960.
Harris, H. A.: Bone growth in health and disease; the biological principles underlying the clinical, radiological and histological diagnosis of perversions of growth and disease in skeleton. London/Oxford: Univ. Press 1933.
Hueter, C.: Anatomische Studien an den Extremitätengelenken Neugeborener und Erwachsener. Virchows Arch. path. Anat. **25**, 572 (1862).
Lehner, A., Dubas, J.: Sekundäre Deformierungen nach Epiphysenlösungen und epiphysenliniennahen Frakturen. Helv. chir. Acta **21**, 388 (1954).
Morscher, E.: Strength and morphology of growth cartilage under hormonal influence of puberty. Reconstr. Surg. and Traumatol., Vol. 10. Basel New York: Karger 1968.
Morscher, E., Taillard, W.: Beinlängenunterschiede. Reconstr. Surg. and Traumatol. Basel, New York: Karger 1965.
Ollier, L.: Traité experimental et clinique de la régénération des os de la production artificielle du tissu osseux, Vol. 1. Paris: Masson 1867.
Pauwels, F.: Gesammelte Abhandlungen zur funktionellen Anatomie des Bewegungsapparates. Springer, Berlin – Heidelberg – New York: Springer 1965.
Rampoldi, A., Boni, M.: I distacchi epifisari traumatici. 42. Congr. soc. ital. ortop. e traumatol. 1957.
Rang, M.: Children's Fractures. J. B. Lippincott Philadelphia, Toronto (1974).
Rettig, H.: Frakturen im Kindesalter. München: Bergmann 1957.
Roux, W.: Gesammelte Abhandlungen über Entwicklungsmechanik der Organismen. Leipzig: Engelmann 1895.
Salter, R. B., Harris, R.: Injuries involving the epiphyseal plate. J. Bone Jt. Surg. **45 A**, 587 (1963).
Steinert, V.: Epiphysenlösung und Epiphysenfrakturen. Arch. orthop. Unfall-Chir. **58**, 200 (1965).
Suessenbach, F., Weber, B. G.: Epiphysenfugenverletzungen am distalen Unterschenkel. Bern, Stuttgart, Wien: Huber 1970.
Titze, A.: Sprunggelenksverletzungen bei Kindern. Zschr. Kinderchir. **4**, 400 (1967).
Titze, A.: Knöchelbrüche bei Kindern und Jugendlichen. Wien. med. Wschr. **7**, 138 (1968).
Trueta, J.: The influence of the blood supply in controlling bone growth. Bull. Hosp. Joint Dis. **14**, 147 (1953).
Trueta, J.: Trauma and bone growth. Congr. SICOT, Barcelona 1957.
Volkmann, R.: Chirurgische Erfahrungen über Knochenverbiegungen und Knochenwachstum. Arch. path. Anat. **4**, 512 (1862).
Wagner, H.: Die Einbettung von Metallschrauben im Knochen und die Heilungsvorgänge des Knochengewebes unter dem Einfluß der stabilen Osteosynthese. Langenbecks Arch. Chir. **305**, 28 (1963).
Wagner, H.: Korrektureingriffe nach Verletzungen des distalen Radiusendes. Langenbecks Arch. Chir. **334**, 211 (1973).
Weber, B. G.: Epiphysenfugen-Verletzungen. Helv. chir. acta **31**, 103–108 (1964).
Weber, B. G.: Epiphysenfugen-Frakturen. Orthopädische Praxis **1/II**, 1966.
Weber, B. G.: Prophylaxe der Achsenfehlstellungen bei der Behandlung kindlicher Frakturen. Z. Unfallmed. Berufskrankh. **I/66**, 80–95 (1966).
Weber, B. G.: Indikationen zur operativen Frakturbehandlung beim Kind. Chirurg **38**, 441–444 (1967).
Weber, B. G.: Epiphysenfugenverletzungen. Fortbildungstagung des Berufsverbandes der Fachärzte für Chirurgie, Gießen, 19./20. Nov. 1969.
Weber, B. G.: Frakturen im Kindesalter. Bericht über die unfallmed. Arbeitstagung Göttingen, 14./15. April 1972.
Weber, B. G.: Epiphyseal injuries: Internal fixation of fractures of Aitken type 2 and 3. Proceedings of the 12th Congress of fractures of the International Society of Orthopaedic Surgery and Traumatology, Tel Aviv, 9.–12. Okt. **9–12**, 1972.
Weber, B. G., Čech, O.: Pseudarthrosen. Bern, Stuttgart, Wien: Huber 1973.
Weber, B. G.: Das Besondere bei der Behandlung der Frakturen im Kindesalter. Mschr. Unfallheilk. **78**, 193–198 (1975).
Weber, B. G., Čech, O.: Pseudarthrosis. Bern, Stuttgart, Wien: Huber 1976.
Willenegger, H., Perren, S., Schenk, R.: Primäre und sekundäre Knochenbruchheilung. Chirurg **42**, 241 (1971).
Witt, A. N.: Die Therapie der Epiphysenfugenschädigungen. Langenbecks Arch. Chir. **289**, 361 (1958).
Witt, A. N., Mittelmeier, H.: Epiphysenverletzungen des Unterschenkels. In: Handb. d. Orthopädie, Bd. IV, S. 1174. Stuttgart: Thieme 1961.
Wolff, J.: Das Gesetz der Transformation der Knochen. Berlin: Hirschwald 1892.

Treatment of Fractures in Children

B.G. Weber, E. Waidelich, F. Kern

CONTENTS

1 General Principles of Therapy

B.G. Weber

The aim of fracture treatment is the restoration of the normal anatomy and function.

1.1 Factors Detrimental to Healing

Four factors may prevent the achievement of the above aim:

a) Severe injury: The damage may be so severe that any medical treatment fails, e.g., amputations and epiphyseal injuries with large residual gaps.

b) Incorrect choice of technique: For each type of fracture, the procedure must be chosen which offers the best chance of perfect healing. Thus, for example, fractures of the femoral neck heal best if they are operated on immediately using a specific surgical technique.

c) Inadequate surgical skill: Not only should the correct technique be chosen; it should also be correctly performed by the surgeon. The best of methods is useless, and may even be dangerous, if the surgeon is unfamiliar with it or lacks the necessary skill.

d) Complications which arise during treatment: Complications may follow any method of fracture treatment. Infection introduced by a *Kirschner* wire may be just as serious as that following internal fixation. A child is particularly vulnerable to pressure sores from a cast; it seems that children are less sensitive to pain than adults, and they often fail to notify the doctor of developing sores. Nerve damage or circulatory disturbances may result from a tight cast or incorrect positioning of the patient and nullify the benefits of bone union in a permanent manner (Fig. 1).

1.2 Indications for Operative or Nonoperative Treatment

In general, *closed treatment* is to be preferred for childrens' fractures. The healing capacity of the growing bone is considerable and pseudarthrosis very seldom occurs. Malunion is corrected by subsequent growth. In children, sequelae of immobilization, cast fixation, and absence of weight bearing are not nearly as frequent as in adults. Thus, the operative treatment of a fracture in a child requires special justification.

Operative treatment should always be considered when closed treatment is expected to fail. Surgery is to be preferred if it will prevent a poor result. Before the final decision to operate is made, the following questions should be posed by the surgeon:

a) Is surgery necessary in order to improve the prognosis, or would the result of correctly performed nonoperative treatment be just as good?

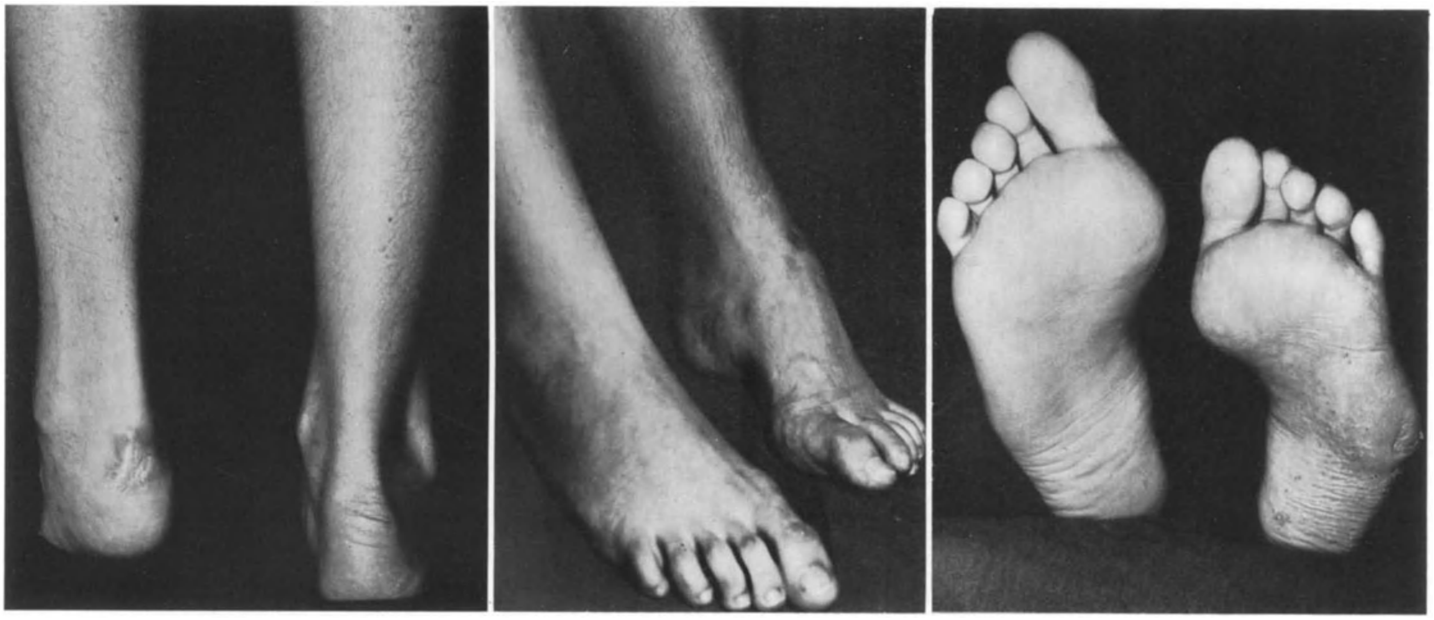


Fig. 1. *Damage caused by a tight circular cast without padding*. W.J., ♀, aged 13 years, No. 132668.
Condition of the leg following closed treatment of a fracture of the lower leg. Pressure sore on the posterior aspect of the medial malleolus. Severe posttraumatic tarsal tunnel and ischemia syndrome with club foot deformity and soft tissue damage

b) Am I able to perform the necessary operation correctly, i.e., do I have the necessary training, experience, and instruments? Am I assured of suitable anesthesia and sterile operating conditions?

c) If a complication occurs, will I be able to treat it effectively so that the end result is no worse than that of perfect nonoperative management?

d) Will my decision withstand the criticism of competent colleagues, or should I call in a more experienced surgeon for advice? Experience in our clinic has shown that it is well worthwhile asking oneself these questions. The action taken on the basis of the answers saves both the less experienced surgeon and the patient from disappointment. In the following pages, the reader is repeatedly shown the regrettable results of adventurous and incompetent treatment which lacks clear guidelines.

1.3 Prevention of Malunion and Disturbances of Growth

The management of fractures of the growing bone has two prophylactic aims:

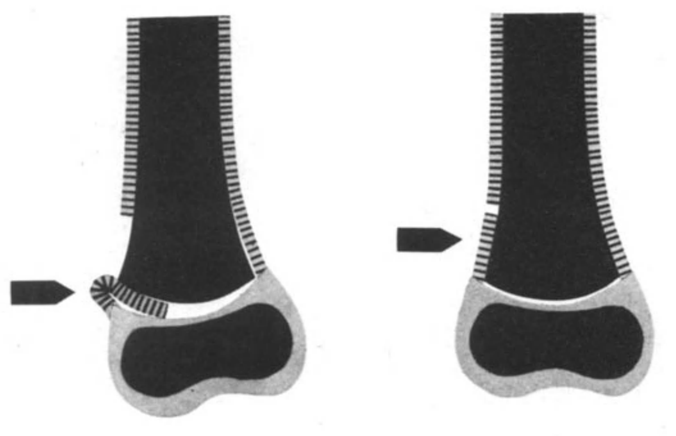
a) Prevention of Malunion. The ability of the bone to spontaneously correct posttraumatic deformity decreases with the age of the child. Residual angulation following reduction of a fracture is of no consequence in an infant. It is tolerable within certain limits in the young child. In the adolescent, however, there should be no residual axial misalignment.

The humerus is the only bone in which residual angulation is permitted. In the upper and lower leg and in the forearm of the older child or adolescent, axially perfect reduction should be aimed at as in the adult.

In the young child, bending and lateral displacement by the width of the shaft are permissible, but torsion at the fracture should be fully corrected. Nature is unable to correct torsional malunion. If the fracture is to heal normally in every respect, reduction should include correction of the torsional deformity, irrespective of the age of the child.

In the course of the operative treatment of a fracture in an adult, axially correct reduction results almost automatically. This is less true of closed reduction so that *comparison of the fractured limb with the intact limb* is even more important following the latter procedure. In order to prevent axial deformity, the *shape and alignment of the fractured limb should be matched with that of the intact limb*.

b) Prevention of Growth Disturbances. Excessive longitudinal growth is regularly seen following fracture of the diaphysis. It is compensated for by allowing the fracture to unite with slight *initial shortening*. Severe angulation should be avoided, since it induces compensatory longitudinal growth in addition to that previously mentioned.



a b

Fig. 2a, b. *Interposition of periosteum following separation of the epiphysis.*
a) In an older child in whom growth has almost ceased, surgery is necessary to remove the periosteal flap, since permanent angular deformity will otherwise result.
b) Angulation is no longer present following anatomically precise reduction

The following points concerning growth disturbances following epiphyseal injury should be noted:

1. Separation of the epiphysis heals perfectly following precise reduction.
2. The prognosis is good following approximate reduction of an epiphyseal separation in a child, since even severe degrees of deformity are corrected by subsequent growth. However, if separation occurs shortly before normal cessation of growth, precise reduction is necessary, since any residual deformity is otherwise likely to remain. Difficulty in reduction is usually caused by the interposition of periosteum or tendon. Open reduction is necessary in order to remove these tissues from the fracture gap (Fig. 2).
3. True fractures of the epiphyseal plate, i.e., those which transect the growth cartilage, must be operated on if reduction is imperfect (Figs. 3 and 4). Unless the fracture is perfectly reduced and firmly held together so as to render the fissure "watertight," a callus bridge will form between the epiphysis and the metaphysis. This bridge transects the epiphyseal plate, causing localized cessation of growth which, in turn, results in asymmetrical growth and tilting of the epiphysis. *Aitken* Type II and III fractures in childen and adolescents should therefore be operated on.

1.4 Timing of Treatment

Childrens' bones react much more quickly to a fracture than those in the adult. Within a few days, the fragments are joined by callus. Thus, at a relatively early stage, precise reduction of the fracture is no longer possible. This characteristic has a particularly important influence on the treatment of fractures of the epiphysis, particularly *Aitken* Types II and III. Here, precise, "watertight", operative or nonoperative reduction, and fixation are easiest within 24 hours of the accident. Definitive treatment should therefore be instituted as soon as possible if there are no contraindications. Any delay complicates treatment and may spoil the end result. This rule applies both to closed and to operative treatment.

2 General Techniques of Treatment

The treatment of fractures in children and adolescents differs from that of fractures in adults in a number of ways. This is true of the operative techniques and also of the closed methods of treatment. The problems associated with childrens' fractures are not smaller; they are different. The techniques applicable to each type of fracture are described in the appropriate chapter. This chapter deals with the basic principles as follows:

2.1 Anesthesia
2.2 Closed Methods of Treatment
2.3 Internal Fixation
2.4 Multiple Trauma and Fractures

2.1 Anesthesia in the Treatment of Fractures in Children

E. WAIDELICH, F. KERN

Successful anesthesia is important to the injured child, his parents, and the doctor. A young child cannot be expected to keep still and cooperate in the same manner as an adult during infiltration or the induction of regional anesthesia. In addition, the parents suffer with their child, and the knowledge that the pain has been abolished by a successful anesthetic increases their confidence in the doctor.

Full analgesia is a prerequisite to unrestricted treatment of the fracture. Perfect anesthesia is therefore essential if a successful result is to be achieved.

When dealing with an injured child, the anesthetist has two aims. He wishes to *calm the child*, who is apprehensive of the impending treatment, and he must *abolish pain*.

The child is frightened by the accident and by the strange new hospital environment. Therefore, he cannot be expected to cooperate in a normal manner. *General*

a


b

c

Fig. 3a–c. ***Abnormal growth following nonoperative treatment of an epiphyseal fracture.*** **B.P., ♂, aged 7 years, No. FK.**
a) Fracture of the epiphyseal plate of the lateral condyle of the humerus (*Aitken* Type III).
b) 1 month following nonoperative treatment with a cast. The fracture has united. Slight dislocation of the lateral condyle is seen.
c) 14 years after the accident. Grossly abnormal growth with incongruence of the joint as a result of epiphyseal fusion at the center of the plate

anesthesia is therefore necessary, even though reduction of the fracture and the application of a cast or traction device require little time and a large proportion of the cases can be treated on an out-patient basis.

Every injured child requires a history and physical examination. The stomach of an injured patient should never be assumed to be empty, since normal gastric emptying ceases after an accident. Thus, the "6 hours after the last meal" rule cannot be relied upon in trauma cases. The use of a gastric tube to empty the stomach prior to the anesthetic is difficult and brutal, and the results are unreliable. Furthermore, the struggling of the child increases the pain of the fracture and heightens the excitation of all concerned.

It is difficult to assess the blood loss in a closed fracture hematoma or that from an open wound. The blood loss cannot be estimated from hemoglobin or hematocrit determinations carried out within a few hours of the accident. The normal hemoglobin values in children differ from the range of 14–16 g% found in adults. They exceed 17 g% in the newborn and then fall to about 11 g%; from the second year of life, they gradually rise and come to lie between 14 g% and 16 g% in 10–12 year old children (*Smith*). Hemorrhagic shock should be diagnosed and treated before the induction of anesthesia. The ratio between blood volume and body weight is greater in the child than in the adult (84 ml/kg body weight in the newborn, 65 ml/kg in the adult (*Friis-Hansen*)). Loss of 10% of the total blood volume can be neglected; 10%–14% should probably be replaced; losses of greater than 14% must always be replaced (*Davenport*). Blood transfusion is also necessary if the hemoglobin and hematocrit values fall below 9 g% and 32 %, respectively (*Smith*).

If serious cranial, thoracic, or abdominal injuries are present or vital systems are endangered, the treatment of the fracture must be postponed until resuscitation is complete and the general condition of the patient has stabilized.

Fat embolism also occurs in children (*Kraus*). It occurs immediately following severe trauma, but may also be a late sequel of localized injury. As in adults, it may manifest itself in the *cerebral* form (somnolence) or in the *pulmonary* form (respiratory distress, fever). Evidence of fat embolism may take the form of petechiae of the skin or arterial emboli in the retinal vessels.

The following anesthetic techniques are currently available:

2.1.1 Infiltration Anesthesia

Younger children cannot be expected to cooperate. Furthermore, infiltration of an open fracture and its environment or needling of a fracture hematoma increase the risk of infection, particularly in emergency cases.

2.1.2 Regional Anesthesia

Many fractures can be treated painlessly following axillary or supraclavicular blocking of the brachial plexus, sciatic nerve block, or epidural or lumbar anesthesia. However, these methods are only applicable to older, cooperative children. Brachial plexus block is particularly suitable for ambulatory patients, since there is no risk of aspiration and close postoperative surveillance is unnecessary. Nevertheless, the risk of iatrogenic pneumothorax should be kept in mind.

2.1.3 General Anesthesia

a) Inhalation Anesthesia. Anesthesia is induced and maintained with an oxygen-nitrous oxide-halothane mixture which is administered in nonacute cases by mask. *Endotracheal intubation* is necessary in acute trauma cases because of the danger of regurgitation and aspiration. Inhalation anesthesia is easily controllable and can be maintained as long as the surgeon wishes. Muscular relaxation is usually adequate and the patient wakens rapidly.

b) Intravenous Anesthesia. Propanidid (Epontol) is extremely short acting and allows rapid wakening. It depresses the protective reflexes and there is therefore an increased *danger of aspiration*.

Thiopental (Phentothal) is short acting with a prolonged waking phase. Repeated doses cumulate in the body. The protective reflexes are depressed and there is therefore an increased *danger of aspiration*.

Ketamine (Ketalar, Ketanest). In contrast to the conventional anesthetic agents, this drug leaves *the protective reflexes* intact, stimulates the circulation, and does not depress respiration significantly. Ketamine can be administered intravenously or intramuscularly. Repeated injections may be given. It can be used on its own or for the induction of inhalation anesthesia, and is also suitable for use during the placing of a regional block. Ketamine causes insignificant muscle relaxation, but it usually suffices for the reduction of a fracture and the application of traction. If necessary, muscle tone may be further reduced by combining ketamine with Diazepam (Valium). Wakening is somewhat prolonged. Patients over 12 years of age frequently experience unpleasant dreams and disturbances of accomodation. However, these side effects can be suppressed with dehydrobenzperidol (*Crusius*). Postoperative surveillance can be left in the hands of suitably instructed lay persons, e.g., the parents of the child. Thus, ketamine is also suitable for ambulatory fracture treatment.

Premedication is basically advisable prior to general anesthesia. It may be limited to atropine (0.1 mg/10 kg body weight) immediately prior to induction. Intravenous induction with barbiturates or propanidid is associated with increased danger of aspiration, and special precautions are therefore necessary until the endotracheal tube is in place. Suitable equipment should be immediately available to deal with any emergencies; this includes equipment for ventilation with oxygen, instruments for endotracheal intubation, and a suction device.

The pulse and respiration are monitored with a stethoscope taped to the precordium. The blood pressure is measured with a cuff, the width of which is suitable for the age and size of the child. After awakening, ambulatory patients should wait 2–3 hours before being discharged. It is essential that the parents be instructed concerning subsequent surveillance of the child and the possible reactions which may occur. Most children are accompanied by an adult, so that it is unnecessary to wait for the return of normal road traffic reactions before discharging the patient.

Of the anesthetic techniques described above, the use of *ketamine* can be said to be particularly advantageous in the light of experience in recent years. We use this agent almost exclusively in treating fractures in children. Its anesthetic action can be divided into four characteristic stages (*Kern*) as follows:

Stage 1: Surgery is possible. The tone of the tongue and jaw muscles is normal and the airway remains unobstructed. Respiration is not depressed. In a normotensive patient, the blood pressure and pulse rate rise. The reflexes are retained, including those which prevent aspiration. In children who were very excited prior to induction of anesthesia, the beginning of this


Fig. 4a–d. *Normal growth following operative treatment of an epiphyseal fracture.* H.M., ♂ aged 6 years, No. 81990.

a) Fracture of the epiphyseal plate of the lateral condyle of the humerus (*Aitken* Type III).

b) Immediate, anatomically precise, open reduction and *Kirschner* wire fixation.

c) $6^1/_2$ years after the accident. Apart from irregularity of the metaphysis, there are no longer any visible signs of the fracture and growth is normal.

d) 12 years after the accident. The elbow joints are symmetrical, both in their anatomical appearance and their ranges of movement phase is frequently accompanied by increased salivation and occasionally a certain degree of muscle rigidity. This may lead to transient respiratory irregularity.

Stage 2: This stage starts with response to commands. Defensive movements occur and the patient may utter sounds. However, the analgesia and amnesia suffice for the application of a cast and for positioning of the fractured limb for a radiographic check following reduction.

Stage 3: The patient responds to commands and external stimuli, but is still disoriented. Surgical manipulation is no longer possible during this stage, which supervenes 30–40 min after the last dose of ketamine.

Stage 4: For the next few hours, the patient prefers to sleep, but can be woken and can converse. Older children frequently experience unpleasant dreams and disturbances of accomodation.

Ketamine anesthesia can be induced intramuscularly or intravenously. If possible, however, maintenance of the anesthesia should be intravenous. The dosages and actions of ketamine are summarized in the following table.

	Intravenous	Intramuscular
Initial dose (mg/kg body weight)	2– 5	8–10
Delay until surgery possible (min)	1– 1.5	4– 6
Duration of analgesia (min)	10–20	20–30
Repetition dose (mg/kg)	1– 2	6– 8
Delay until full orientation (min)	40–50	50–80

The surgical conditions under ketamine anesthesia range from adequate to good, and the residual muscle tone allows reduction of a fracture. Regurgitation of stomach contents occasionally occurs, but the danger of aspiration is extremely slight because the protective reflexes are not depressed. The patient usually ejects vomitus with his tongue. Snoring and gurgling which is due to excessive salivation can be combated by repeatedly sucking out the pharynx, keeping the airway free by raising the jaw, and administering atropine. Bradycardia rarely occurs in patients who have not been premedicated; here too, atropine is effective. Severe cerebral damage, manifest cardiac insufficiency, hypertension greater than 160 mmHg, and renal insufficiency are considered to be contraindications to the use of ketamine.

Ketamine anesthesia is simple and does not require additional aids and equipment under normal conditions. Nevertheless, *as with any other general anesthetic, it should only be administered by an anesthesiologist.*

2.1.4 References

Crusius, H. G.: Zur Frage der Ausschaltung unangenehmer postnarkotischer Träume und Angstzustände mit motorischer Unruhe nach dissoziativer Anaesthesie mit Ketamine. Anaesthesist **20**, 157 (1971).

Davenport, H. T., Barr, M. N.: Blood loss during paediatric operations. Canad. med. Ass. J. **89**, 1309 (1963).

Friis-Hansen, B. J.: Changes in body water compartments during growth. Acta. paediat. (Uppsala), Supp. **110,** 1 (1957).

Kern, F.: Ketalaranaesthesie für konservative Frakturbehandlung bei Kindern.

Vortrag Orthop.-Symposium St. Gallen, März 1970.

Kraus, K. A.: Mschr. Unfallheilk. **58**, 2 (1955).

Smith, R. M.: Anaesthesia for infants and children, p. 78. St. Louis: Mosby 1968.

2.2 Nonoperative Methods of Treatment

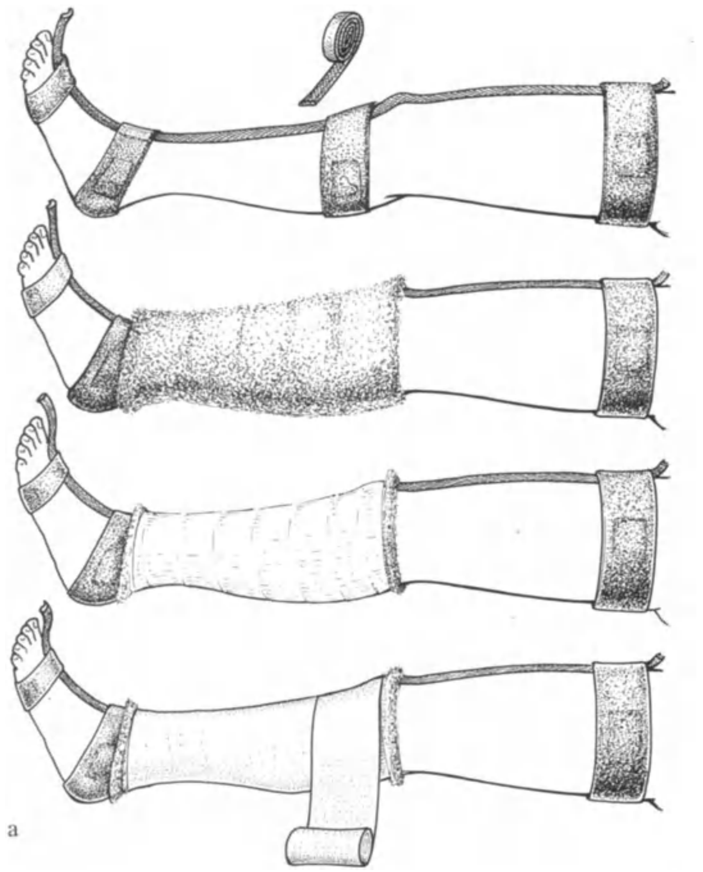
B.G. WEBER

Infants and young children cannot be expected to cooperate in a useful manner during treatment. Only adults and older children may be in a position to play an active part in therapy. The doctor cannot rely on a young child for warnings of impending problems; symptoms, such as pain and sensory or circulatory disturbances frequently remain unnoticed or unmentioned by the child. Pressure sores cannot be reliably diagnosed by questioning. Thus, in planning treatment, a number of safety features must be incorporated so as to render the management foolproof. This is particularly important, since many fractures are treated on an ambulatory basis and do not receive the same close medical supervision as those in hospitalized patients.

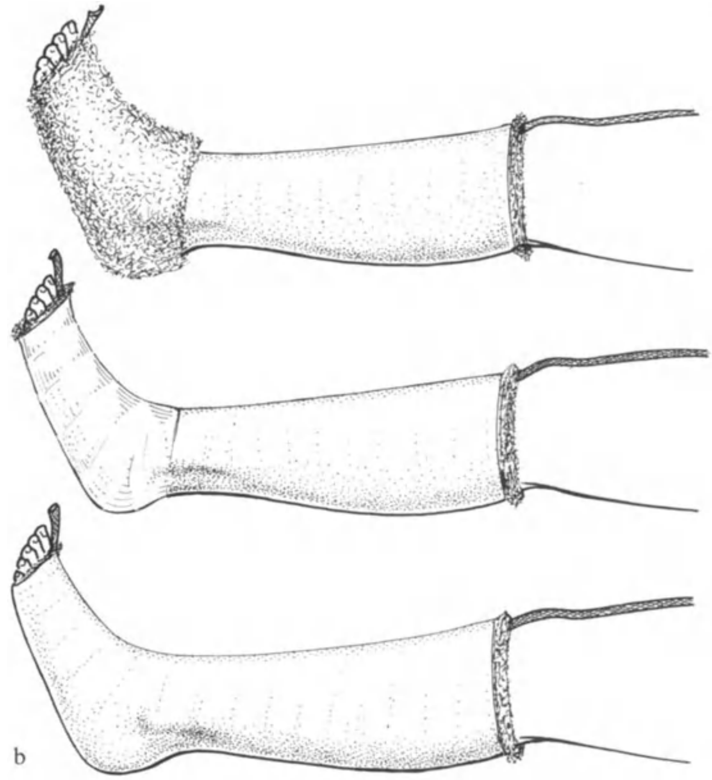
2.2.1 Immediate Cast Fixation

A cast which is immediately applied following reduction should never be allowed to cause one of the complications mentioned above. Furthermore, childrens' fractures unite within a few days so that further reduction a few days later is impossible. Thus, a cast should only be applied when the fracture has been satisfactorily reduced.

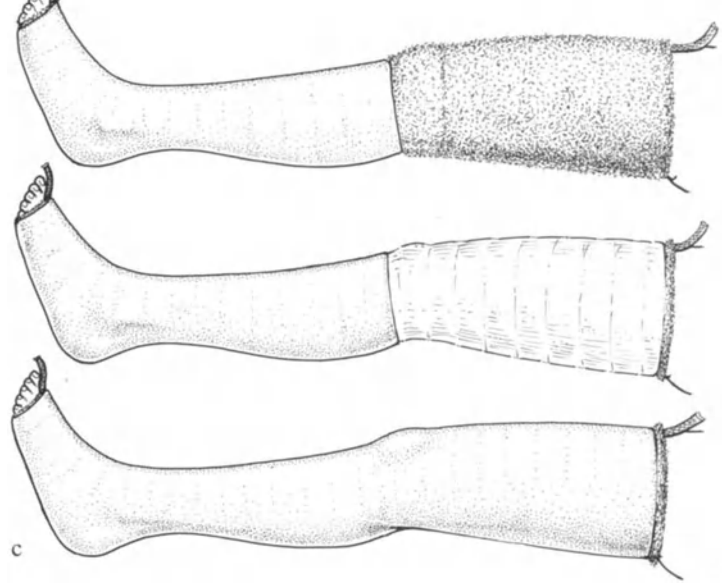
The *padded, circular cast* is the only external fixation device which is safe enough and rigid enough for the treatment of a fracture in a child. It is usually applied in stages (Fig. 5).



a



b



c

Fig. 5a–c. *Application of a padded primary circular cast to a child, exemplified by the three-stage full-leg cast.*
a) *Stage 1:* Lower leg. Padding of the bony prominences, e.g., malleoli, head of the fibula, head of the metatarsals, anterior border of the tibia. A strip of webbing is laid along the leg. Padding of the lower leg with loose cellulose gauze or special synthetic wadding. The leg is bandaged with crepe paper; thus, a smooth contour is already present at this stage. Application of the circular plaster of Paris bandage.
b) *Stage 2*: Foot. Padding, crepe paper, circular plaster of Paris bandage.
c) *Stage 3:* Thigh. Padding, crepe paper, circular plaster of Paris bandage

Using loose cellulose felt or special synthetic wadding, a padding layer is applied which is free from gaps and folds. This is followed by a layer of crepe which gives the bandage the appearance of a finished cast; it fits snugly and takes on the contours of the underlying limb.

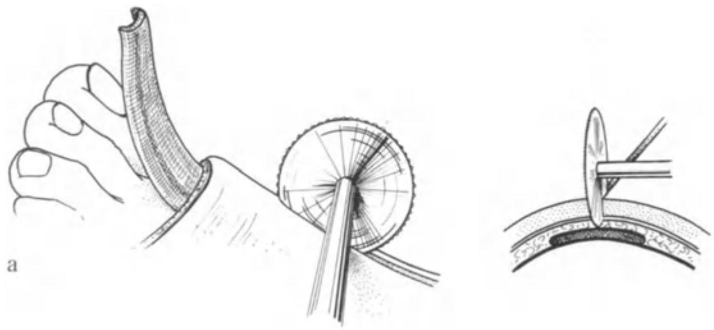
A plaster of Paris bandage is then applied in a circular fashion so as to form a tube at the level of the fracture. This tube holds the fragments temporarily in the required position.

The tube is now extended proximally and distally.

The tube is reinforced by applying plaster slabs to the critical points.

When the cast has hardened, the plaster layer is split longitudinally without necessarily cutting through the layer of padding. We leave the latter layer intact if the patient is to remain in the hospital and frequent checks are possible. If the patient is to be discharged following application of the cast, the latter must be completely slit, i.e., down to the skin. Splitting of the cast is greatly simplified if a length of webbing is laid along the limb before the padding and plaster bandage are applied. It is then easy to split the cast along the line of this webbing (Fig. 6).

The *circulation* and the *innervation* distal to the fracture must be *checked frequently and thoroughly*. The



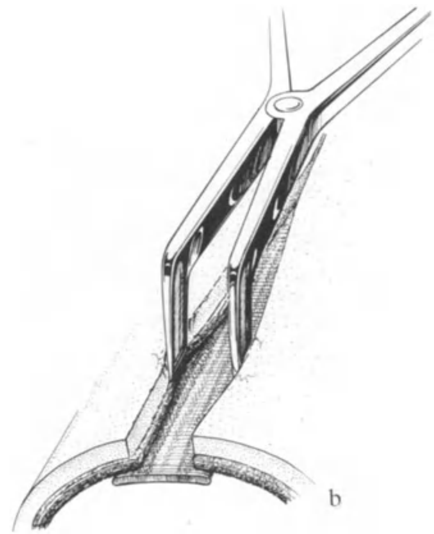


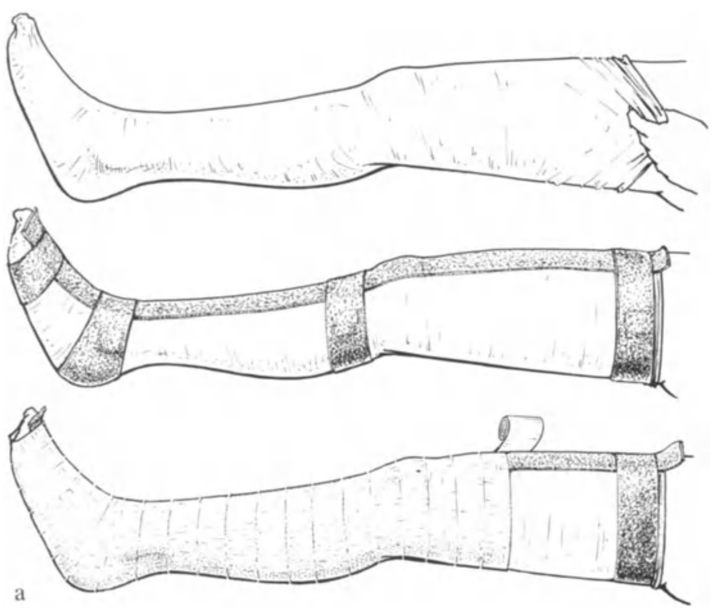
Fig. 6a, b. *Splitting the circular cast.*
a) Following hardening of the plaster, the cast is cut longitudinally over the webbing strip; the latter prevents injury to the skin.
b) The gap is widened with the distractor to prevent constriction of the limb. If necessary, the padding is split

capillary circulation is best checked by examining the nailbeds of the fingers or toes. The innervation should be tested with a needle, since children report pain much more reliably than simple touch sensation.

2.2.2 Secondary Cast Fixation

A replacement cast may be applied if the previous one no longer fits snugly. A secondary cast may also be applied following an initial period of traction. One should wait until the *initial swelling has subsided*, at which point partial bone union has already occurred.

The cast should provide maximum rigidity with a minimum of material (Fig. 7). Padding is restricted to the bony prominences, using small pieces of felt. An additional felt strip should be placed next to the skin so as to protect the latter from the shears or cast cutter during removal. If possible, the cast should be applied and molded in one piece; joints between



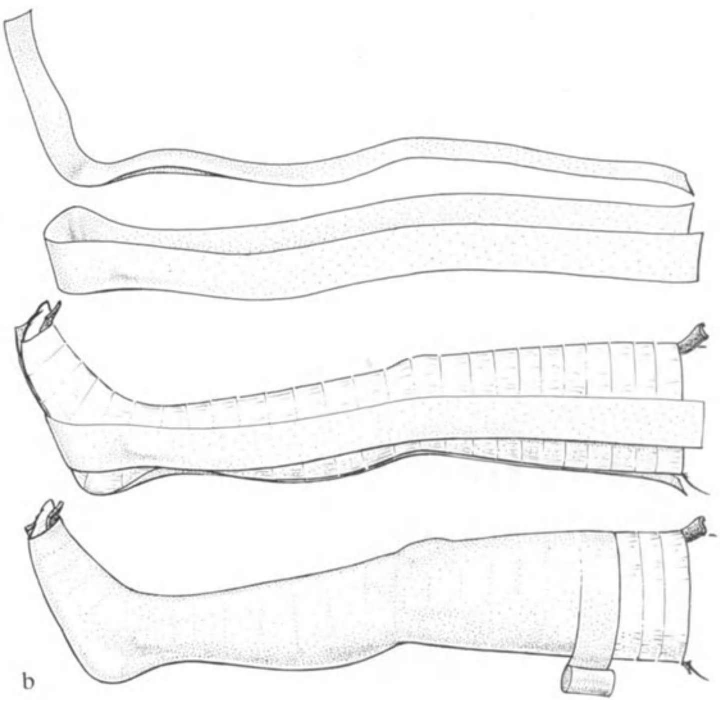


Fig. 7a, b. *Application of a secondary cast to a child, exemplified by a full-leg cast.*
a) *Padding the leg:* 1. stockinette tube. 2. Padding is restricted to the bony prominences and is also used for protection of the anterior border of the leg during subsequent opening of the cast with the plaster shears or motor-driven cast cutter. 3. Circular, crepe paper bandage.

b) *Application of the cast* (to be completed in one stage, if possible): 1. Preparation of the circular bandages and plaster splints; the long U-splint and dorsal L-splint are shown here. 2. First circular layer of plaster bandages, followed by application of the splints. 3. Completion of the cast with a final circular layer of plaster bandages.

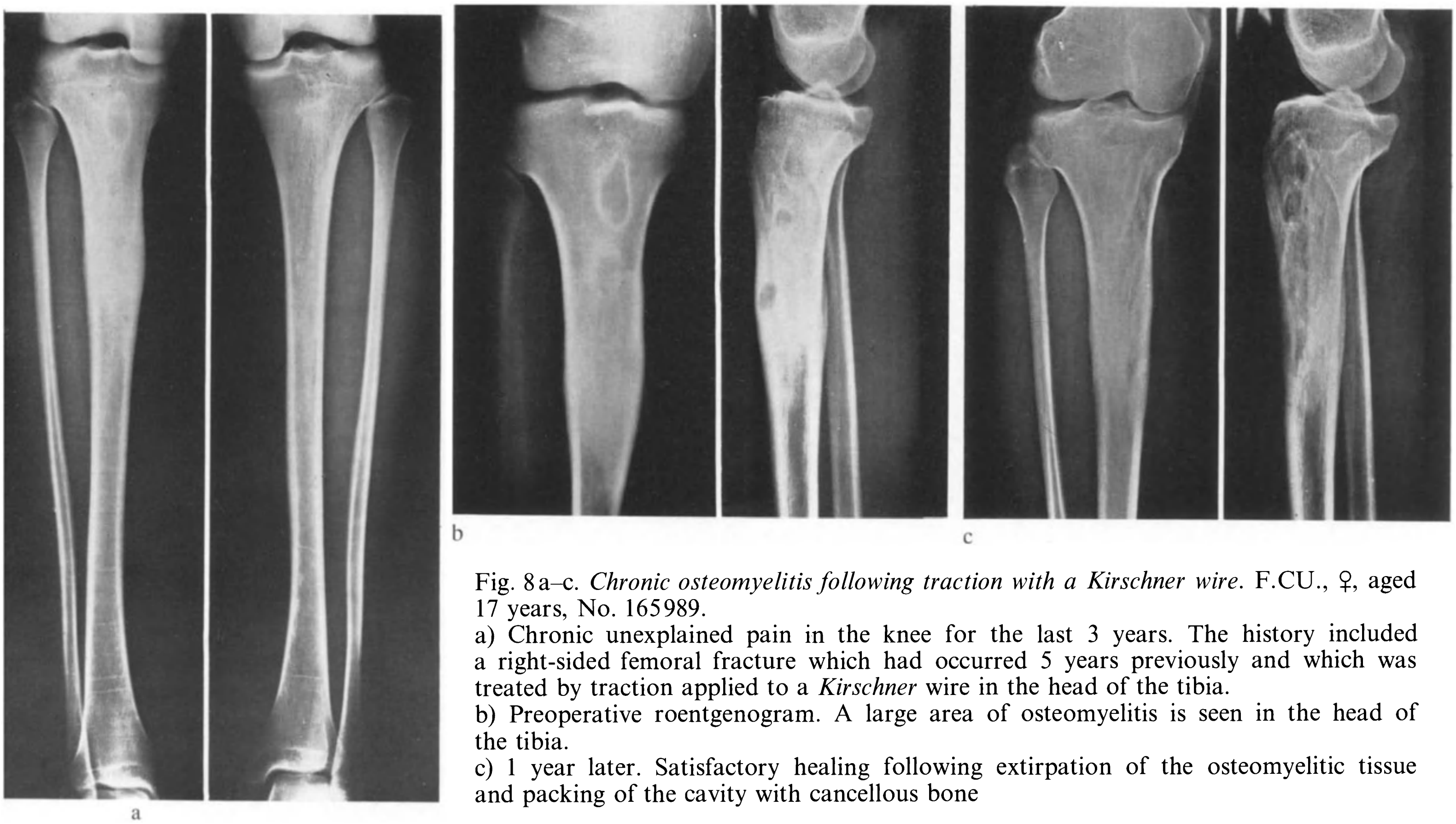


Fig. 8a–c. *Chronic osteomyelitis following traction with a Kirschner wire.* F.CU., ♀, aged 17 years, No. 165989.
a) Chronic unexplained pain in the knee for the last 3 years. The history included a right-sided femoral fracture which had occurred 5 years previously and which was treated by traction applied to a *Kirschner* wire in the head of the tibia.
b) Preoperative roentgenogram. A large area of osteomyelitis is seen in the head of the tibia.
c) 1 year later. Satisfactory healing following extirpation of the osteomyelitic tissue and packing of the cavity with cancellous bone

individual sections represent weak points which may subsequently fracture.

2.2.3 Skin Traction with Adhesive Plaster

Nowadays we very seldom use this type of traction for the treatment of fractures. The adhesive plaster generally slips at some point during treatment because its adhesion is insufficient to withstand the traction applied to the limb. Skeletal traction is more reliable and obviates the troublesome replacement of adhesive plaster necessitated by skin traction.

2.2.4 Skeletal Traction

a) Steinmann Pin Traction. This method is preferable to use of the *Kirschner* wire in every respect.

Kirschner wires slide back and forth in the bone. They also rotate relative to the bone since they are clamped in the traction yoke. The movement relative to the bone or soft tissues stimulates infection which may manifest itself immediately or may remain latent for months or even years (Fig. 8).

When a *Kirschner* wire is used together with a U-yoke, it is never clear how much traction is actually being exerted on the limb. The weight of the U-yoke must always be known and accounted for in the calculation.

Unlike the *Kirschner* wire, the *Steinmann* pin is firmly fixed in the bone. Relative movement between the traction cord and the limb is not transmitted to the pin, since the cord can rotate freely about the projecting ends of the pin. Infection following the use of a firmly anchored *Steinmann* pin is therefore very rare.

Steinmann pins are sometimes so firmly embedded at the end of a period of traction that they have to be removed under ketamine anesthesia.

Use of a *Steinmann* pin for skeletal traction is limited to the distal femur and the calcaneus; it is occasionally used in the distal tibia. Neither *Kirschner* wires nor *Steinmann* pins should be used in the proximal tibia, since there is considerable danger of damaging the epiphyseal plate of the tibial tuberosity (Fig. 9).

The insertion of a *Steinmann pin* should be accompanied by the same *aseptic and antiseptic precautions* as any major surgical procedure, i.e., disinfection, draping, masking, and gowning of the surgeon (Fig. 10).

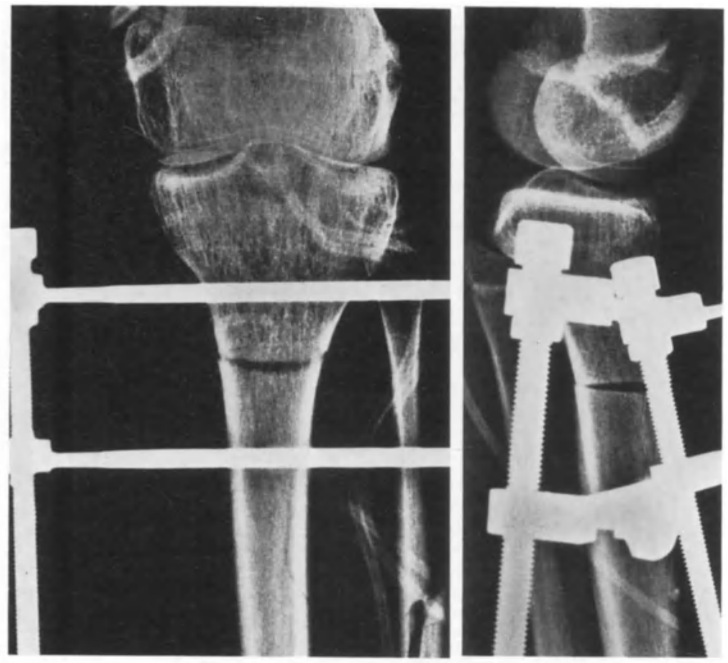
The site of the epiphyseal plate should be precisely known, so that the pin pierces the bone on the metaphyseal side of the plate. A stab incision is made

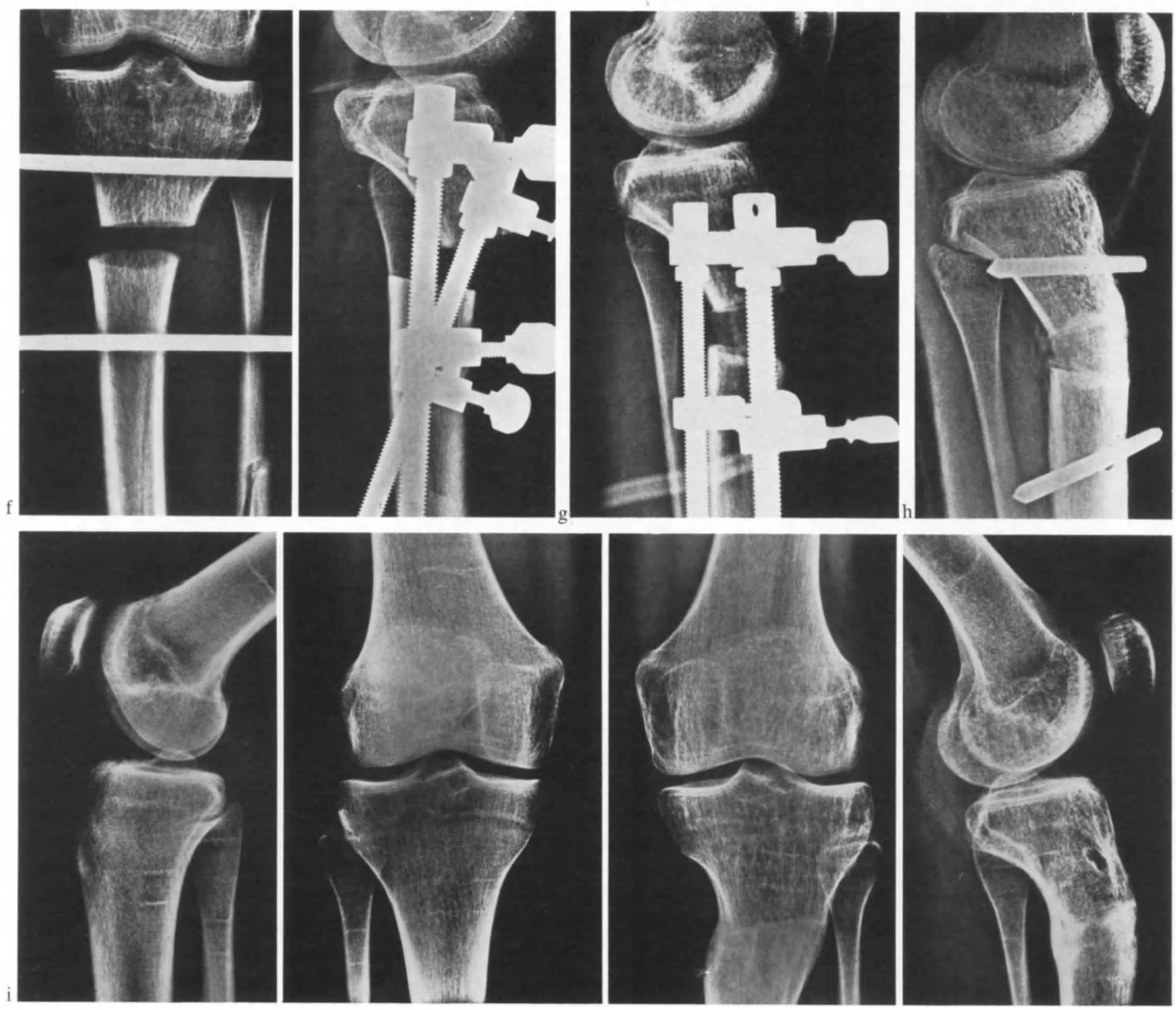
Fig. 9a–i. *Abnormal growth following Kirschner wire traction.* L.D., ♀, aged 12 years, No. 126128.
a) Mid-diaphyseal fracture of the femur treated by traction applied to a *Kirschner* wire in the head of the tibia.
b) Because the positioning of the fragments was unsatisfactory, the *Kirschner* wire was removed from the head of the tibia and supracondylar traction was applied with a *Steinmann* pin on the *Weber* traction table. Subsequent fracture healing was uneventful.
c) $3^1/_3$ years after the accident: The *Kirschner* wire had caused fusion to occur across the epiphyseal plate of the tibial tuberosity. Retrocurvature of the knee has resulted.
d) $5^1/_2$ years after the accident: Retrocurvature of the knee with tilting of the tibial plateau at an angle of 25°.

and a 4.0 mm, 4.5 mm, or 5.0 mm diameter pin held in a hand chuck is driven in *by hand* as far as the bone. The surgeon positions the tip of the pin by feel and then drives it through the metaphysis by hand; in doing so, the pin is rotated to and fro under constant pressure so that its diamond-shaped tip cuts easily through the bone. A power drill should never be used to introduce the pin, since the heat generated at the tip would burn the bone and soft tissues, and thus cause necrosis and infection. Furthermore, *Steinmann* pins should never be hammered in since this would split the bone.

The sites at which the pin pierces the skin are once more disinfected and are then covered with sterile dressings and small plaster-of-Paris plaques (Fig. 10). Finally, an elastic bandage is applied which prevents the child from picking at the skin in the vicinity of the pin.

Fig. 9e–i. e) Treatment: Transverse osteotomy of the head of the tibia followed by application of external fixation clamps so as to allow steady correction of the angulation and lengthening of the bone.
f) Roentgenogram taken after correction of the angulation and of the length of the tibia.
g) With the external fixation clamps still in place, an autologous bone graft is inserted.
h) 5 weeks after grafting.
i) 1 year following corrective surgery. The retrocurvature and shortening have both been eliminated





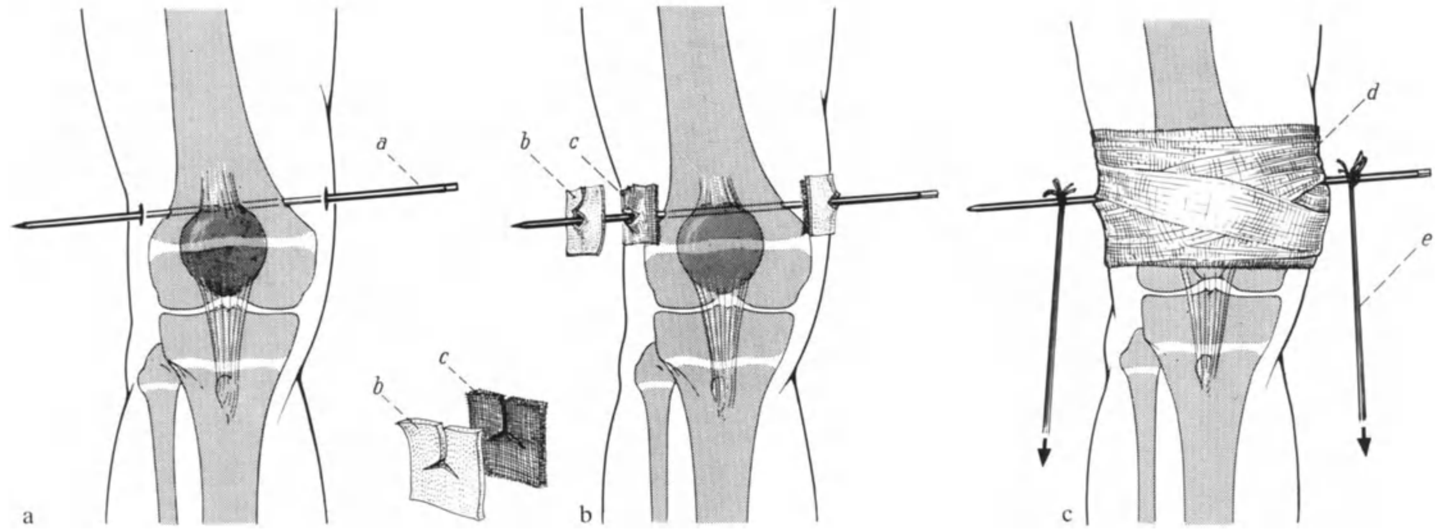


Fig. 10a–c. *Insertion of the Steinmann pin.*
a) The skin is swabbed with antiseptic solution and draped with sterile towels. The surgeon wears a sterile gown and gloves. A stab incision is made and the *Steinmann* pin is drilled through the metaphysis by hand. A stab incision is made on the opposite side just before the pin pierces the skin.
b) The skin is once more swabbed with antiseptic and the points of entry and exit of the pin are covered with sterile gauze and sterile plaster of Paris squares.
c) Coverage is completed with a crossed elastic bandage and the two thin traction cords are attached

A strong, thin cord is attached to both sides of the pin and the traction weight is then fastened to the cord. The latter then runs over pulleys with the two limbs of the traction loop parallel to each other.

In our clinic, the *Steinmann* pin is used for traction at the following sites: (1) supracondylar femur; (2) calcaneus; (3) supramalleolar in the distal tibia (only in special cases); (Fig. 11).

b) Cortical Bone Screw Traction. This technique is used in the *olecranon*. It replaces the traditional *Kirschner* wire traction and lacks the disadvantages of the latter (infections caused by movement of the wire; delayed damage to the ulnar nerve).
Full aseptic and antiseptic precautions are taken when inserting the cortical screw; the procedure should be treated as a real operation in this respect (Fig. 12).

A dorsal stab incision is made in the skin covering the ulna and a small drill guide is placed against the dorsal border of the ulna. A 3.2 mm hole is then drilled through the ulna approximately 2–3 cm distal to the tip of the olecranon; care is taken to protect the epiphyseal plate during this procedure. A cortical thread is tapped and a cortical screw of at least 40 mm in length is screwed in.

The site of operation is once more disinfected and covered with a sterile dressing. An elastic bandage is then applied.

The traction cord is tied round the head of the screw.

This type of skeletal traction has the advantage of being stably anchored in the bone and, furthermore, it is easily removed with the screwdriver when it has served its purpose (Fig. 13).

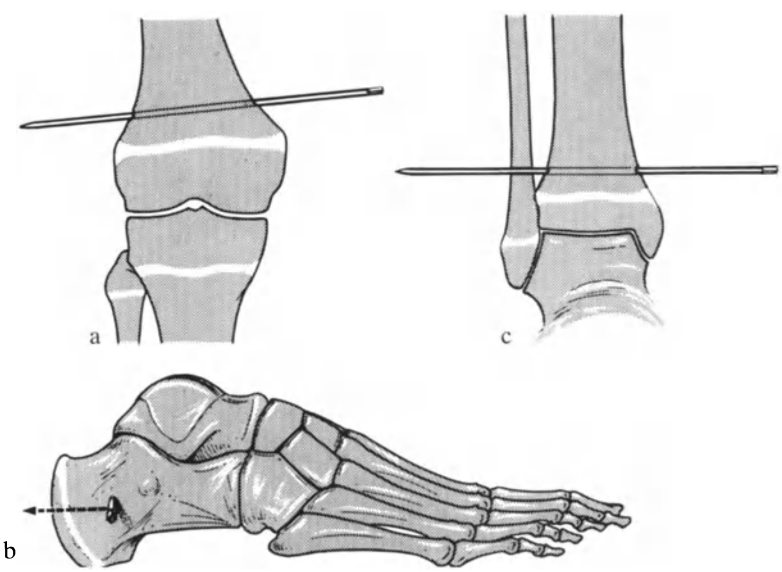


Fig. 11a–c. *The three points at which traction may be applied with a Steinmann pin.*
a) Supracondylar part of the distal femur.
b) As far dorsally as possible in the calcaneus, but not in the cartilage of the calcaneal traction epiphysis.
c) In the distal, supramalleolar part of the tibia

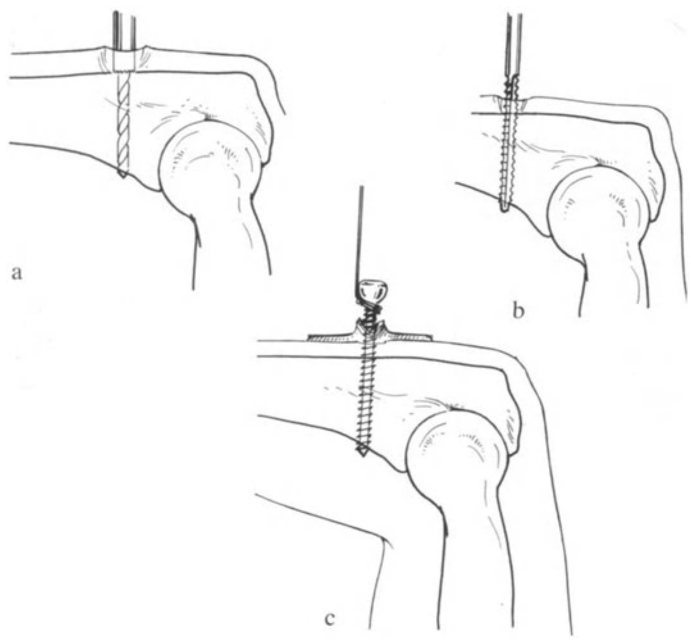


Fig. 12a–c. *Insertion of an olecranon traction screw.*
a) Following sterile draping with full aseptic and antiseptic precautions, a stab incision is made and a 3.2 mm hole is drilled just distal to the coronoid process of the ulna. The surrounding tissues are protected with the drill guide.
b) Cutting the thread.
c) Insertion of the 4.5 mm cortical bone screw so as to leave 1 cm projecting superficial to the skin. A sterile dressing is applied and the traction cord is attached to the head of the screw by means of a wire loop

2.3 Internal Fixation

Internal fixation of a fracture in a growing bone is indicated much less often than that of an adult fracture. The individual indications are discussed in the relevant chapters. Internal fixation is indicated:

exceptionally for fractures of the diaphysis;
rather more often for injuries of the epiphyseal plate;
most frequently for fractures involving a joint.

Internal fixation of a fracture in an adult should be sufficiently stable to allow unprotected movement of the joints and physiotherapy; this is not essential in children. The postoperative management of a fracture in a child may include the use of a circular cast without immobilization disease occurring. The aims of internal fixation in children are different and can be fulfilled with relatively little implant material. The implants which are most frequently used are *Kirschner-wires*, *lag screws*, and *plates*. *Medullary nails* are only used in the femur of the adolescent and even there their use is very seldom indicated.

The consistency of a child's bone, particularly that of the metaphysis and epiphysis, is different from that in the adult. It is more compact and the cancellous bone is uniformly firm. Thus, a child's bone offers screws and even *Kirschner*-wires an unusually good hold. The younger the child, the more homogeneous is the structure of the long bones. The functional differentiation between cortical and cancellous bone is not as advanced as that in the adult. The active turnover in the growing bone is accompanied by an excelent blood supply.

The *internal fixation techniques* used in children do not differ from those used in the adult. The ASIF instrument set is used according to the usual rules and guidelines, but the choice of implant differs somewhat. If a plate is indicated, a small narrow one is chosen, even for the majority of femoral fractures.

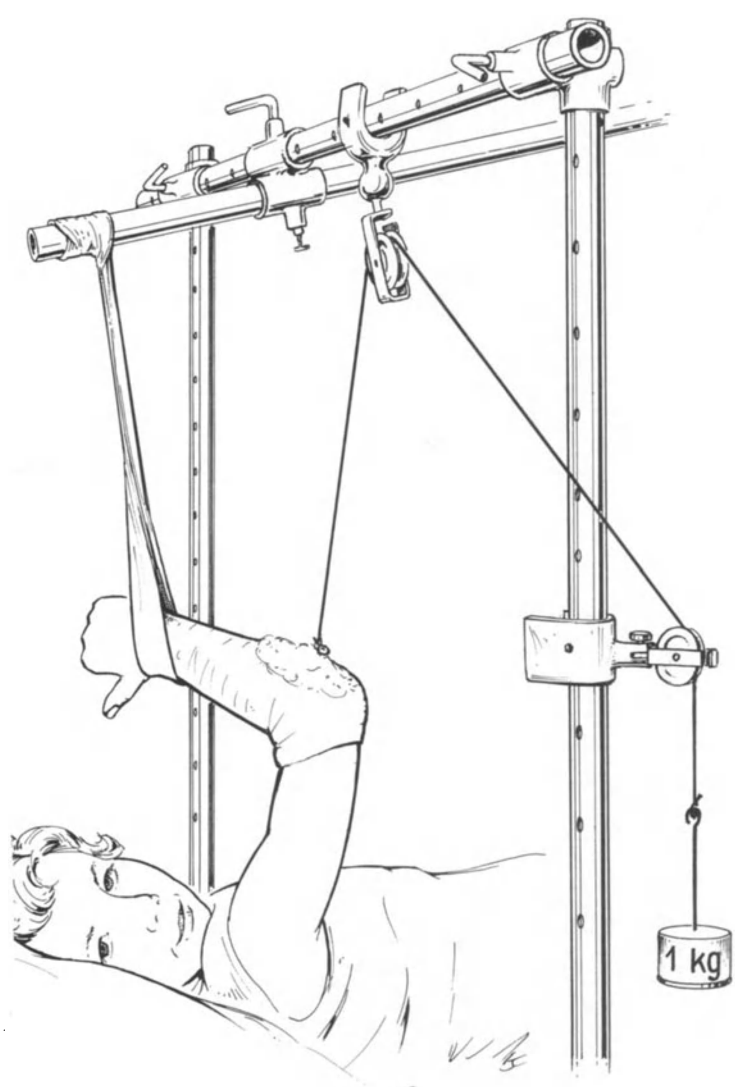


Fig. 13. *Olecranon screw traction.* According to the type of fracture, the thumb is pointed at the nose of the child (neutral rotation position) or at the sternum (full physiological internal rotation). The distal forearm is suspended with a towel loop. Traction is applied to the *olecranon* using a weight which is adequate for the type of fracture and degree of dislocation

Nowadays, self-tensioning, slotted plates are preferred, i.e., the dynamic compression plates (DCP) of *Allgöwer, Perren,* and *Matter*. They do not require additional room for the plate tensioning device, so that less extensive surgical exposure is necessary.

The internal fixation techniques used in the *diaphysis* of a child are usually the same as those used in the adult. In the *metaphysis* and *epiphysis*, however, angled plates are never used. At these sites, *Kirschner* wires and lag screws suffice. An attempt to drive the blade of a plate into the very hard bone would not only be difficult, but also dangerous; the fragments would be driven apart from each other or split by the blade.

If possible, when dealing with fractures of the *epiphyseal plate* the growth cartilage itself should not be pierced by implant material. Screws would cause relatively large defects in the plate and thus cause localized closure of the epiphysis in a manner similar to *Blount* stapling. *Kirschner* wires are the only permissible implants if transfixion of the epiphyseal plate cannot be avoided. They should pierce the growth cartilage at as near as possible to a *right angle to the plane of the plate* in order to minimize the damage to the latter and prevent growth disturbances. Within a short time the implant material will be surrounded by new bone. It should therefore be removed earlier than in the adult.

The implants are removed 1–6 months following occurrence of the fracture, as long as the *Kirschner*-wires, screw heads, and plates are easy to find. A further reason for early removal of the implant is the increased growth caused by the metal.

As in the adult, *Redon* vacuum drains are left in the wound. In neither case are prophylactic antibiotics used. Instead, infection is combated by rigid asepsis and antisepsis and gentle surgery with minimum damage to the tissues. The wound is closed with the suture techniques used in plastic surgery.

The specific internal fixation techniques are dealt with in the relevant chapters.

2.4 Multiple Trauma and Fractures

In the multiply injured patient, life-saving measures frequently take precedence, and the diagnosis of a fracture may easily be missed or its treatment may be delayed or neglected.

There is no question that *resuscitation has absolute priority*. However, once resuscitation has succeeded, the danger to life is replaced by another problem: the *danger of disablement*. Closest attention must therefore be given to fractures.

Severe malunion of a shaft fracture in a multiply injured patient is not a very serious problem. Permanent disablement can be prevented by corrective orthopedic procedures. On the other hand, neglect of a true fracture of an epiphyseal plate, or of fractures of the neck of the talus, neck of the femur, or head of the radius involves serious risk. *These fractures have a grave prognosis* and should be accorded a *therapeutic priority second only to that of resuscitation*. Restoration of the vital functions is usually rapid, but the problems associated with a neglected fracture may occupy the patient for the rest of his life. There will be no residual disability if the same fracture is treated promptly and correctly. In the management of multiple trauma in the child, expert treatment by specialists is more important than in the adult, and *close cooperation* between the anesthesiologist and the individual surgical specialists plays an important part. In our clinic, an orthopedic surgeon with general surgical training is responsible for the reception and primary admission of multiply injured children, and our experience with this arrangement has been satisfactory. The anesthetist, abdominal surgeon, and neurosurgeon are responsible for life-saving emergency procedures. The orthopedic surgeon remains in the immediate vicinity and initiates treatment of fractures and dislocations as soon as the circumstances allow. In our experience, it is preferable that, for example, splenectomy be followed by internal fixation of a fracture of the femoral neck under the same anesthetic. When treating the multiply injured child, no procedure should be omitted or postponed which can be carried out within a short time of the accident.

2.5 References

Aitken, A. P.: The end results of the fractured distal tibial epiphysis. J. Bone Jt Surg. **18**, 3, 685 (1936).

Aitken, A. P., Magill, H. K.: Fractures involving the distal femoral epiphyseal cartilage. J. Bone Jt Surg. **96**, 17–34 (1952).

Blount, W. P.: Fractures in Children. Baltimore: Williams and Wilkins 1954.

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1960.

Müller, M. E., Allgöwer, M., Schneider, R., Willenegger, H.: Manual of Internal Fixation, 2nd ed. Berlin-Heidelberg-New York: Springer 1979.

Rehn, J.: Unfallverletzungen bei Kindern. Prophylaxe, Diagnostik, Therapie, Rehabilitation. Berlin-Heidelberg-New York: Springer 1974.

Rettig, H.: Frakturen im Kindesalter. München: Bergmann 1957.

Salter, R. B.: Textbook of Disorders and Injuries of the Musculo-Skeletal System. Baltimore: Williams and Wilkins 1970.

Weber, B. G.: Epiphysenfugen-Verletzungen. Helv. chir. acta **31**, 103–108 (1964).
Weber, B. G.: Epiphysenfugen-Frakturen. Orthopädische Praxis **1/II**, 1966.
Weber, B. G.: Prophylaxe der Achsenfehlstellungen bei der Behandlung kindlicher Frakturen. Z. Unfallmed. Berufskrankh. **I/66**, 80–95 (1966).
Weber, B. G.: Indikationen zur operativen Frakturbehandlung beim Kind. Chirurg **38**, 441–444 (1967).
Weber, B. G.: Epiphysenfugenverletzungen. Fortbildungstagung des Berufsverbandes der Fachärzte für Chirurgie, Gießen, 19./20. Nov. 1969.
Weber, B. G.: Frakturen im Kindesalter. Bericht über die unfallmed. Arbeitstagung Göttingen, 14./15. April 1972.
Weber, B. G.: Epiphyseal injuries: Internal fixation of fractures of Aitken type 2 and 3. Proceedings of the 12th Congress of fractures of the International Society of Orthopaedic Surgery and Traumatology, Tel Aviv, 9.–12. Okt. **9–12,** 1972.
Weber, B. G., Čech, O.: Pseudarthrosen. Bern-Stuttgart-Wien: Huber 1973.
Weber, B. G.: Das Besondere bei der Behandlung der Frakturen im Kindesalter. Mschr. Unfallheilk. **78,** 193–198 (1975).
Weber, B. G., Čech, O.: Pseudarthrosis. Bern-Stuttgart-Wien: Huber 1976.
Wiedmer, U., Freuler, F., Bianchini, D.: Cast manual for adults and children. Berlin-Heidelberg-New York: Springer 1979.

3 Summary

The aim of fracture treatment in the child is the restoration of the normal anatomy and physiology. Growth and the corrective capacity of the growing bone assist in achieving this aim, even if the initial union is not completely satisfactory. However, nature withholds her assistance completely in certain types of fracture. In these cases, perfect reduction is absolutely necessary and must be followed by internal fixation which is suited to the child's skeleton. Closed treatment should be designed to be foolproof in order to avoid iatrogenic injury and its serious consequences. A cast which is applied to a fracture in a child immediately following the accident must be padded. Traction should be applied by means of *Steinmann* pins and *olecranon* screws rather than *Kirschner* wires.

Emergency treatment should always be accompanied by effective anesthesia. General anesthesia is usually necessary.

In the course of resuscitation of a multiply injured child, the danger of disablement due to the neglect of a fracture should never be forgotten. The priority of fracture treatment is secondary only to that of resuscitation. Treatment of fractures should start as soon as the vital functions have been stabilized.

Birth Injury. Thoracic, Abdominal, and Multiple Injuries. The Battered Child

R. MORGER

CONTENTS

1 Birth Injury

Birth is a natural process. Nevertheless it may be accompanied by small structural changes in the skeleton and soft tissues. It is frequently difficult to classify the changes in a given case as normal or pathological. However, an abnormal birth may cause definite injury. Birth injuries are summarized in the following table:

1.1 Types of Birth Injury

Table 1

Skin injuries	Pressure marks Cuts during cesarian section Sclerema neonatorum
Tumor in the sternocleidomastoid muscle following breech delivery	Cephalhematoma Torticollis
CNS injuries	Subdural and intraventricular hemorrhage Spinal cord transection
Intraabdominal injury	Rupture of spleen Liver Kidney Adrenals (Fig. 1)
Iatrogenic injury during resuscitation	Intravenous or intraarterial injection of hypertonic or alkaline solutions leading to hepatic necroses and thrombosis. Pneumothorax Pneumomediastinum
Skeletal injuries	Fracture of skull, clavicle, humerus, femur. Separation of epiphysis
Peripheral nerve injury	Facial nerve, brachial plexus

1.2 Skeletal Injury

Any one of a number of bones may be fractured during manual or instrumental delivery. A fracture frequently goes unnoticed during the first few days following birth. Swelling or lack of movement then becomes apparent and the diagnosis is made.

1.2.1 Fracture of the Skull

The decrease in the frequency of forceps delivery has been accompanied by a decrease in the frequency of skull fractures in newborn children. The frequent depression fractures had to be treated operatively. The doctor who examines a roentgenogram should be familiar with the metopic suture and the posterior intraoccipital synchondrosis, which frequently have the appearance of fracture lines. Linear skull fractures which are not accompanied by neurological abnormality do not require special treatment, since the infant is anyway recumbent. Additional lesions, such as an epidural or subdural hematoma require immediate intervention.

Fig. 1. *Blunt abdominal trauma*. Plain film of the abdomen taken 6 h after the accident. There is diffuse shadowing of the right side of the abdomen which is not distinguishable from that of the liver and which is caused by adrenal hemorrhage on the right side. Emergency laparotomy was performed 20 h after the accident. On opening the abdomen, 50 ml of blood were found. The ascending and transverse colon were displaced by a hematoma which was completely evacuated. The site of the injury was drained externally. The subsequent course was uneventful

Fig. 2. *Fracture of the clavicle*. Thoracic roentgenogram of a child aged 8 days. A large round callus is seen at the middle of the left clavicle. There was concomitant damage to the upper part of the brachial plexus

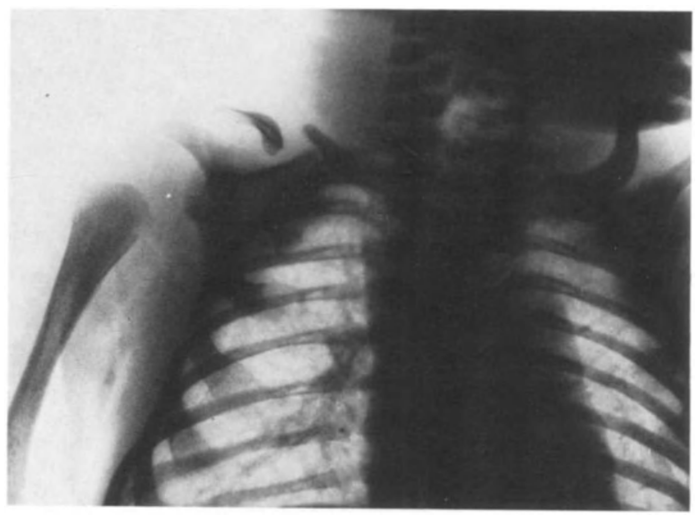


Fig. 3. *Congenital pseudarthrosis of the clavicle*. Thoracic roentgenogram of a child aged 1 month. The congenital pseudarthrosis of the right clavicle is of genetic origin

1.2.2 Fracture of the Clavicle

Fracture of the clavicle is one of the commonest types of birth injury. The diagnosis is often delayed until the worried mother calls attention to the swelling caused by the hypertrophic callus 8–10 days following birth (Fig. 2). The fracture may occur during a normal birth, e.g., if the shoulder of the child is forced against the symphysis of the mother. This type of fracture is harmless and the late prognosis is excellent, whether or not it is treated. From time to time, a fracture of the clavicle is accompanied by damage to the brachial plexus. In such cases, the prognosis mainly depends on the severity of the injury to the plexus and on its treatment; the fracture is unimportant in this respect. The differential diagnosis on the basis of a roentgenogram should include congenital pseudarthrosis of the clavicle (Fig. 3).

1.2.3 Fracture of the Humerus

Second in frequency is fracture of the shaft of the humerus (Fig. 4). It occurs during freeing of the arm in the course of breech delivery. Surprisingly, the injury never includes damage to the radial nerve. Treatment is no problem: the arm is immobilized on a plaster splint for 14 days.

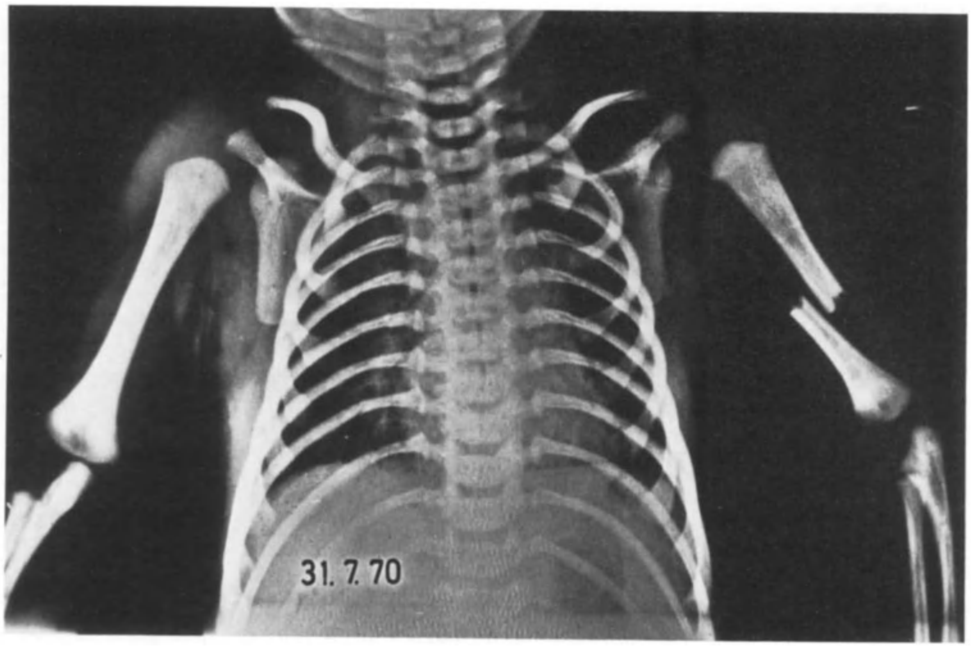
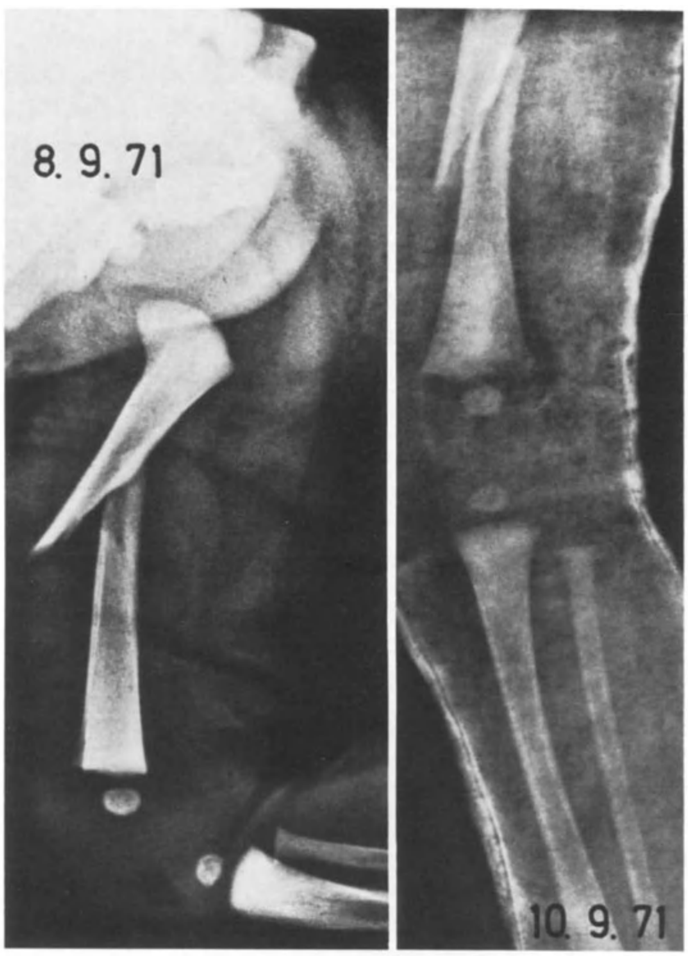


Fig. 4. *Fracture of the shaft of the humerus*. Roentgenogram of the thorax and upper extremities taken 2 h after birth. The transverse fracture of the humerus on the left occurred while freeing the arm in the course of breech delivery



a b

Fig. 5a, b. *Fracture of the shaft of the femur*. Fracture of the shaft of the femur which occurred during breech delivery.
a) Roentgenogram taken shortly after birth.
b) The leg has been placed in traction. The skin is covered with a zinc bandage

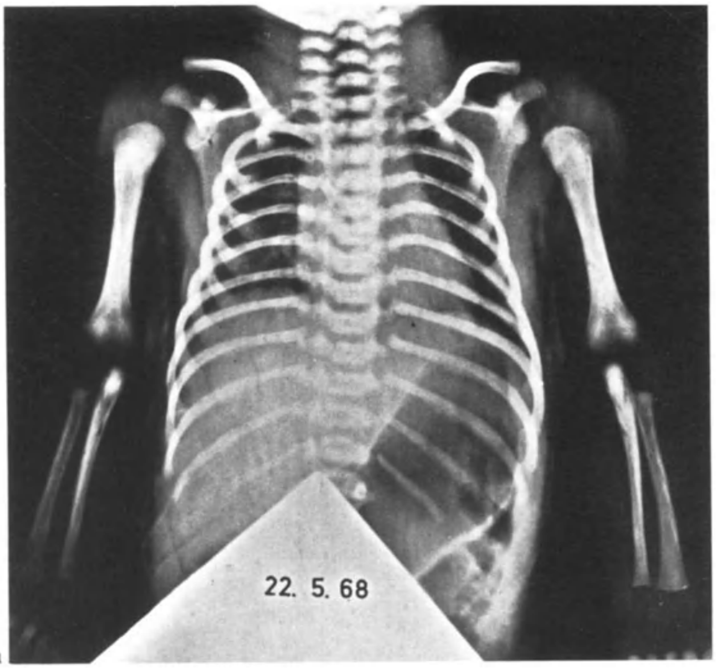
1.2.4 Fracture of the Femur

Fracture of the femur is rare and occurs during extraction of the child in the course of breech delivery. It is usually a transverse fracture of the upper third or middle of the shaft with the usual signs of shortening, external rotation, and valgus angulation (Fig. 5). It is treated by vertical traction with adhesive plaster, i.e., with the hip in 90° flexion. Adhesive plaster traction should preferably be applied over a zinc paste cast, since the skin of a newborn child is very sensitive. Three to five hundred grams traction suffices.

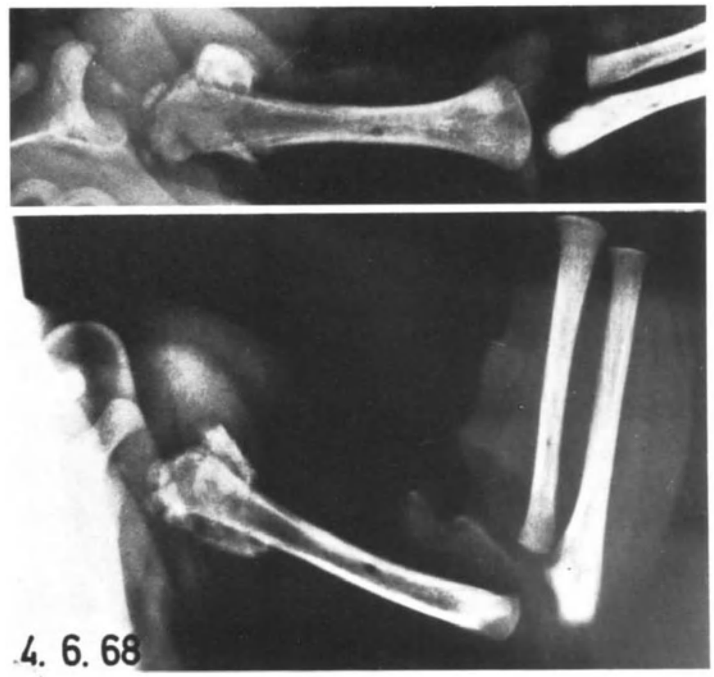
1.2.5 Separation of the Upper Epiphysis of the Humerus at Birth

This lesion occurs when the arms are pulled down during breech delivery. At first, the only sign is limitation of movement of the affected arm; the differential diagnosis includes damage to the brachial plexus. Later, a large swelling develops and then a hypertrophic callus. In the initial stages, the roentgenograms show slight widening of the joint space which is only apparent when the two sides are compared (Fig. 6). The radiological diagnosis only becomes certain when callus appears. To avoid missing gross dislocation, arthrography should be performed. Therapy consists of 14 days immobilization on a plaster splint in abduction and external rotation with the elbow flexed at 90° (as for brachial plexus injuries). If the injury is correctly treated, the prognosis is good.

Separation of the distal epiphysis of the humerus very seldom occurs at birth. If the lesion is left un-



a



b

c

Fig. 6a–c. *Separation of the epiphysis of the head of the humerus.*
a) Roentgenogram of the chest, abdomen, and extremities of a 2 day old child, taken on 22 May 1968. The child had undergone a difficult breech delivery during which the left arm was pulled down. The child failed to move the left arm spontaneously. The joint space on the left is wider than that on the right.
b) Roentgenogram taken on 4 June 1968 shows marked callus formation with separation of the epiphysis.
c) By 30 August 1968 complete recovery has occurred. The lengths of the arms were equal in January 1974

treated, serious malformation results, rotation of up to 90° being the commonest deformity.

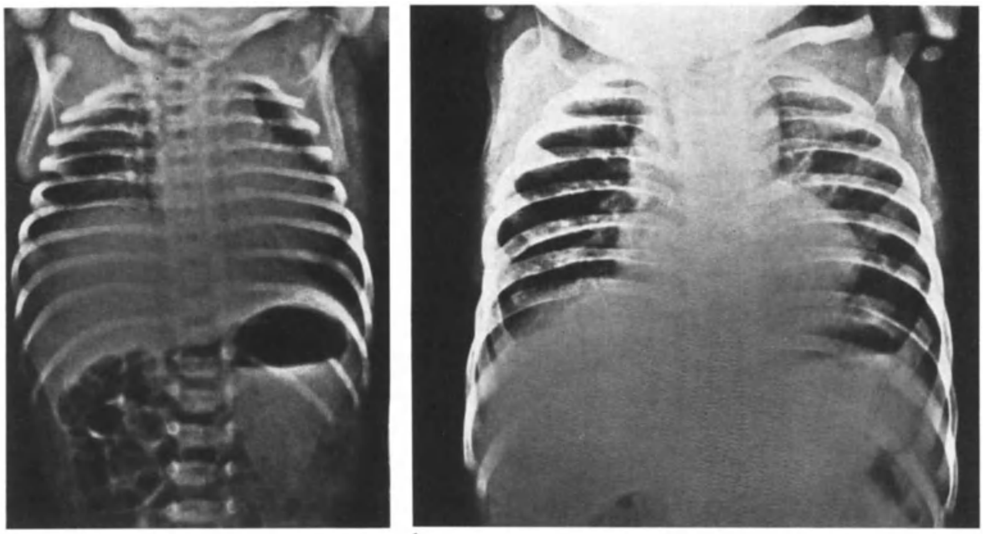
1.2.6 Separation of the Head of the Femur at Birth

This injury occurs during a difficult breech delivery. The fracture passes through the neck of the femur, which consists of pure cartilage at this stage, and it is therefore difficult to see on a roentgenogram. The clinical signs are hematoma, and shortening and external rotation of the leg. The diagnosis is confirmed by arthrography. Treatment consists of adhesive plaster traction with the limb in slight abduction. The prognosis is usually good.

1.3 Injury to Peripheral Nerves

Paresis of the facial nerve used to be seen frequently following forceps delivery. It is occasionally seen after normal delivery and is the result of excessive pressure on the preaural area of the face. When the child cries, retraction of the mouth is restricted to the normal side. If the upper branches of the facial nerve are also damaged, the child cannot close the eye completely. The eye must therefore be protected from infection. Recovery is rapid in the majority of cases and occurs within 6 weeks.

Injuries to the brachial plexus result from excessive stretching of the nerves. This, in turn, may be caused by any one of a number of abnormal situations which may arise during delivery. It is particularly frequent following breech delivery if difficulty is encountered with disengagement of the head. C5 and C6 are the



a b

Fig. 7a, b. *Damage to the phrenic nerve with paralysis of the diaphragm.*
a) Roentgenogram of the thorax and abdomen of a child 3 days after a difficult breech delivery. There was plexus damage and facial nerve paralysis on the right side with severe dyspnea and cyanosis. The diaphragm was flaccid on the right side. Following thoracotomy and retensioning of the diaphragm, the child made a rapid recovery.
b) Normal thoracic roentgenogram 4 weeks after the operation

roots which are most frequently injured, resulting in paresis or paralysis of the shoulder and upper arm muscles. The arm hangs down loosely in adduction and pronation (upper plexus, or *Duchenne-Erb* paralysis). Other conditions which should be included in the differential diagnosis are: *Parrot*'s pseudoparalysis, due to syphilitic osteochondritis; osteomyelitis; serous or purulent arthritis of the shoulder joint. Differentiation from other skeletal birth injuries in the shoulder girdle (separation of an epiphysis, dislocations, sprains) may be very difficult, especially since they may be combined with a plexus injury. This is not particularly important in practice, since the treatment is the same: immobilization of the arm for 3–6 weeks in an angled plaster splint with the upper arm horizontal in abduction, the elbow flexed at 90°, and the forearm supinated with the palm of the hand directed forwards.

The prognosis is always unsure. In some cases, the paresis regresses over a period of weeks or months. In others, paresis remains, the deltoid muscle being most frequently affected. In these cases, neuroplasty is indicated. Physiotherapy should begin immediately. Repeated electromyography may be necessary for clarification of the prognosis.

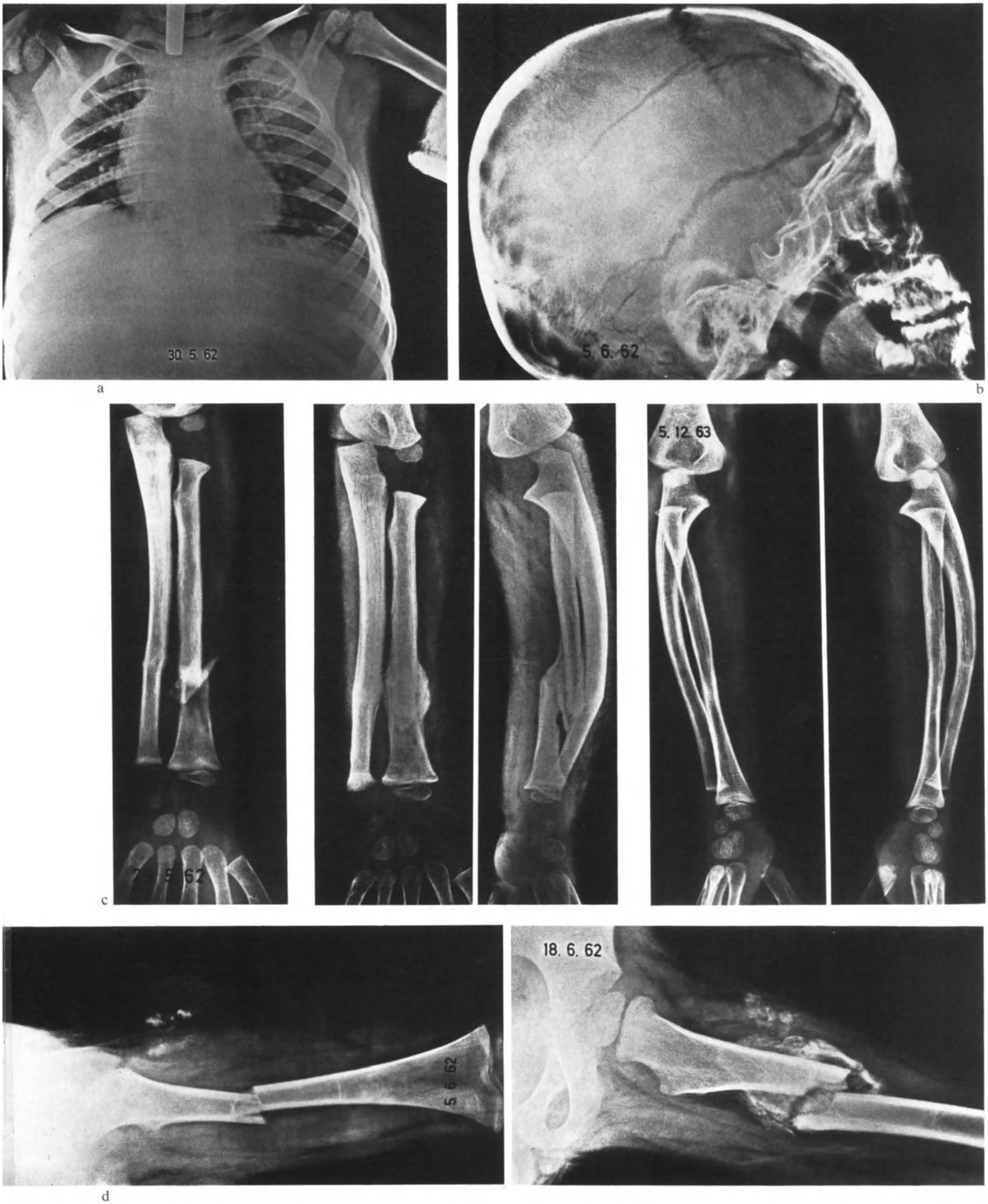
Damage to the lower fibers of the brachial plexus is much less frequent and causes paralysis of the muscles of the forearm and hand (lower plexus, or *Klumpke*'s paralysis). If the communicating branches to the sympathetic trunk are also injured at the level of T1, *Horner*'s syndrome results (miosis, ptosis, and enopthalmos on the same side). Phrenic nerve injury resulting from damage to C4 is frequently combined with *Duchenne-Erb* paralysis. It is more frequently right-sided. It frequently goes unnoticed or, if it causes dyspnea or cyanosis, it is often misdiagnosed as pneumonia, a congenital heart defect, or brain damage. Fluoroscopy shows elevation and paradoxical respiratory movement of the diaphragm. In very severe cases, the diaphragm relaxes completely and the heart is displaced into the intact thoracic cavity, causing circulatory embarrassment and further reduction of the vital respiratory capacity (Fig. 7). In such cases, emergency surgery is necessary to tauten the paralyzed diaphragm. In recent years, we have seen two such cases and were able to treat both successfully. In less severe cases, the paralysis regresses in the course of a few weeks.

2 Thoracic Trauma

Nowadays, blunt thoracic injury is almost always the result of a road traffic accident. Between 70%–80% of all thoracic injuries are accompanied by damage

→

Fig. 8a–d. *Multiple injury.*
a) Thoracic roentgenogram taken 5 days after operation, following a fall from the fourth story on to an asphalt pavement. There was severe injury to the skull, brain, and thorax (the endotracheal tube and the gastric tube are visible). There are clear signs of pulmonary hematoma. Before this roentgenogram was taken, laparotomy had been performed for treatment of ruptures of the liver and spleen.
b) Lateral skull roentgenogram 10 days after the accident. The fracture lines are clearly visible.
c) (*1*) Bilateral forearm fractures (the roentgenogram on the left was taken on the day of the accident). (*2*) Left forearm 5 weeks later, showing angulation and marked callus formation (*3*) $1^1/_2$ years after the accident, the appearance is more or less normal.
d) (*1*) Fracture of the left femur in traction 10 days after the accident. (*2*) 3 weeks later, a good callus has already formed


30. 5. 62
a
5. 6. 62
b
c
5. 12. 63
5. 6. 62
18. 6. 62
d

to other parts of the body (*Rehn*). We classify thoracic injuries in the child as follows:

1. Rib fractures.
2. Sternum fractures.
3. Pulmonary hematomas.
4. Pulmonary rupture.

The clinical picture is determined by the degree of restriction of gas exchange and by the circulatory embarrassment. The main features are shock, dyspnea, cyanosis, in some cases hemoptysis, and the localized pain which accompanies fractures of the ribs or sternum. Occasionally subcutaneous emphysema is also present.

2.1 Fractures of the Ribs and Sternum

The clinical and radiological diagnosis of rib fractures is easy. In the child, they are treated with a tubular stockinet bandage. Fractures of the sternum are rare and do not occur in the first decade of life. *Reimann* and *Böhler* described a sternum fracture in an 11-year old boy which had occurred during gymnastics on the parallel bars. The injury usually takes the form of a dislocation at the junction of the body of the sternum and the manubrium. It is treated with a bandage, as in the case of a rib fracture.

2.2 Pulmonary Hematoma

Pulmonary hematoma is rare, but may follow any high-energy trauma. It may be single or multiple. *Kemény* and others distinguish three forms as follows:

1. Hemorrhage with the clinical features of bronchopneumonia (Fig. 8a).
2. Circumscribed hematoma, which appears as a round opacification on a roentgenogram.
3. Formation of a cavity within the area of hemorrhage.

Operative treatment of a pulmonary contusion is usually unnecessary. The pathogenetic mechanism is assumed to be a sudden rise in intrabronchial pressure caused by compression of the thorax with simultaneous reflex closure of the glottis.

2.3 Rupture of the Lung

Rupture of the lung is caused by sudden pressure on the semiflexible thoracic wall which transmits the force to the underlying lung. It may also be caused by the jagged end of a broken rib. Depending on the type and severity of the trauma, rupture of the lung may be accompanied by pneumothorax, hemothorax, or injuries to other thoracic organs. Immediate surgery is necessary.

Six cases of traumatic rupture of the lung in children were reported from the Rehbein Clinic. Five children had multiple injuries, including serious rupture of intraabdominal organs, head injuries, and fractures. All six children had radiographically visible pneumohemothorax which required immediate operation. Three died, two of them because of their severe accompanying injuries.

Rapid preoperative investigation is particularly important.

3 Abdominal Injury. Multiple Injuries

Recently, numerous publications on abdominal injuries and polytrauma have appeared. One of our own cases is shown in Fig. 8; it confirms the results of *Hofmann* shown in the following table, in which a number of injuries are classified by body region.

Table 2. Analysis of 145 cases of multiple injury in children (after *Hofmann*, 1972)

Head injuries	116
Thoracic and pulmonary injuries	38
Abdominal injuries	46
Fractures	125
Soft tissue injuries	41
Nerve injury	1

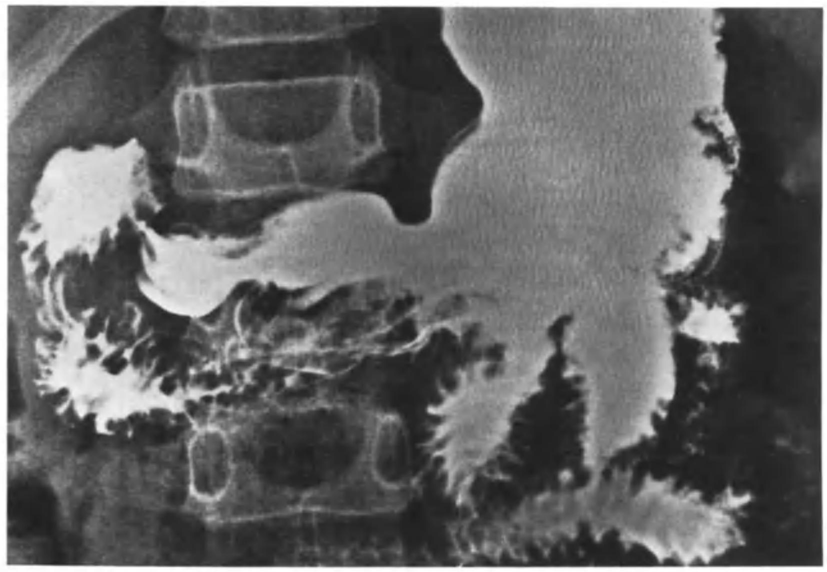
Head injuries and trauma to the extremities with fractures constitute the vast majority.

The order of frequency of the abdominal injuries is as follows:

1. Rupture of the spleen.
2. Rupture of the liver.
3. Intestinal or mesenteric injuries (Fig. 9).
4. Pancreas injuries (Fig. 10).
5. Renal or urinary tract injuries.
6. Rupture of the diaphragm.

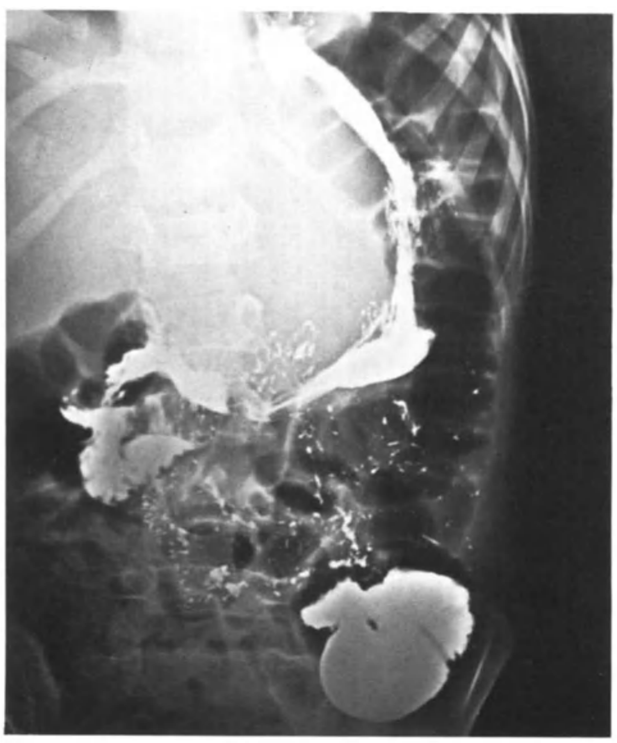
The clinical picture of abdominal trauma in children is dominated by shock to a much greater extent than in the adult. This tends to mask localized signs. Thus, the treatment of shock should be accompanied by

a



b

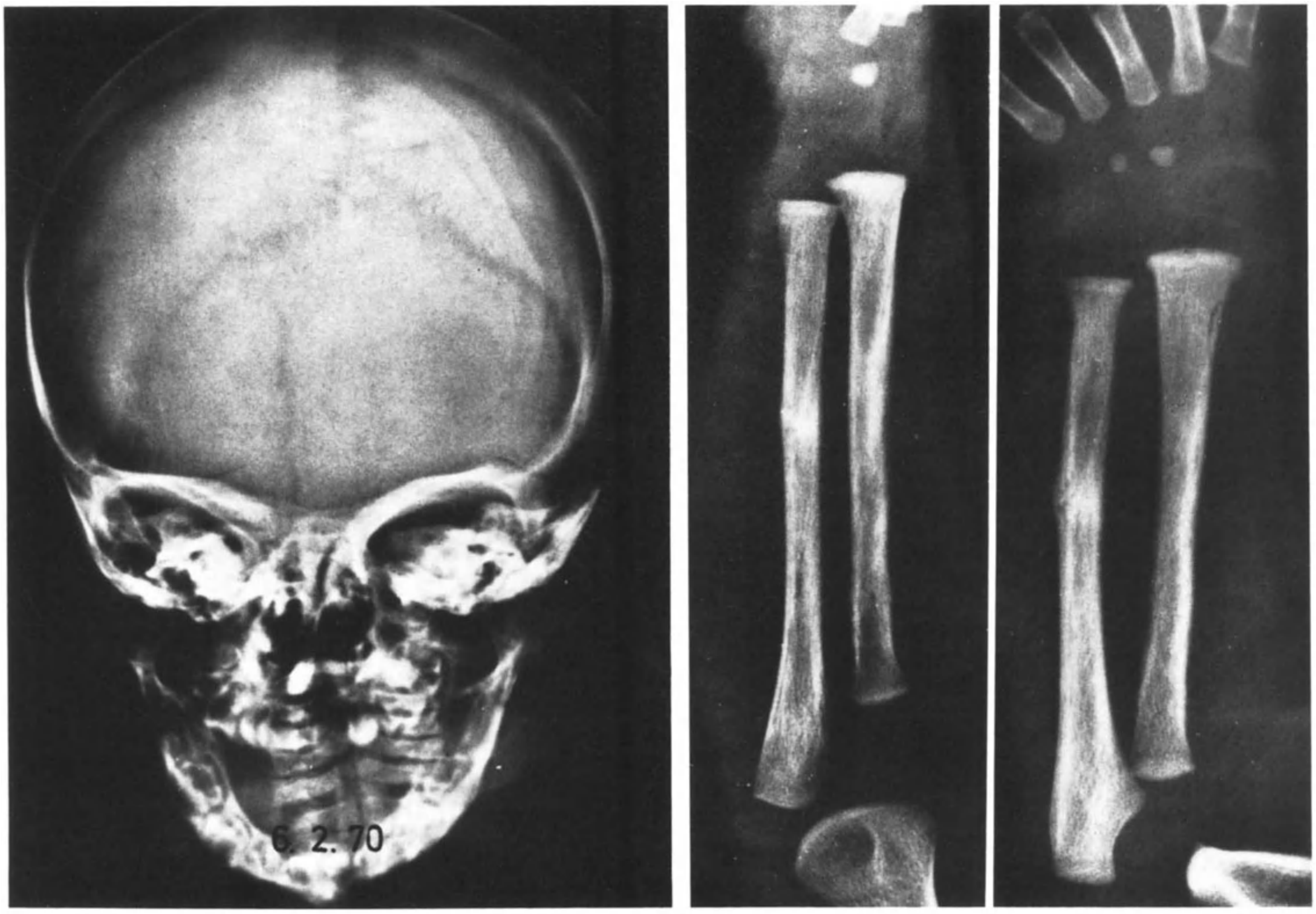
Fig. 9a, b. *Intestinal and mesenteric injury*.
a) Contrast roentgenogram of the gastrointestinal tract of a 7-year old boy. While skiing 10 days previously, he had collided with a wire which was stretched across the trail level with his upper abdomen. Upper gastrointestinal obstruction occurred. This view shows a spherical structure which obstructs the flow of the contrast medium in the pars descendens of the duodenum. At laparotomy, a fist-sized hematoma in the wall of the duodenum was found and was evacuated through a small serosal incision.
b) Normal passage of contrast medium in the duodenum 4 weeks following evacuation of the hematoma



a

b

Fig. 10a, b. *Pancreatic injury*.
a) Pseudocyst of the pancreas 18 days following blunt abdominal trauma. The stomach is displaced far to the left by the cyst.
b) 5 weeks following Roux-en-Y anastomosis. The gastrointestinal series is radiologically normal



a b

Fig. 11 a, b. *The battered child syndrome.*
a) Skull roentgenogram of a girl aged 2 months. A parasagittal fracture is visible. There was a subdural hematoma and respiratory arrest occurred. The operative treatment was successful.

b) Roentgenogram of the right forearm of the same child, taken at the same time. An old fracture of the ulna is visible. A typical sign of previous maltreatment

careful observation in the hours following the accident. Fever or leukocyte counts in the range 15000–20000 mm^2 should raise suspicion of internal injury. In doubtful cases, an abdominal tap should be carried out to aspirate peritoneal fluid or blood. The prognosis depends on the adequacy of the shock treatment and the timeliness of any laparotomy which becomes necessary.

4 The Battered Child

The victims are frequently small children under 3 years of age. This is the reason why so many cases go undetected. The types of ill-treatment are numerous, and the injuries may be somatic or psychological. The assailants are frequently parents of the children. Unfortunately, the doctor and social worker are all too frequently mislead by the descriptions of the alleged accidents. A fatal outcome is not rare. The causes of death are intracranial bleeding, exsanguinating hemorrhage in the abdomen, fat emboli secondary to fractures, and a variety of other injuries. Ill-treatment of children mainly occurs in so-called problem families, but may also take place within families which seem to be intact; in the latter cases, detection of the act causes special problems. The situation is exemplified by a number of illustrations from one of our own cases (Fig. 11). If a battered child syndrome is suspected, roentgenograms of the whole skeleton should always be ordered.

The situation in Germany is summarized in the following table which is taken from a publication by *E. Trube:*

Table 3. The battered child syndrome

When suspected:	X-ray whole skeleton
Most frequent cause of death:	Subdural hematoma
In Germany:	More than 600 battered children per year, with 100 deaths

5 References

Bettex, M.: Für das Kindesalter typische traumatische Schädigungen des Skeletes. In: Handbuch der Kinderheilkunde, Bd. 6, S. 460–476. Berlin-Heidelberg-New York: Springer 1967.

Brandesky, G.: Die wachsende Schädelfraktur im Säuglings- und Kleinkindesalter. Z. Kinderchir., Supplement zu **11**, 381–391 (1972).

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Klingenberg. A.: Zur massiven Nebennierenblutung des Neugeborenen. Schweiz. med. Wschr. **100**, 417–424 (1970).

Prod'hom, L. S.: In: Franconi/Wallgren: Lehrbuch der Pädiatrie, S. 317. Basel, Stuttgart: Benno Schwabe 1972.

Dénes, J., et al: Geburtstraumatische Epiphyseolysen Kinderchir., Supplement **11**, 193–199 (1972).

Geley, L., Hartl, H.: Geburtsverletzungen. Z. Kinderchir., Supplement **11**, 178–185 (1972).

Morger, R.: Frakturen und Luxationen am kindlichen Ellbogen. Basel-New York: Karger 1965.

Thoracic injury

Gelehrter, G.: Brustkorbverletzungen. In: Verletzungen bei Kindern und Jugendlichen (W. Ehalt, Hrsg.). Stuttgart: Enke 1961.

Kemény, P., et al.: Pulmonale Haematome nach stumpfen Thoraxverletzungen im Kindesalter. Z. Kinderchir. **2**, 201–210 (1965).

Kolb, H.: Traumatische Lungenrupturen im Kindesalter. Z. Kinderchir., Supplement zu Band **11**, 412–420 (1972).

Rehn, J.: Verletzungen der Thoraxwand nach stumpfen Trauma. Münch. med. Wschr. **113**, 541–543 (1971).

Abdominal injury, multiple injuries

Bauer, U., Waldschmitt, J., Hasse, W.: Das stumpfe Bauchtrauma im Kindesalter. Pädiat. Praxis **10**, 85–90 (1971).

Bruésière, J.: Nieren- und Harnwegsverletzungen beim Kind. Concours med. **94**, 6005–6018 (1972).

Ehrensperger, J.: Die traumatische Zwerchfellruptur beim Kind. Z. Kinderchir., Supplement **11**, 433–449 (1972).

Grob, M., Stauffer, U. G.: Traumatische Pankreaspseudocysten im Kindesalter. Helv. paediat. Acta **26**, 625–635 (1971).

Hofmann, S., et al.: Probleme der Mehrfachverletzungen beim Kind. Z. Kinderchir., Supplement **11**, 345–371 (1972).

Löhrer, A.: Zur Pankreaspseudocyste im Kindesalter. Praxis **59**, 954–965 (1970).

Sauer, H.: Das stumpfe Bauchtrauma im Kindesalter. Z. Kinderchir., Supplement **11**, 459–466 (1972).

Schäfer, U.: Die traumatische Zwerchfellruptur. Z. Kinderchir., Supplement **11**, 450–458 (1972).

Schärli, A.: Zur Klinik und Behandlung des stumpfen Bauchtraumas im Kindesalter. Unfallheilkunde **102**, 98–109 (1970).

Welz, K.: Abdominalverletzungen im Kindes- und Jugendalter. Zbl. Chir. **94**, 1771–1781 (1969).

The Battered Child

Biermann, G.: Kinderzüchtigung und Kindesmißhandlung, eine Dokumentation. München 1969.

Trube-Becker, E.: Die Kindesmißhandlung und ihre Folgen. Pädiat. Praxis **12**, 389–399 (1973).

SPECIAL PART

Fractures of the Clavicle and Scapula

R. Liechti

CONTENTS

Fractures of the Clavicle

Fractures of the Clavicle

1 Introduction

Fractures of the clavicle are among the most frequent and least harmful of the fractures which may occur in children. They constituted 9.4% of the series reported by *Ehalt*, and 10%–15% of the cases reported by *Renné* and *Weller*. Clavicular fractures made up 3% of the cases in our own records.

The clavicle joins the shoulder girdle to the trunk, and any force on the shoulder in a medial direction is transmitted by this bone. Thus, fractures are very often caused by the *indirect forces* which arise during the *more common types of accident*, such as a fall on the outstretched arm, elbow, or shoulder. Occasionally, the clavicle may be fractured by a *force applied directly* to it.

Thus, a fracture of the clavicle may result from almost any severe accident and the doctor should therefore include this injury in his checklist when examining the patient.

As a *birth injury*, the fracture may result from compression of the shoulder girdle during delivery. This injury is not as rare as one might think. It occurred during 1.7% of 300 births reported by *Farkas* and *Levine*. Many fractures are clinically silent and are therefore not noticed. A few weeks later a large callus forms, and palpation and a roentgenogram allow rapid diagnosis. On the other hand, pseudoparalysis of the arm may be present following birth, and the differential diagnosis includes fracture of the clavicle as well as traumatic separation of the proximal epiphysis of the humerus. Differentiation from plexus injury is relatively easy: following fracture, the child holds the arm in the position of minimum pain, and passive movement is hardly possible.

2 Fracture Types

We distinguish three types of fracture on the basis of their localizations (Fig. 1) as follows:

1. Fractures of the lateral third.
2. Fractures of the middle third.
3. Fractures of the medial third.

Depending on the age of the child and the magnitude of the force, the fracture may be of the greenstick type or dislocated.

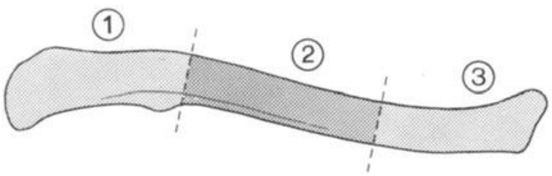


Fig. 1. *Sites of clavicular fractures.* (*1*) Lateral third. (*2*) Middle third. (*3*) Medial third

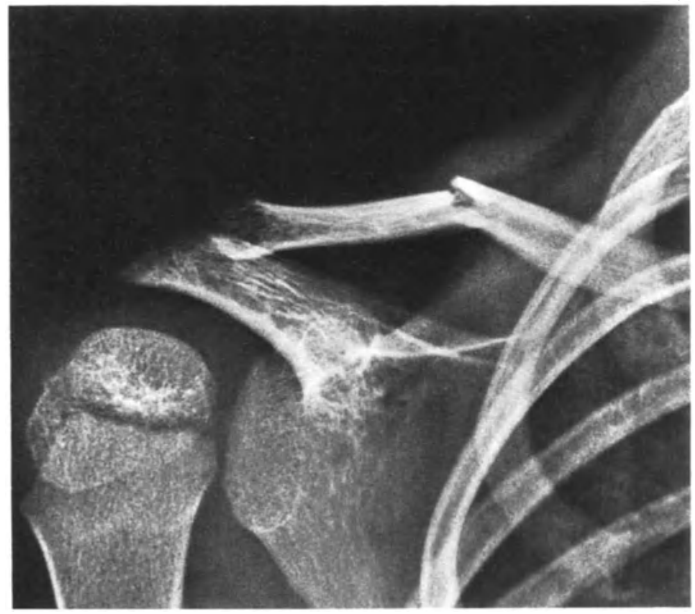


Fig. 2. *Greenstick fracture.* S.P., ♂, aged 3 years, No. 187228.
Typical greenstick fracture at the junction between the middle and lateral third of the clavicle with tearing of the dorsal periosteum and typical angulation

Greenstick Fractures. Bending forces cause a hemicircumferential fracture of the cortex with tearing of the overlying periosteum. The cortex on the opposite side is only bent and the corresponding periosteum remains intact (Fig. 2).

Since the fracture is incomplete, dislocation is impossible. The roentgenogram shows a greater or lesser degree of angulation. Greenstick fractures are frequently seen immediately following birth (as the result of birth injury) and also in young children up to the age of approximately 6 years. One reason for this is that the periosteum in young children is much tougher and more elastic than that in older children or adolescents.

Dislocated Fractures. The force causes complete fracture of the cortex, and the periosteum, which would otherwise splint the fragments, is completely torn. Thus, the fracture is completely unstable. Deformity is always present and may be severe. Dislocated fractures of the clavicle mainly occur in children over 6 years of age; greenstick fractures are relatively rare

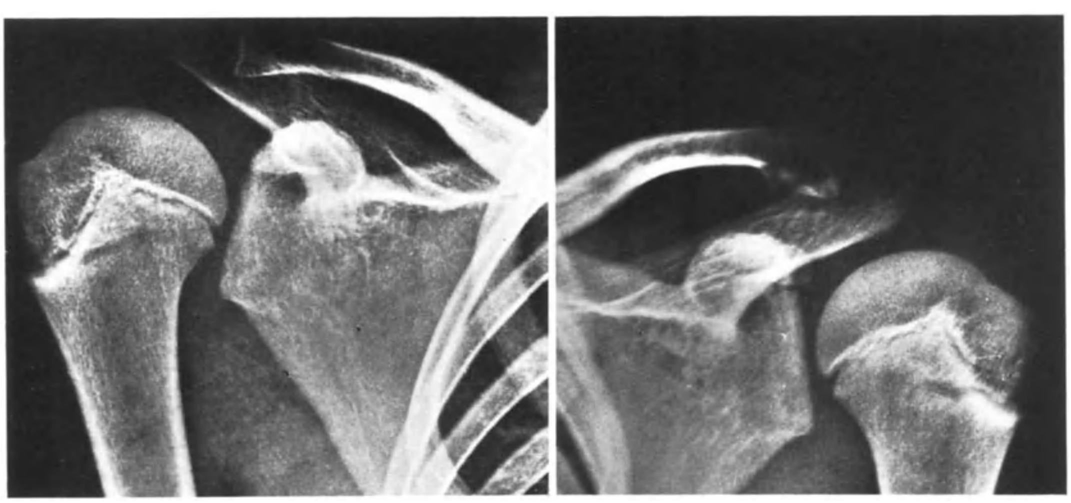


Fig. 3. *Fracture of the lateral part of the clavicle.* P.L., ♂, aged 11 years, No. 199445.
Typical subperiosteal comminuted fracture of the lateral part of the clavicle on the left without significant dislocation. The right side is shown for comparison

in this age group. The reasons lie in the mechanical properties of the periosteum and the wider variety of accidents.

2.1 Fractures of the Lateral Third of the Clavicle

These fractures are very rare and result from direct force on the clavicle. Clinically, this fracture has to be differentiated from *pseudodislocation* of the acromioclavicular joint (see below). In both cases, upward displacement of the proximal fragment may give the impression that the coracoclavicular ligaments are damaged.

2.1.1 Fractures of the Lateral Third of the Clavicle

These are frequently transverse fractures, but comminution occasionally results if the force is sufficiently great. Dislocation is limited if the periosteum is only slightly torn, since the fragments are restrained by the intact acromioclavicular and coracoclavicular ligaments (Fig. 3). However, if the tear in the periosteal cuff is extensive, the splinting effect of the latter is lost and the proximal fragment dislocates in an upward direction.

2.1.2 Pseudodislocation of the Acromioclavicular Joint

This injury consists of separation of the distal epiphysis, the ligaments remaining intact. The ligaments and the tough periosteum are stripped from the clavicle in a manner similar to the peeling of a banana (Fig. 4). Open reduction is followed by suture of the periosteal cuff, and the fragments are temporarily fixed with an axial *Kirschner* wire.

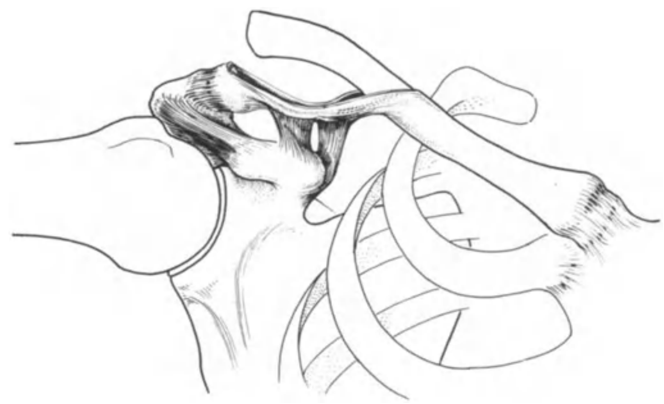


Fig. 4. *Pseudodislocation of the acromioclavicular joint*. Separation of the distal clavicular epiphysis occurs. The acromioclavicular joint itself remains intact. The periosteum tears along the upper surface of the clavicle and the lateral end of the bone dislocated upwards, giving it the appearance of a skinned banana

2.2 Fractures of the Middle Third of the Clavicle

The middle third is by far the most frequent site of a clavicular fracture. This is because both direct and indirect forces may cause a fracture in this area. *Greenstick fracture* is frequently accompanied by forward angulation. If the bone is *completely fractured*, the medial fragment is usually dislocated backwards and upwards by the pull of the sternocleidomastoid muscle. The distal fragment, on the other hand, is displaced forwards and downwards by the weight of the upper limb and by the pull of the pectoralis muscle. Severe direct trauma may cause *multifragmentation* of the clavicle, and displaced bone splinters from such a fracture may injure the subclavian artery or vein, the brachial plexus, or the apex of the pleura.

2.3 Fractures of the Medial Third of the Clavicle

The medial end of the clavicle is joined to the first rib and the sternum by powerful ligaments. Fractures of the medial third are rare and result from a direct blow or an indirect lateral force applied to the shoulder. Usually the fragments are not dislocated (*Tachdjian*), and displacement of the medial fragment is only possible if the costoclavicular ligament is ruptured. *Separation of the medial epiphysis* is extremely rare and belongs to this category of injury. It simulates a dislocation of the sternoclavicular joint; the metaphyseal end of the bone lies immediately under the skin and is easily palpated.

3 Treatment

The treatment of a clavicular fracture depends on the type of fracture and on the age of the child. Operative stabilization is rarely necessary and is restricted to special cases.

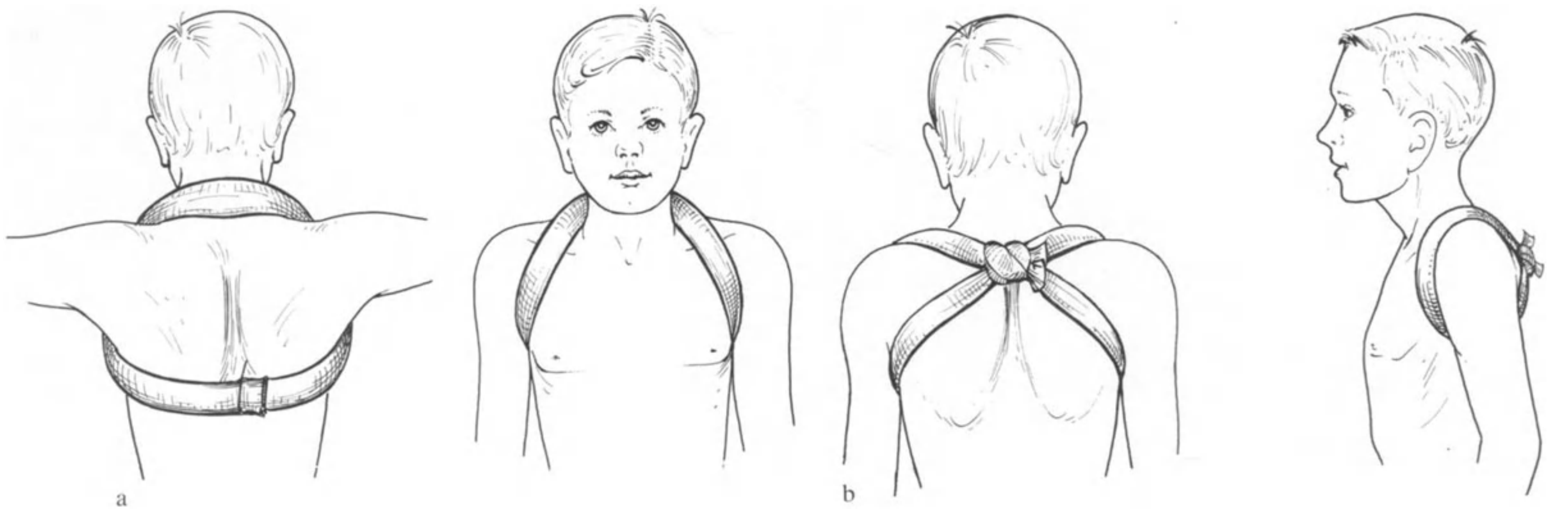


Fig. 5a, b. *"Rucksack" bandage (Type I).*
a) A stockinet tube filled with padding material is pulled tightly around the back of the neck and both shoulders and the ends are joined behind with safety pins.
b) The two horizontal parts of the tube are strapped together with a broad strip of adhesive plaster so as to increase the backward pull on the shoulders.

3.1 Nonoperative Treatment

3.1.1 Greenstick Fractures

Reduction: Manual straightening of a greenstick fracture is unnecessary. The angulation is corrected by subsequent growth, and the frequently large callus usually disappears within a few months (*Blount*). However, it is advisable to inform the parents about these aspects of healing.

Immobilization is by means of a figure-of-eight bandage (Type I) (*Wiedmer, Freuler* and *Bianchini*). A stockinet tube filled with wadding is placed tightly round the shoulders and the ends are joined with a safety pin. The two posterior, horizontal limbs of the tube are then pulled together and joined with broad strips of adhesive plaster. The latter step increases the backward pull on the shoulders (Fig. 5).

Warning: if the bandage is too tight, disturbances of circulation or sensation may result.

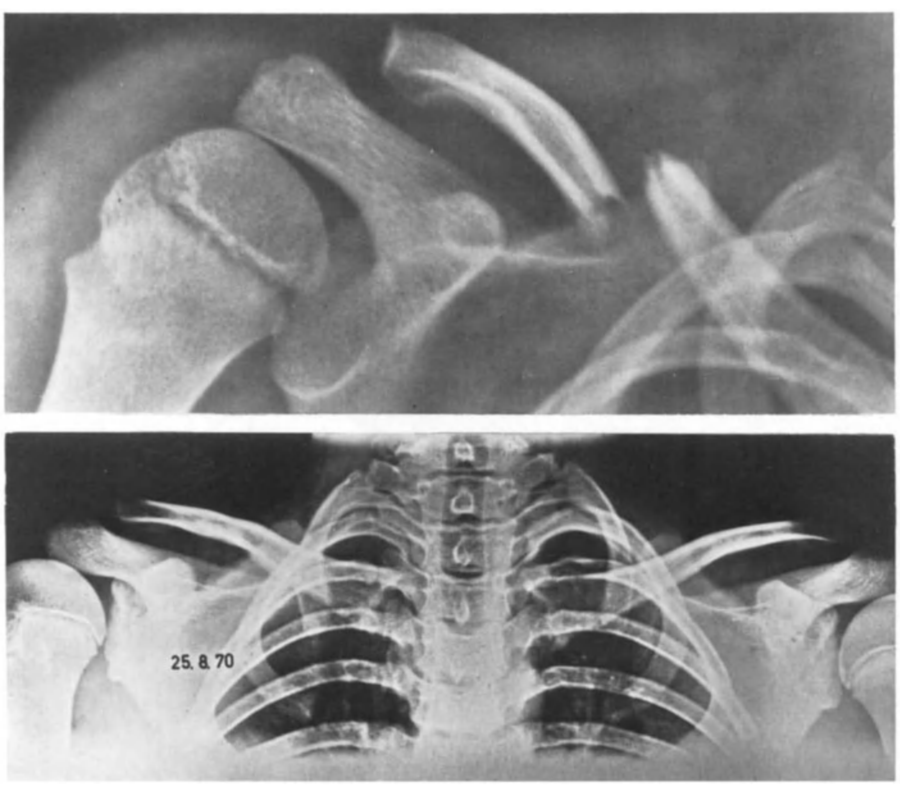


Fig. 6a, b. *Dislocated fracture of the clavicle.* F.R., ♂, aged 5 years. No. 70183.
a) Dislocated fracture of the middle third with typical upward and backward dislocation of the proximal fragment.
b) 9 years after the accident. There are hardly any residual radiological signs of the fracture and the shoulders are symmetrical in breadth

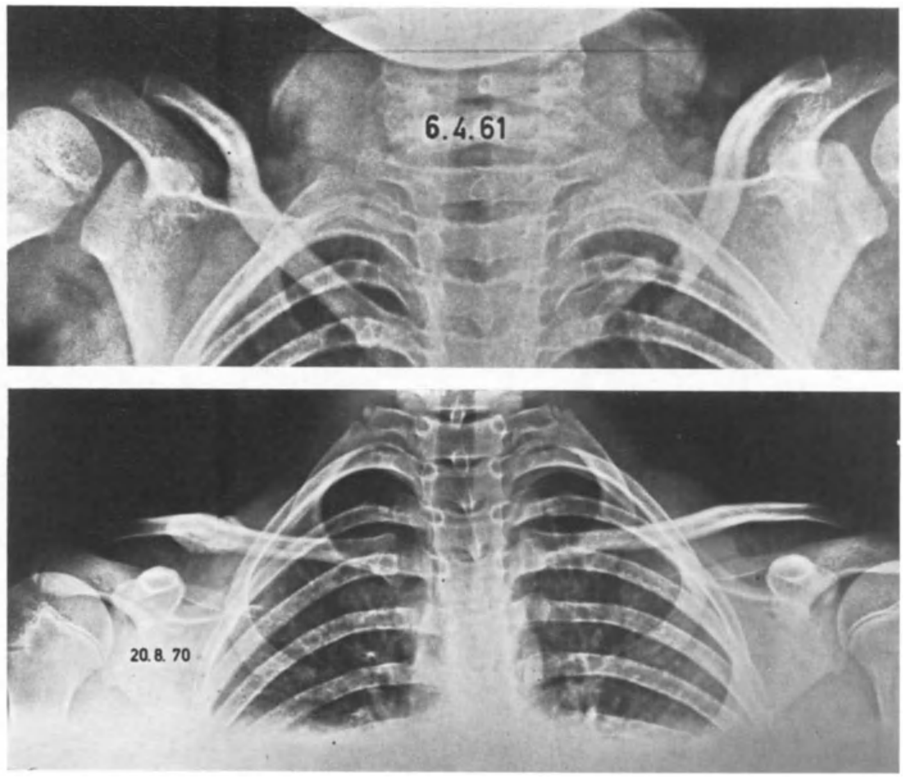


Fig. 7a, b. *Spontaneous correction of a dislocated fracture of the clavicle.* W.J., ♂, aged 5 years. No. 56313.
a) Left-sided fracture of the proximal part of the clavicle. A right-sided fracture of the clavicle occurred 2 years previously and has healed with correct alignment of the fragments.
b) 7 years later. A nondislocated fracture of the middle third of the right clavicle occurred and has already united with formation of a large ball of callus (roentgenogram taken 2 months after the accident occurred). The left clavicle was fractured 4 years ago. There are no residual clinical or radiological signs of the three previous fractures of the clavicle

Immobilization of a birth injury to the clavicle is only necessary if the child cries or if there is pseudoparalysis. In such cases, it suffices to fix the arms to the thorax with strips of adhesive plaster.

Duration of immobilization: 2–4 weeks, depending on the age of the child.

3.1.2 Dislocated Fractures

3.1.2.1 Fractures in Children up to 6 years of Age

Reduction of the fracture is not indicated, even if there is marked dislocation of the fragments; any malunion is corrected by subsequent growth (Figs. 6 and 7).

Immobilization is by means of a figure-of-eight bandage (Type I). Check sensation and circulation.

Duration of immobilization: 3–4 weeks.

3.1.2.2 Fractures in Children over 6 Years of Age

Reduction is recommended if there is considerable dislocation of the fragments. The fracture may be infiltrated with local anesthetic if necessary.

Reduction: The seated child is bound to the back of the chair with a towel. The arms are raised laterally and the shoulders are then pulled back. This usually reduces the fragments satisfactorily (Fig. 8). Nervous patients may require a general anesthetic for reduction.

Immobilization is by means of a figure-of-eight bandage (Type I or Type II) (*Freuler, Wiedmer, Bianchini*). The Type II bandage (Fig. 9) provides the most reliable and stable fracture fixation, but the knot may prevent the child from sleeping comfortably. A broad calico bandage is draped over the head and down the back as far as the sacrum, and is then bound to the trunk with an elastic bandage. Two stuffed stockinet rings of a suitable size are fitted round the shoulders. Finally, the ends of the stockinet rings and those of the calico bandage are knotted over a pad. In this manner, maximum traction is exerted on the shoulder girdle and results in stable fixation of the bone fragments. When the bandage has been applied, the radial artery should be easily palpable and there should be no signs of venous obstruction. If the rings loosen, they must be retightened.

Duration of immobilization: 4 weeks.

3.2 Operative Treatment

The indications for open reduction and fixation of a clavicular fracture are very rare and are almost completely restricted to the following situations:

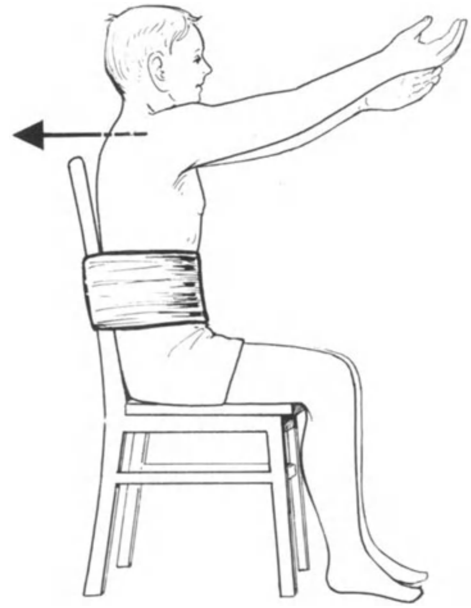


Fig. 8. *Maneuver for reduction of a severely dislocated fracture of the clavicle in a child over 6 years of age.* The child is seated and bound to the back of the chair by a towel which passes round the trunk. The elevated arms are pulled laterally and backwards, thus pulling the shoulders backwards and reducing the fracture

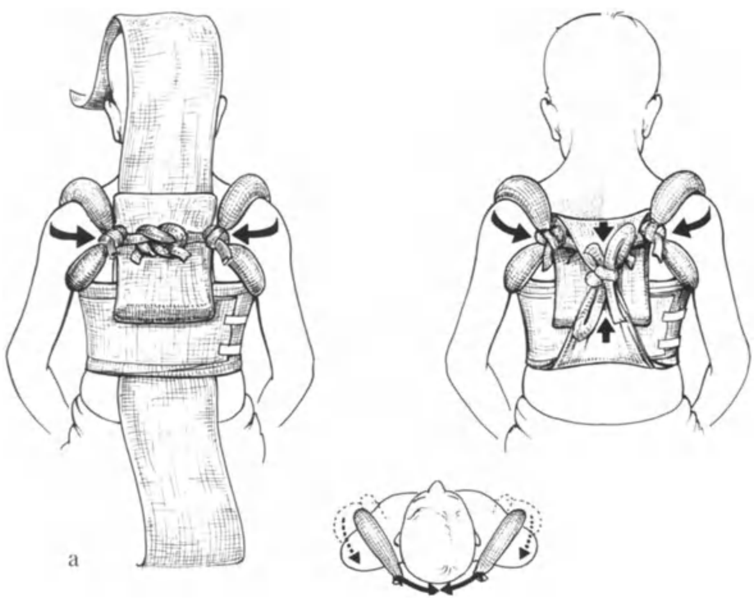
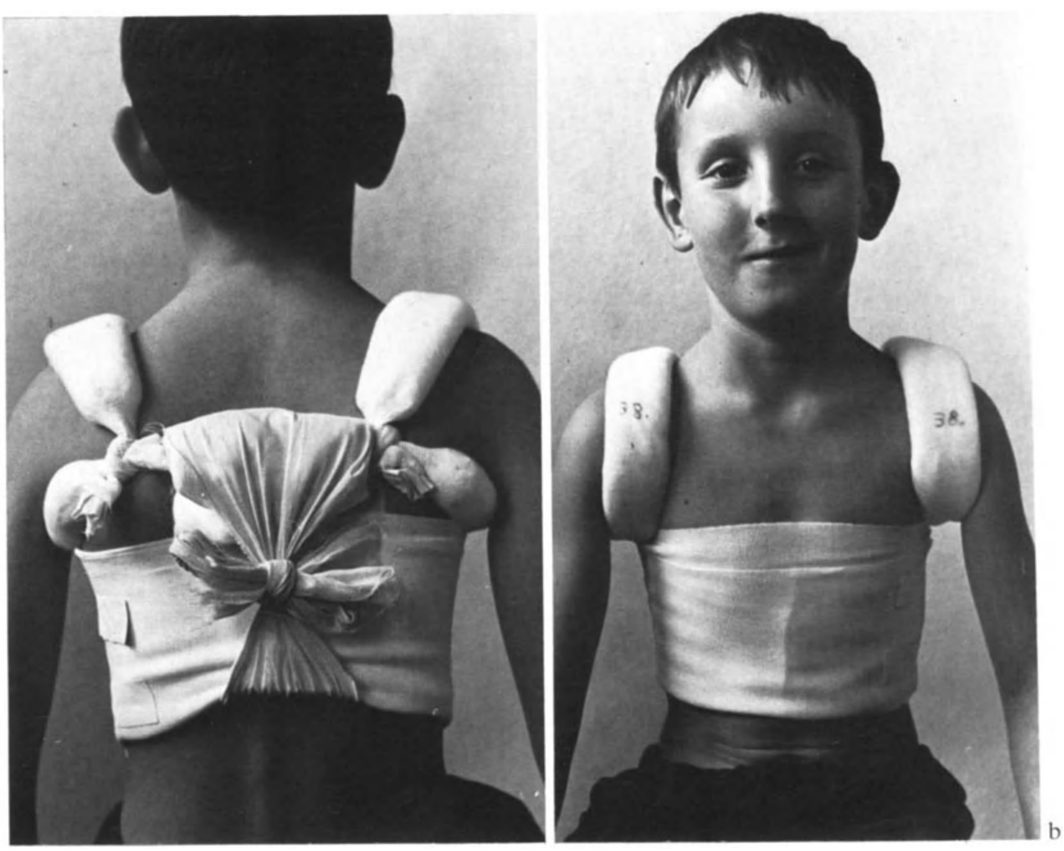


Fig. 9a, b. *"Rucksack" bandage (Type II).*
a) 2 padded rings, one calico bandage, one elastic bandage to serve as a belt, one cotton wool pad. First, the two padded rings are fitted over the shoulders and the calico strip is draped over the head so as to extend from the forehead down to the buttocks. The two shoulder rings are then tied together with the calico bandage, which is knotted over the cotton wool pad. Finally, the elastic bandage is applied as a belt and the calico strip is knotted over it.
b) Final appearance of the Type II "rucksack" bandage



1. Concomitant injury of the subclavian artery or vein, brachial plexus, or pleural apex (*Tachdjian*).
2. Rotation of a fragment through 90° so that it projects against the skin, causing danger of perforation.
3. Pseudodislocation of the acromioclavicular joint (see Chap. 2.1.2).

Fixation: *Kirschner* wire or 1/3-tubular plate or semitubular plate. The *Kirschner* wires should be bent round at their subcutaneous ends in order to prevent them from migrating.

4 Prognosis

4.1 Fracture Healing and Fracture Type

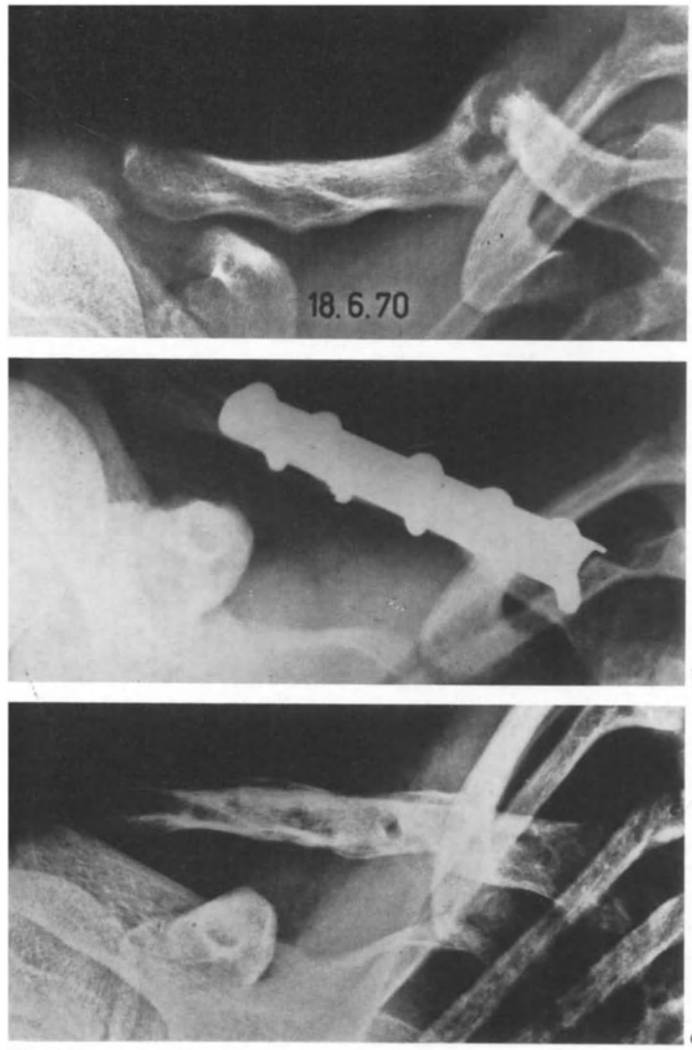
If the soft tissue damage is not severe and the fragments are not grossly dislocated, the fracture almost always heals, irrespective of the method of treatment. An excessively large ball of callus usually develops, particularly following greenstick fracture. This may cause the parents worry, but it usually disappears spontaneously within 6–9 months. If surgical correction is requested for cosmetic reasons, it should not be carried out before growth has ceased. The comment of *Chigot* and *Estève* is worthy of note in this context: *"La cicatrice croit, le cal s'amenuise"* (scar tissue grows, but callus resorbs itself). Fracture of the clavicle is never followed by disturbance of growth. Pseudarthrosis occurs extremely rarely following repeated refracture, but heals uneventfully following stable internal fixation (Fig. 10).

4.2 Primary Malunion

Even severe malunion with shortening of the fragments is corrected by subsequent growth. Primary malunion of a clavicular fracture is therefore of no significance and hardly affects the functional end result.

5 Results

Seventy-four fractures of the clavicle which were treated between 1961 and 1969 were followed up. The *differences in length* ranged from 0.5 cm to 1.5 cm. This was mainly accounted for by excessive growth; reduced growth was only seen in cases in which considerable shortening was already present following reduction. However, the differences in length were only detectable on the roentgenogram and were of no functional significance. One patient suffered six fractures



a

b

c

Fig. 10a–c. *Pseudarthrosis of the clavicle, which occurs extremely rarely, following nonoperative fracture treatment.* B.M., ♂, aged 15 years, No. 87816.
a) Fractures of the clavicle had occurred 9, 8, 6, 5, and 2 years, and 3 months ago. An active pseudarthrosis has formed.
b) Fixation with a 5-hole semitubular compression plate.
c) 6 months later, the pseudarthrosis has healed

of the right clavicle between the second and fifteenth years of age. The last fracture was followed by *pseudarthrosis* which healed following fixation with a semitubular plate (Fig. 10). All of the 74 patients who were followed-up were symptom-free and none of them had any limitation of function.

6 Summary

Fractures of the clavicle are seen very frequently. Nonoperative treatment results in healing with no adverse sequelae. Any malunion or shortening is corrected spontaneously by subsequent growth. Differences in length do not significantly affect the final result. Operative treatment is only indicated in exceptional cases, i.e.,

Fractures of the clavicle with concomitant injury to vessels or nerves;
Threatened perforation of the skin by a fragment of the fractured clavicle;
Pseudodislocation of the acromioclavicular joint.

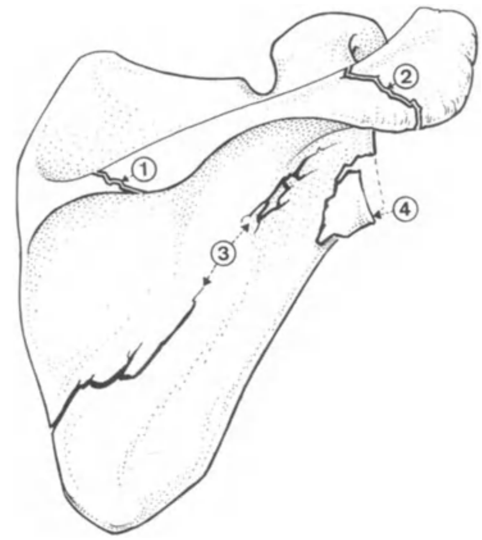


Fig. 11. *Fractures of the scapula classified according to site.* (*1*) Fracture of the spine. (*2*) Fracture of the acromion. (*3*) Fracture of the body of the scapula. (*4*) Glenoid fracture

Fractures of the Scapula

1 Introduction

Fractures of the scapula are extremely rare in children. According to *Renné* and *Weller*, they occur in less than 1% of cases. We ourselves have seen only one scapular fracture over a period of 10 years. They are caused by direct or indirect, high-energy trauma (road traffic accidents, falls from great heights) and may therefore be accompanied by fractures of the ribs or vertebrae. The latter tend to dominate the clinical picture, and a fracture of the scapula may therefore be missed.

2 Fracture Types and Treatment

The fractures are classified by their localization as follows (Fig. 11):

1. Fractures of the spine.
2. Fractures of the acromion.
3. Fractures of the body of the scapula.
4. Fractures of the glenoid.

Fractures of the spine, acromion, and body of the scapula are seldom severely dislocated, since they are surrounded by muscle.

2.1 Fractures of the Spine (Fig. 12)

These fractures are caused by direct trauma. Nonoperative treatment is always indicated.

Immobilization: *Velpeau* or *Gilchrist* bandage to combat pain (see *Wiedmer, Freuler, Bianchini*).

Duration of fixation: 5–7 days.

2.2 Fractures of the Acromion (Fig. 13)

This fracture is caused by a direct blow or indirectly by a force which acts longitudinally on the humerus. In the latter case, concomitant impression of the head of the humerus may be seen.

Reduction is superfluous; a good functional result is achieved without precise restoration of the original anatomy.

Immobilization: *Velpeau* or *Gilchrist* bandage.

Duration of fixation: 2–3 weeks.

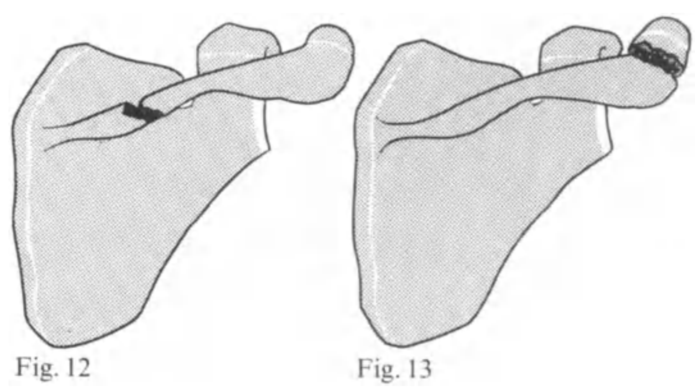
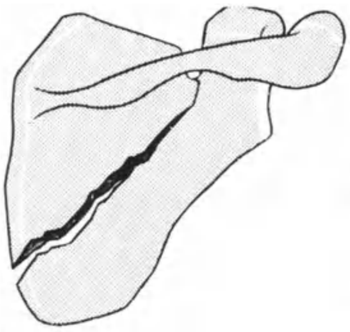


Fig. 12. *Fracture of the spine.* This fracture results from a direct blow

Fig. 13. *Fracture of the acromion.* This fracture is caused by a blow, or indirectly by an axial impact transmitted by the head of the humerus



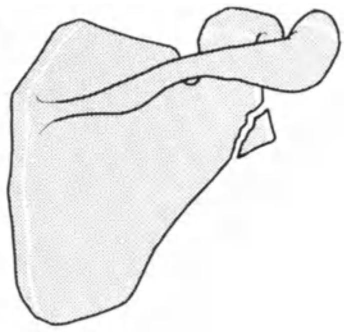


Fig. 14. *Fracture of the body of the scapula.* This fracture results from direct violence

Fig. 15. *Glenoid fracture.* This is a shear fracture which is caused by an oblique blow from the head of the humerus

2.3 Fractures of the Body of the Scapula (Fig. 14)

A severe direct force usually causes multifragmentation of the scapula which may be accompanied by a fracture of its spine. Open fractures are extremely rare, but simultaneous injuries to the thorax and vertebral column are frequently present.

Immobilization: Bed rest is always necessary because of the accompanying injuries. If there is severe pain, the shoulder can be immobilized with a *Velpeau* or *Gilchrist* bandage.

Duration of fixation: 2–3 weeks.

2.4 Fractures of the Glenoid (Fig. 15)

2.4.1 Pathological Features

The force caused by a fall onto the flexed elbow is transmitted to the shoulder joint, and a fracture of the rim of the glenoid occasionally results. Depending on the position of the upper arm during the accident, a ventral or dorsal chip is broken away. If the fragment is large, subluxation of the head of the humerus may also be present.

2.4.2 Treatment

Nonoperative Treatment is indicated if the rim fragment is small and there is no subluxation of the head of the humerus.

Immobilization: *Velpeau* bandage.

Duration of fixation: 3 weeks.

Operative treatment is indicated if there is fracture dislocation with severe displacement of the glenoid fragment.

Operative procedure: using a deltopectoral or dorsal approach, the fracture is reduced and the fragment is fixed with a screw. The torn joint capsule is sutured.

Postoperative management: *Velpeau* bandage. The screws are removed after 3 months.

Duration of fixation: 3–4 weeks.

3 Prognosis

The healing of a scapular fracture does not usually present problems. The occasional malunion is corrected by subsequent growth. Posttraumatic irregularities of the scapular joint surface may cause symptoms which necessitate surgical correction. The latter is best carried out by internal fixation immediately following the accident.

4 Summary

Fracture of the scapula is extremely rare in children. It heals with simple nonoperative treatment. Surgery is only justified if there is fracture dislocation of the glenoid cavity.

5 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme, 1957.

Chigot, P. L., Estève, P.: Traumatologie infantile. Paris: Expansion Scientifique, 1958.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1961.

Farkas., R. Levine, S.: X-ray incidence of fractured clavicle in vertex presentation. Amer. J. Obstet. Gynec. **59,** 204 (1950).

Renné, J., Weller, S.: Verrenkungen und Frakturen der oberen Gliedmaßen. Unfallverletzungen bei Kindern, (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer, 1974.

Tachdjian, M. O.: Pediatric Orthopedics. Philadelphia-London-Torònto: W. B. Saunders, 1972.

Wiedmer, U., Freuler, F., Bianchini, D.: Cast manual for adults and children, Berlin-Heidelberg-New York: Springer, 1979.

Fractures of the Proximal Humerus

F. MAGERL

CONTENTS

1 Introduction

Fractures of the proximal humerus are much less common during growth than in elderly persons. This well-known fact has been confirmed by the data published by *Tondeur*. *Neer* and *Horwitz* found involvement of the upper humeral epiphysis in only 3% of 2500 epiphyseal separations and fracture separations. In our case records, fractures of the proximal humerus make up 3.4% of all fractures in children.

1.1 Causes of Fractures

The most frequent causes of proximal humerus fractures are falls from moderate or great heights, accidents sustained during sports or play, and road traffic

Fig. 1. *Subcapital buckling of the humerus*. S.D., ♀, aged 7 years, No. 131645.
Fall onto the outstretched arm

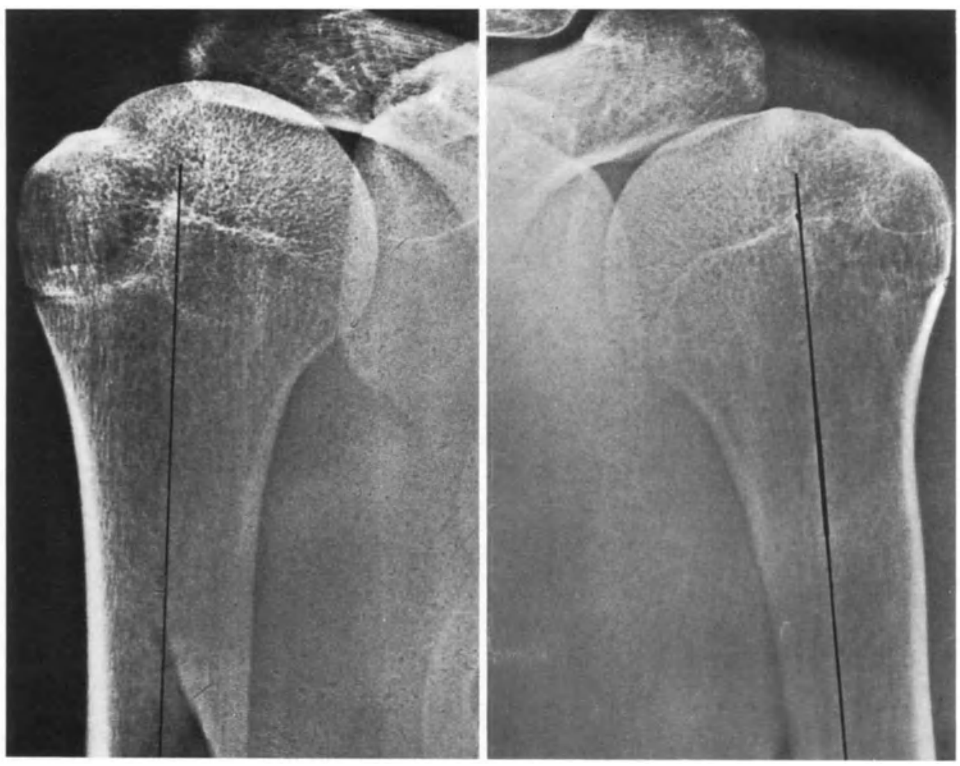


Fig. 2a–d. *Subchondral impression of the head of the humerus*. B.K., ♂, aged 15 years, No. 103899.
a) Immediately following the accident: fracture separation has occurred.
b) 2 months after the accident. Subchondral bone resorption is occurring in the head of the humerus opposite to the acromion. The fracture separation has healed.
c) 4 months after the accident. Cystic areas of resorption are seen in the head of the humerus, with impression of the latter and bone sclerosis around the cysts. The accident had probably caused a subchondral impression fracture which has resulted in partial subchondral aseptic necrosis.
d) Follow-up 6 years after the accident. There is slight flattening of the head of the humerus, but the remaining structures have returned to normal

accidents. Separation of the epiphysis resulting from birth trauma has been described in the literature (*Blount, Daubenspeck, Ehalt, Matzner*).

1.2 Fracture Mechanisms

The fractures mainly result from a fall onto the outstretched arm or onto the shoulder, or from a severe blow to the shoulder. A fall on an arm which is extended backwards, adducted, and in slight external rotation causes *longitudinal compression* of the humerus. If this force is purely axial, circumferential buckling of the bone results (Fig. 1); in one of our cases there was an additional subchondral fracture of the head of the humerus opposite to the acromion (Fig. 2). Depending on the position of the humerus relative to the scapula at the time of the accident, axial compression may be complemented by *bending forces* generated by muscle pull. This causes either adduction fracture with varus dislocation as a result of traction on the tubercula, or abduction fracture with valgus angulation produced by the pull of the

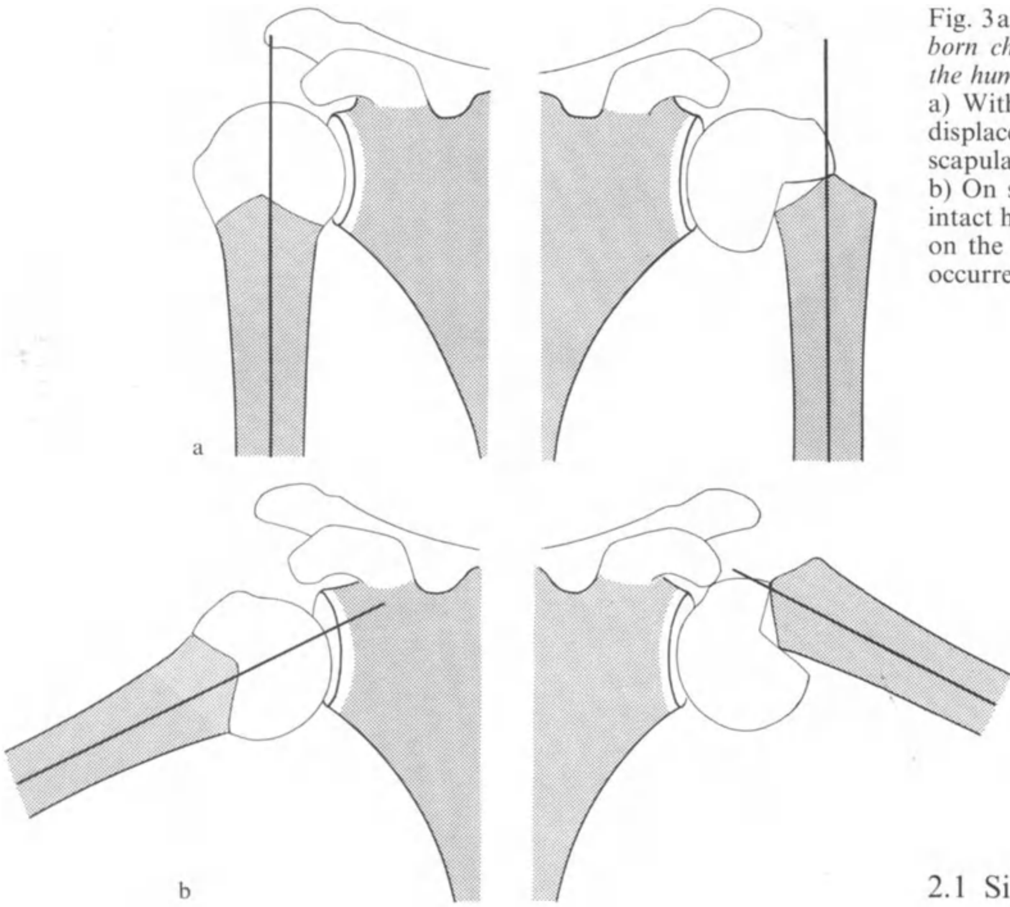


Fig. 3a, b. *Diagram of the radiological findings in a new born child with separation of the epiphysis of the head of the humerus.*
a) With both arms in the normal position, slight lateral displacement of the shaft of the humerus relative to the scapula is seen.
b) On symmetrical abduction of the arms, the axis of the intact humerus passes through the glenoid cavity while that on the opposite side, on which epiphyseal separation has occurred, lies outside the glenoid cavity

pectoralis major, teres major, and latissimus dorsi muscles.

Fractures are quite frequently caused by a fall onto the shoulder, which most probably generates *bending* and *shear* forces (*Neer* and *Horwitz, Smith).*

Avulsion mechanisms and *shear* forces cause simple separation of the epiphysis. In contrast, *torsion* causes short infratubercular spiral fractures. Thus, in one of our cases, fracture was caused by wresting an object from the child.

2 Types of Fracture and Their Treatment

In contrast to fractures at other sites, the types of fracture of the proximal humerus in the child are very limited. Intraarticular fractures and fractures which transect the epiphyseal plate (*Aitken* II or *Salter* III, *Aitken* III or *Salter* IV) are never seen (*Aitken, Salter,* and *Harris*). The fractures are best classified morphologically as follows:

1. Simple separations of the epiphysis.
2. Fracture separations (*Aitken* I or *Salter* II).
3. Infratubercular fractures.

2.1 Simple Separations of the Epiphysis

Simple separations of the epiphysis make up a very small proportion of proximal humerus injuries; we saw only two cases in a total of 53 fractures (Table 1). *Dameron* and *Reibel* reported only six cases of epiphyseal separation in a total of 69 fractures. This rare injury may occur at any age, but is more frequent in small children, whose epiphyses are still broad and relatively weak. The frequency of these injuries increases again at puberty; here, the second growth spurt is accompanied by a decrease in the density of the epiphyseal plate. Both our cases belonged to this age group (Table 1).

Table 1. Age distribution and types of the 53 fractures of the proximal humerus treated between 1961 and 1969.

Fracture types	Number of cases	Mean age	Age distribution
Epiphyseal separation	2	14.0	(14)
Fracture separation	14	14.4	(10–17)
Comminuted fracture separation	10	8.8	(4–14)
Infratubercular fracture	27	9.0	(1–17)

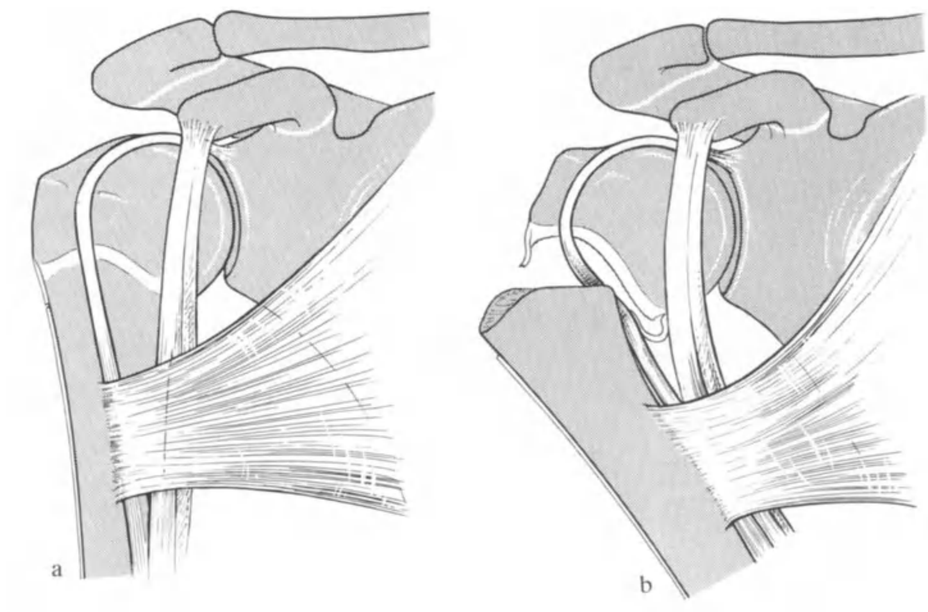


Fig. 4a, b. *Diagram of epiphyseal separation.*
a) Before separation: the tendon of the long head of biceps lies in its groove.
b) Following separation, the distal fragment dislocates upwards and the tendon of the long head of biceps is trapped between the fragments

2.1.1 Epiphyseal Separation Resulting from Birth Trauma

2.1.1.1 Pathological Anatomy

This is a rare, but typical birth injury (*Blount, Daubenspeck, Matzner*) caused by forcible manipulation during delivery. Changes in the epiphyseal plate, such as those which accompany congenital syphilis, may encourage separation. Epiphyseal separation resulting from birth injury must be carefully differentiated from plexus damage, since the clinical pictures are similar; however, the two injuries may be concomitant. In the literature, the following symptoms are described as being characteristic (*Blount, Daubenspeck, Tondeur*):

1. Swelling of the affected shoulder.
2. Carriage of the arm in a position of minimum pain; failure to move the arm. Thus, the term pseudoparalysis is used (*Parrot*'s pseudoparalysis, which is associated with congenital syphilis in particular) and the condition may be confused with true paralysis caused by plexus injury. Following separation of the epiphysis, passive movement of the shoulder joint elicits pain and the child protests loudly.

These clinical criteria are frequently insufficient for the diagnosis of separation of an epiphysis. Since the proximal epiphysis of the humerus is not ossified in the newborn, simple roentgenograms of the shoulder girdle generally fail to furnish further, useful information. However, comparison of roentgenograms of both shoulder joints with the upper arm in abduction and adduction allows detection of differences in the orientations of the humeri with respect to the joints (*Rehn*) (Fig. 3). If the latter method also fails to confirm the diagnosis, arthrography will always provide the necessary information (*Tondeur*) and will also show the extent of any dislocation which may be present.

2.1.1.2 Treatment

Non-operative Treatment: Reduction is always carried out under general anesthesia; longitudinal traction is exerted with the elbow flexed at a right angle and at the same time, the arm is brought into abduction, flexion, and slight external rotation. In this position, the distal fragment is carefully forced under the epiphyseal plate, and the position is then checked with a further series of comparative roentgenograms.

Immobilization: *Velpeau* bandage.

Duration of fixation: 10–14 days.

Operative treatment: Open reduction is indicated if closed reduction fails (*Blount, Daubenspeck*), since severe posttraumatic deformity may otherwise result (*Blount, Weil*). The fracture is reduced, using the same maneuver as above, and the torn periosteum is sutured.

Postoperative treatment includes immobilization with a *Velpeau* bandage. The skin sutures are removed after 10–14 days and the patient is discharged.

2.1.2 Separation of the Epiphysis in the Child

2.1.2.1 Pathological Anatomy

Experimental epiphyseal separations were accompanied by flexion, abduction, and slight external rotation of the proximal fragment (*Dameron* and *Reibel*). On the other hand, the distal fragment was dislocated forwards and medially by the pull of the pectoralis major muscle, the medial periosteum remaining intact. The lateral periosteum was torn and the distal fragment slipped lateral to the tendon of the long head of biceps (Fig. 4).

2.1.2.2 Treatment

Nonoperative Treatment: Reduction is always carried out under general anesthesia with ketamine (Ketalar). In order to reduce the epiphyseal dislocation described, the distal fragment is brought under the epiphyseal plate with the elbow flexed at a right angle and with simultaneous abduction, flexion, and slight external rotation. The position is checked with the image intensifier.

Immobilization: *Velpeau* bandage.

Duration of fixation: 3 weeks.

Operative Treatment: Surgery is only indicated if closed reduction fails. This is usually caused by the intact medial periosteum.

Reduction and fixation: Using an anterior deltopectoral approach, the fragments are reduced and fixed with two *Kirschner* wires which are driven in in an upward direction (Fig. 5). The latter should be so placed that they can be removed through stab incisions. Additional stabilization is assured by suturing the lateral part of the periosteal cuff.

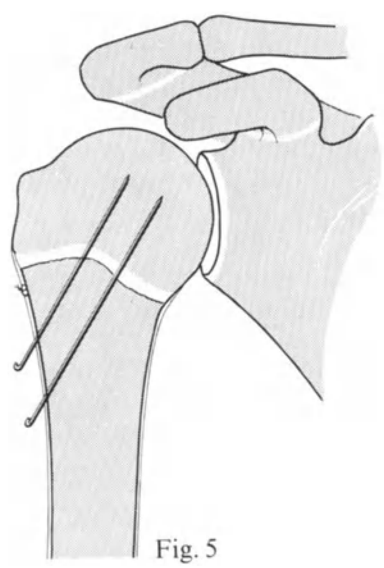


Fig. 5

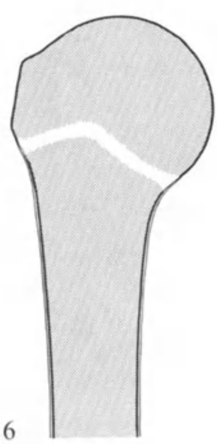


Fig. 6

Fig. 5. *Diagram of the operative treatment of epiphyseal separation.* Open reduction is followed by transfixation with two thin *Kirschner* wires, the ends of which are bent round, and the torn periosteum is sutured

Fig. 6. *The proximal epiphyseal plate in the humerus of an adolescent.* In the adolescent, the epiphyseal plate takes on the shape of a flattened tent. This is the reason why shearing off of the epiphysis hardly ever occurs after puberty

Postoperative treatment: immobilization with a *Velpeau* bandage. The *Kirschner* wires are removed after 6–8 weeks.

Duration of fixation: 3 weeks, after which the child is allowed to use the arm freely.

2.1.3 Separation of the Epiphysis in the Adolescent

2.1.3.1 Pathological Anatomy

The dislocation and periosteal damage observed in the experiments of *Dameron* and *Reibel* probably also occur in the adolescent. However, the cartilage in the epiphyseal plate of a young child differs significantly from that of the adolescent. In the latter, the epiphyseal plate is already quite narrow and has the shape of a flat cone (Fig. 6). This bonds the epiphysis firmly to the metaphysis so that pure *shear* fractures hardly ever occur in the adolescent; above all, their frequency decreases following puberty. Avulsion of the epiphysis caused by varus *bending* is much more likely to occur. The center of rotation in such cases must lie at the level of the epiphyseal plate, medially and dorsally, in order that the tip of the metaphysis emerge under the tubercula without necessitating excessive elastic deformation or the breaking off of a medial wedge. Furthermore, because the shape of the epiphyseal plate is slightly conical the slight shear dislocation which a flat epiphyseal plate permits is unlikely to occur. In agreement with this, both our cases exhibited severe tilting of the epiphysis.

2.1.3.2 Treatment

Nonoperative Treatment: Reduction is carried out under general anesthesia. The distal fragment is brought under the epiphysis by longitudinal traction and simultaneous abduction, flexion, and slight external rotation. The position is checked with the image intensifier (Fig. 7).

Immobilization: *Velpeau* bandage.

Duration of fixation: 4 weeks.

Operative Treatment: The intact part of the medial periosteal cuff may prevent reduction, in which case surgery is indicated.

Fixation: The fragments are stabilized with *Kirschner* wires which are driven in from below. It is advisable to position the wires in such a way that they can be removed through stab incisions. Shortly before cessation of growth, the head of the humerus can also be fixed with two screws, since damage to the epiphyseal plate no longer has serious consequences.

Fig. 7a, b. *Separation of the epiphysis in an adolescent*. S.A., ♀, aged 14 years, No. 80162.
a) Severe dislocation following simple separation of the epiphysis of the head of the humerus. Treatment: reduction under anesthesia, followed by application of a *Velpeau* bandage.
b) 6 weeks after the accident. Healing has taken place with correct alignment of the fragment

a b

a

b

c

Fig. 8a–c. *Fracture separation of the proximal epiphysis of the humerus*. M.K., ♂, 13 years, No. 87579.
a) Fracture separation with a long distal fragment on the lateral side which projects under the skin.
b) Reduction under general anesthesia, followed by immobilization in a *Velpeau* bandage.
c) Follow-up 5 years and 9 months following the accident. Uneventful healing has taken place

Fig. 9a–e. *Fracture separation with a large metaphyseal wedge*. R.S., ♀, aged 14 years, No. 131826.
a) Large medial metaphyseal wedge which simulates an infratubercular fracture.
b) During the reduction maneuver, the distal tip broke off on the lateral side, rendering the fracture unstable.
c) Correct axial alignment is achieved by placing the arm in the saluting position.
d) Follow-up roentgenogram following bone union.
e) $3^1/_2$ months after the accident. The fracture has healed with correct alignment of the fragments

Postoperative treatment: immobilization with a *Velpeau* bandage. The *Kirschner* wires are removed after 6–8 weeks, screws after 3 months.

Duration of fixation: 4 weeks, followed by discharge.

2.2 Fracture Separations (AITKEN I = SALTER II)

2.2.1 Pathological Anatomy

In this type of fracture, there is a partial separation of the epiphysis and, in addition, a mediodorsal fragment is broken away from the metaphysis. The proliferative cartilage layer is not damaged and subsequent growth can therefore be expected to be normal. The periosteum remains intact on the medial side, being only partially detached from the distal fragment. The periosteal cuff is torn open on the lateral side and the distal fragment projects. It is pulled forwards and medially by the pectoralis major muscle and may occasionally be buried in the deltoid muscle or come to lie immediately under the skin (Fig. 8). The metaphyseal fragments are usually small in younger children, but tend to be large in adolescents (*Aitken*). The metaphyseal wedge which accompanies the epiphyseal separation may be very small, so that the situation borders on that of pure epiphyseal separation. On the other hand, a very large wedge may simulate an oblique infratubercular fracture, since the fracture line begins on the lateral side of the epiphyseal plate (Fig. 9). Fractures which are only slightly dislocated result in only slight angulation, but slight varus deformity is always present. With increasing dislocation, the varus angulation and flexion of the proximal fragment increase, causing angulation forwards and laterally.

2.2.2 Treatment

Nonoperative Treatment. The ability of the intact medial periosteum to resist traction plays an important part in treatment. It is placed under tension on abduction of the reduced fracture, and thus pulls the distal fragment against the epiphysis.

Nondislocated or hardly dislocated fracture separations

Immobilization: *Velpeau* bandage.

Duration of fixation: 3–4 weeks.

Dislocated fracture separations. Reduction is carried out under general anesthesia. With the elbow flexed, longitudinal traction is exerted so as to withdraw the distal fragment from the deltoid muscle. By pronounced abduction, flexion, and slight external rotation, the distal fragment can be reduced through the lateral tear in the periosteal cuff, thus bringing the arm into the "saluting" position. The position is checked with the image intensifier. If the fracture remains reduced with the arm in full adduction, it is immobilized with a *Velpeau* bandage (Fig. 10). A radiographic check is carried out 5 days later.

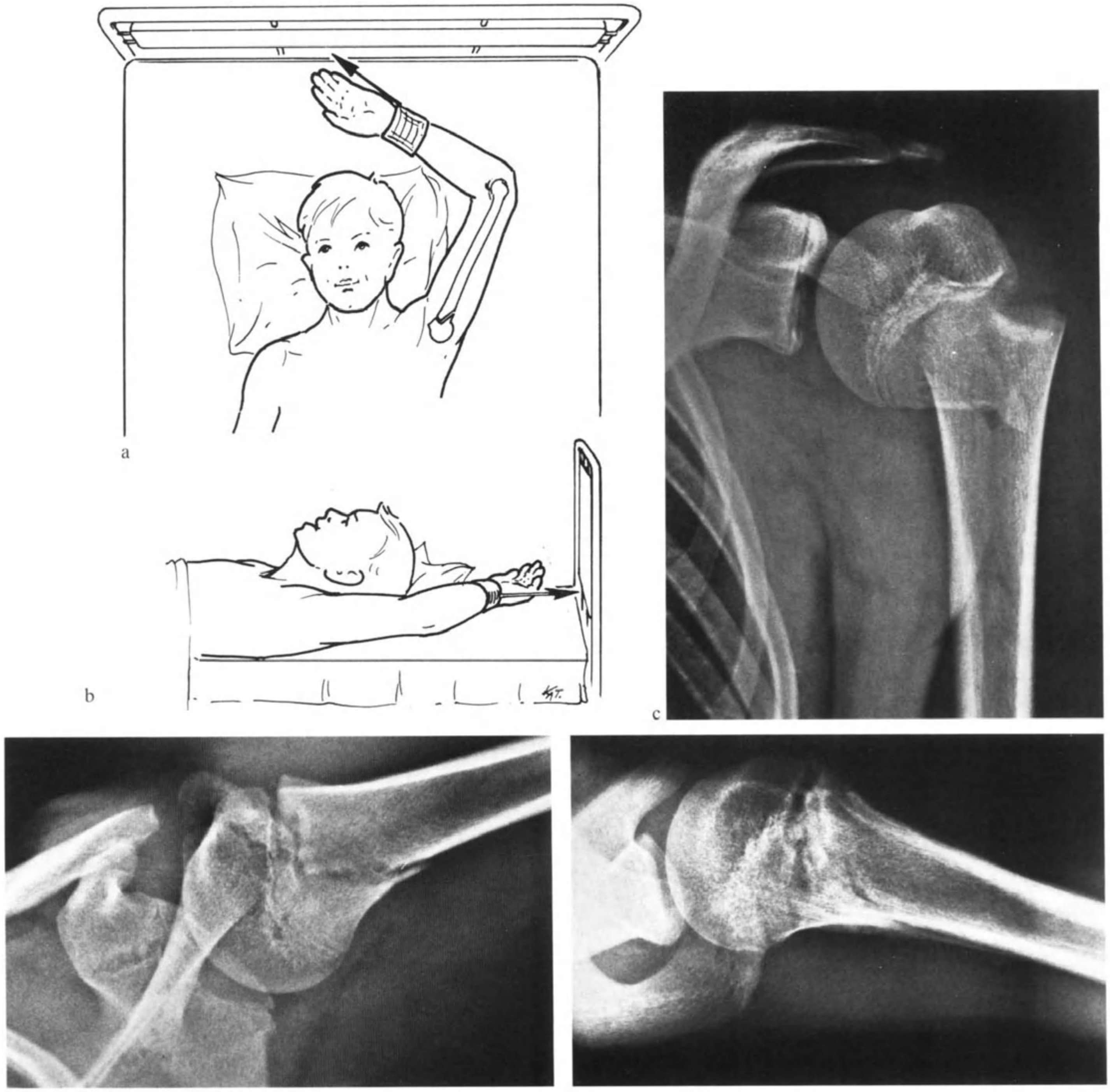
Fig. 10. *Simplified version of the Velpeau bandage.* A stockinet tube is pulled over the upper part of the trunk and the hand is brought into the correct position through a slit in the front of the bandage. The ends of the bandage are cut through and tied. Cotton wool padding is placed in the axilla, under the elbow and under the hand

Duration of fixation: 3–4 weeks.

If the fracture is not stable with the arm in adduction, the latter must be held in abduction. With the elbow flexed, the arm is brought into abduction until the wrist is above the head. This position is maintained by a wristband which is fastened to the upper end of the bed (Fig. 11). A radiographic check is carried out 5 days later. This method of treatment is simple and is well tolerated by the child.

Duration of abduction: 2 weeks. Subsequently, the arm is gradually brought into adduction over a period of 3–4 days and is then immobilized in a *Velpeau* bandage for 2 weeks.

If reduction cannot be maintained, even using the latter method, the arm should be brought into the saluting position by traction with adhesive plaster or an olecranon screw (Fig. 12). In this position, the upper arm is in approximately 135° abduction, 30° flexion, and slight external rotation. Traction is main-

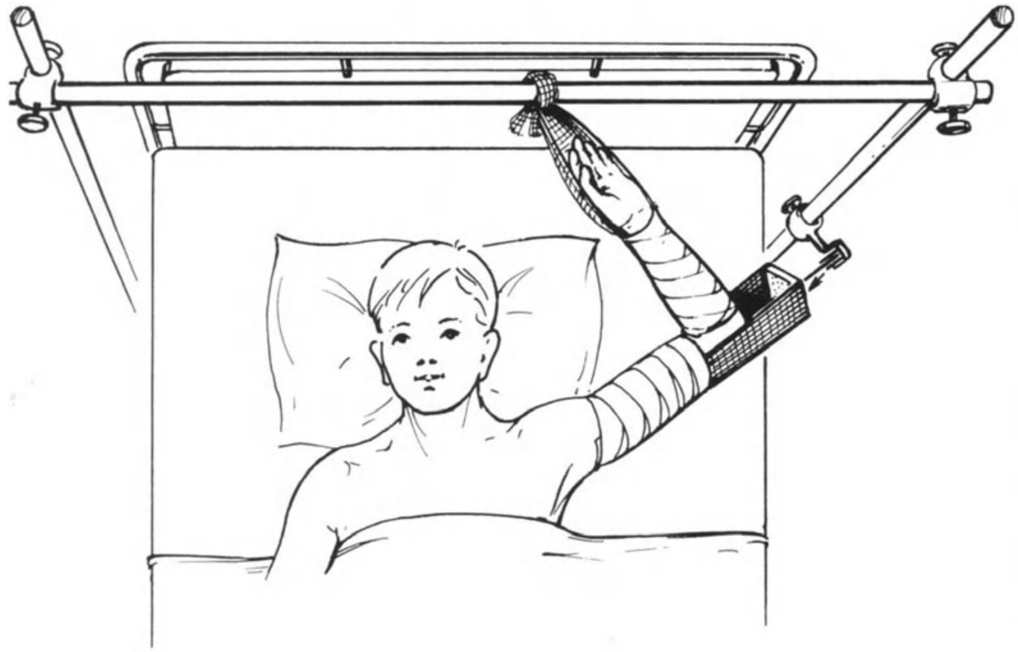


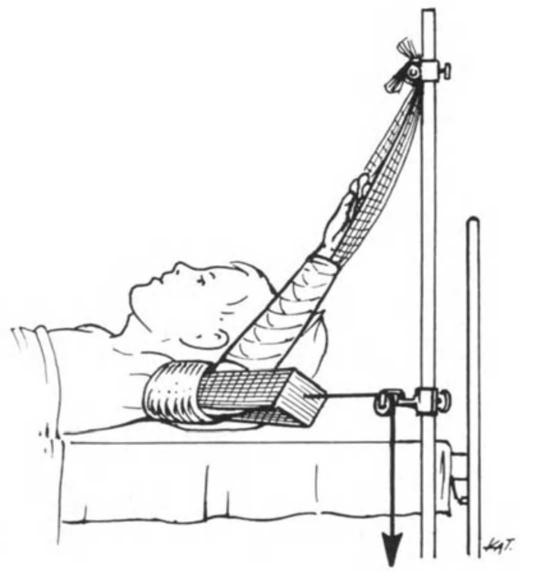
d e

Fig. 11a–e. *Positioning of the arm in the saluting position.* a, b) Immobilization of an unstable fracture dislocation by placing the arm in the saluting position. The forearm is attached to the head of the bed with a cuff placed around the wrist.
c) St.D., ♂, aged 13 years, No. 201343. Typical fracture dislocation with a large medial metaphyseal wedge.
d) Immobilization in the saluting position.
e) 2 months later. Bone union has taken place with correct axial alignment of the fragments

tained for 2–3 weeks. Subsequently the arm is gradually brought into adduction over a period of 3–4 days and is then immobilized in a *Velpeau* bandage for 2 weeks.

Multifragmented fracture separations. Here there is an additional fracture of the tip of the distal fragment; it mainly occurs in younger children (Table 1) (Fig. 13). The fracture cannot be stabilized by abduction since the lateral support, which is necessary for the tension band effect, is missing. In order to prevent correction from resulting in excessive valgus, fractures of this type must be placed in traction in the saluting position. If this method fails to prevent valgus angulation, vertical traction is applied with the arm in neutral rotation (compare with the intact side). The subse-





a

b

Fig. 12a, b. *The saluting position with internal rotation of the distal fragment.*
a) Adhesive plaster traction is applied if immobilization in the saluting position with slight inward rotation of the distal humerus is required. The forearm and the hand are placed in a stockinet tube, and traction is applied with a wooden plate and a cord which passes over a pulley.
b) S.A., ♀, aged 14 years, No. 80162. Olecranon screw traction has proved better in older children

quent treatment is the same as that of fracture separations in traction.

Operative Treatment

Surgery is not often necessary, but may be indicated in the following situations:

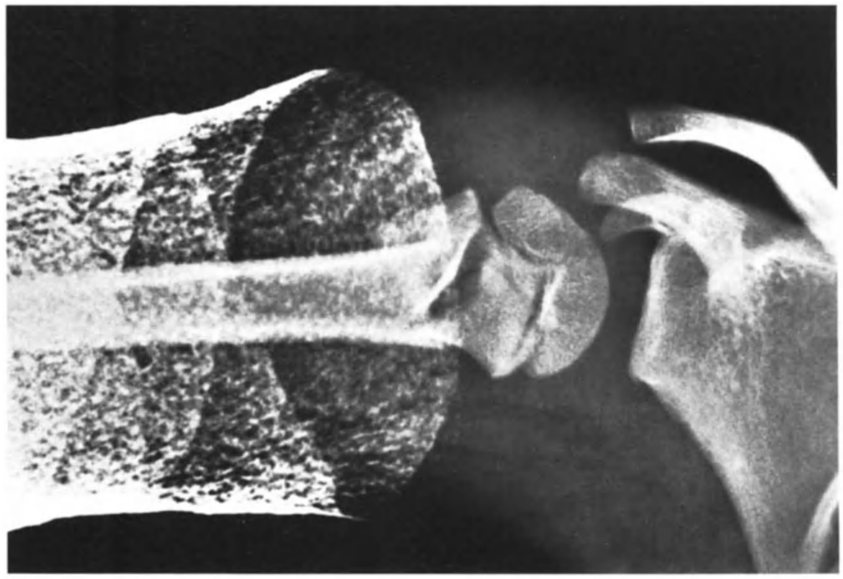
1. Fractures which cannot be reduced. As in one of our cases, the reason may be interposition of the biceps tendon. This has been repeatedly described in the literature (*Neer* and *Horwitz*, *Salter* and *Harris, Smith, Stewart*, and *Hundley*). More frequently, however, reduction may be prevented by inward folding of the periosteum, which acts as a buttonhole (*Neer* and *Horwitz*).

2. Old, malunited fractures which can no longer be reduced.

3. Following puberty. Excessive deformity which cannot be corrected by nonoperative techniques, i.e., more than 10° angulation (*Blount*), requires surgical treatment. The shorter the time until final closure of the epiphysis and the greater the deformity, the stronger is the indication for operative treatment.

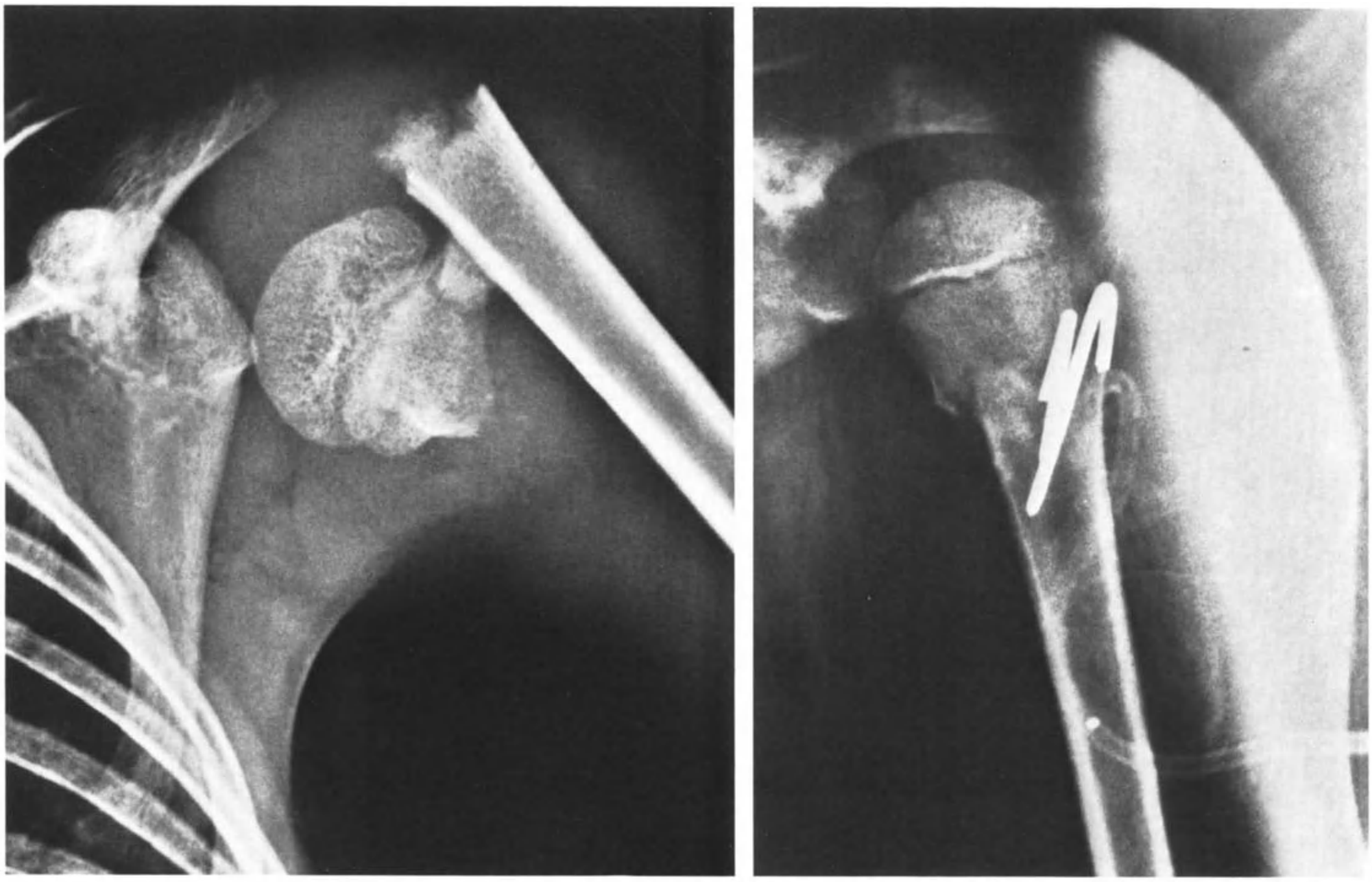
4. Open fractures. Here the fracture is anyway exposed in the course of exploration and decontamination of the wound (*Weber*).


a


b


c

Fig. 13a–c. *Fracture separation with several fragments*. S.W., ♂, aged 5 years, No. 68376.
a) In addition to the metaphyseal wedge which is attached to the proximal fragment, there is a comminuted fracture on the lateral side.
b) Vertical traction with correct alignment of the fragments.
c) 9 years after the accident. Uneventful healing has taken place with correct axial alignment. A slight increase in length of the humerus is discernable



a b

c

Fig. 14a–c. *Kirschner wire fixation*. Z.E., ♂, aged 7 years, No. 172426.

Road traffic accident with multiple injuries including comminuted fracture separation and dislocation of the head of the humerus.

a) Severe dislocation of the fragments.

b) Open reduction has been carried out and the fracture has been stabilized with two *Kirschner* wires whose ends are buried under the skin.

c) 2 years after the accident. The fracture has healed with correct axial alignment

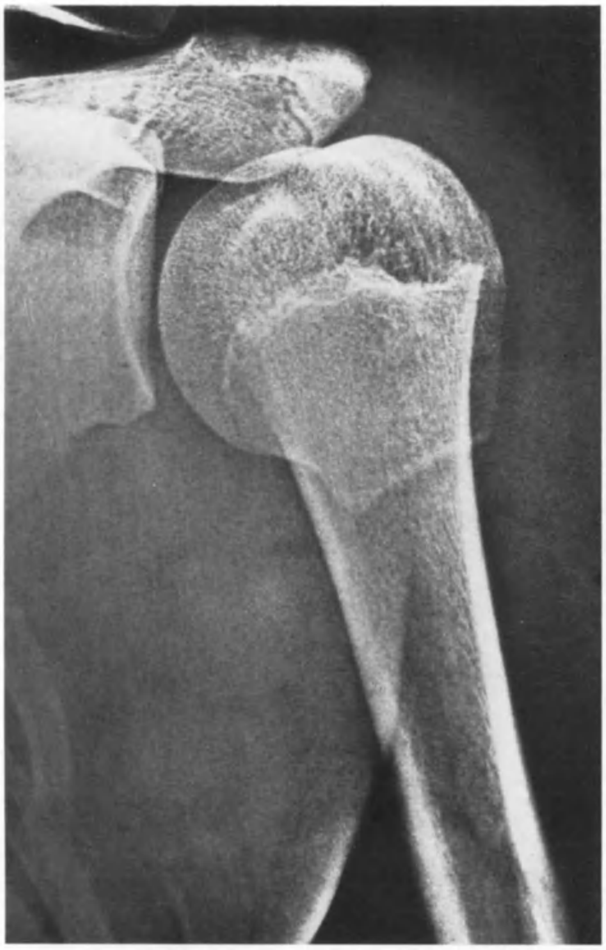
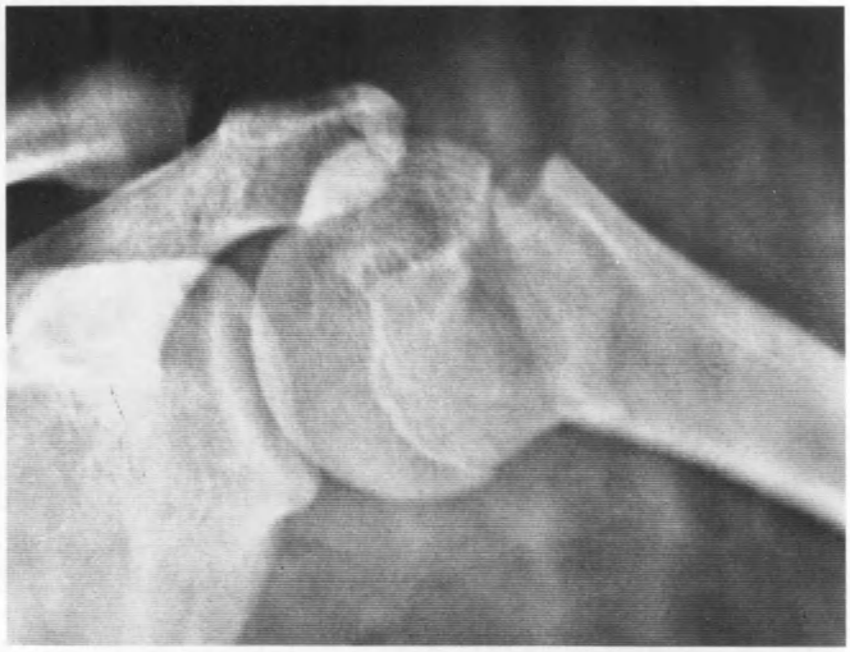
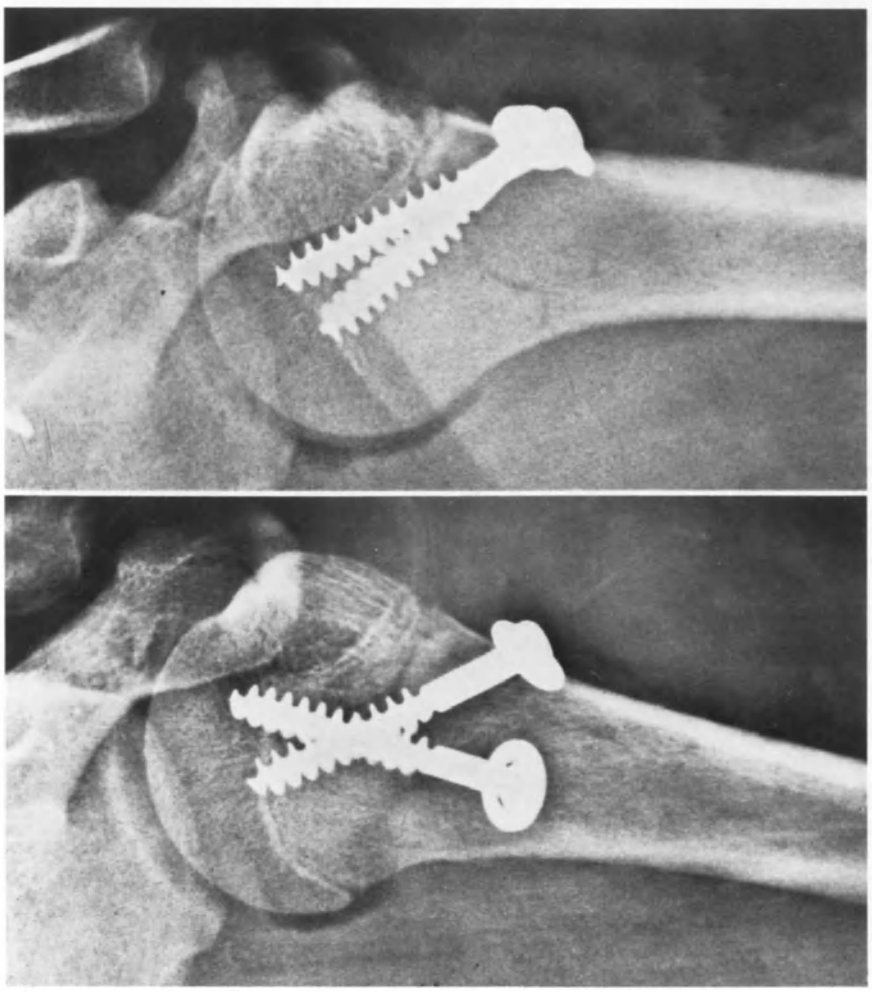

a

Fig. 15a–d. *Screw fixation*. Technique of internal fixation after puberty. E.B., ♂, aged 16 years, No. 116575.
a) Fracture separation shortly before cessation of growth.
b) Closed reduction unsatisfactory because of interposition of soft tissues.
c) Roentgenogram taken during the operation. The tips of the screws have been driven into the epiphysis. This is of no consequence, since the patient has almost ceased to grow.
d) Follow-up $2^1/_2$ years after the accident. Uneventful healing has taken place


b


c


d

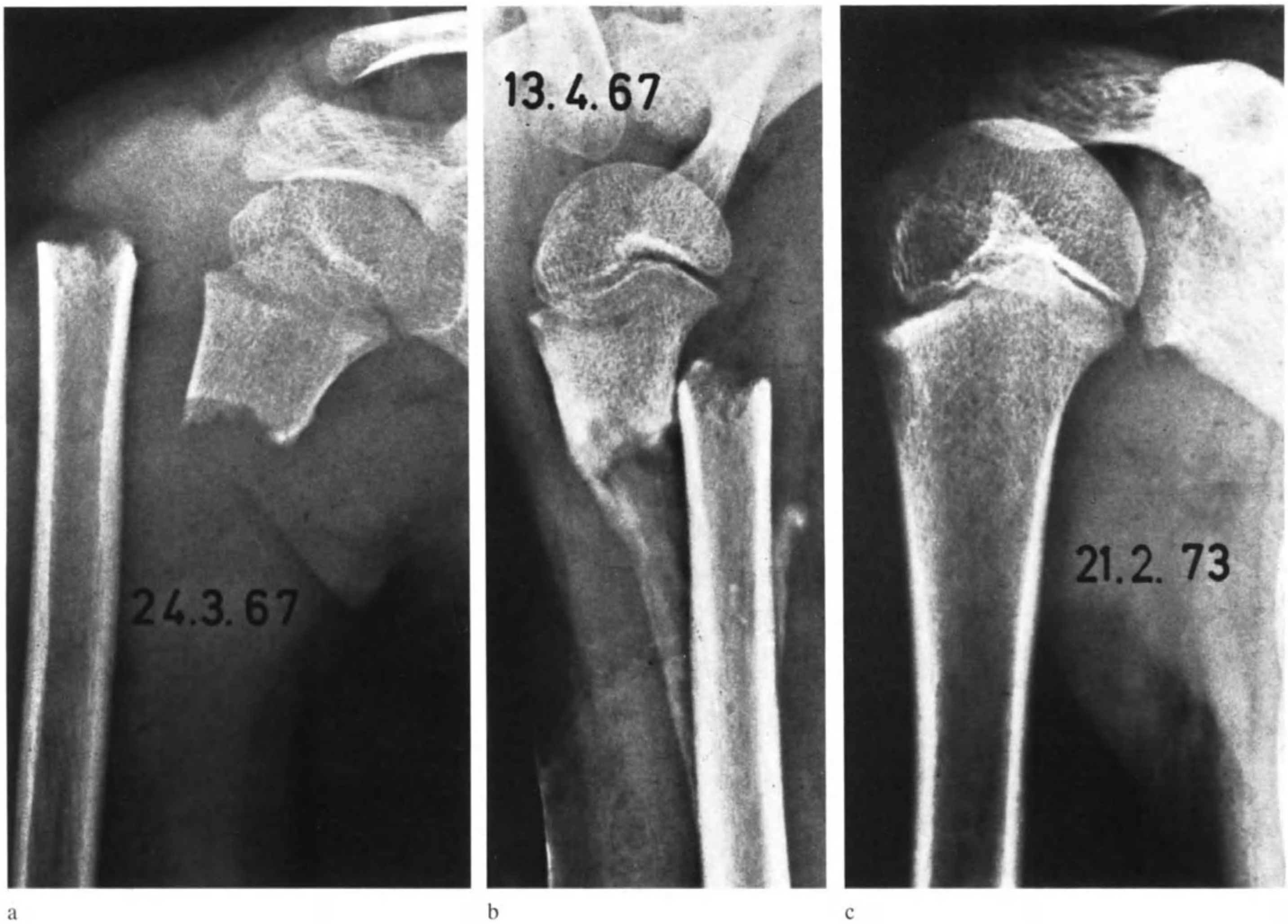


Fig. 16a–c. *Infratubercular fracture of the humerus*. K.S., ♀, aged 5 years, No. 111984.
a) Infratubercular fracture of the humerus with severe dislocation by twice the width of the shaft and with severe shortening.
b) Vertical traction has resulted in bone union, but lateral displacement by the width of the shaft has occurred.
c) Follow-up 6 years after the accident. Complete recovery with no residual signs of dislocation

Internal fixation technique. Surgical exposure: our experience with the anterolateral approach via the deltopectoral sulcus has been very satisfactory.

Prior to puberty: The fracture is fixed with two buried *Kirschner* wires whose ends are bent round (Fig. 14).

Postoperative treatment includes immobilization with a *Velpeau* bandage for 4 weeks. The *Kirschner* wires are removed through stab incisions after 8 weeks.

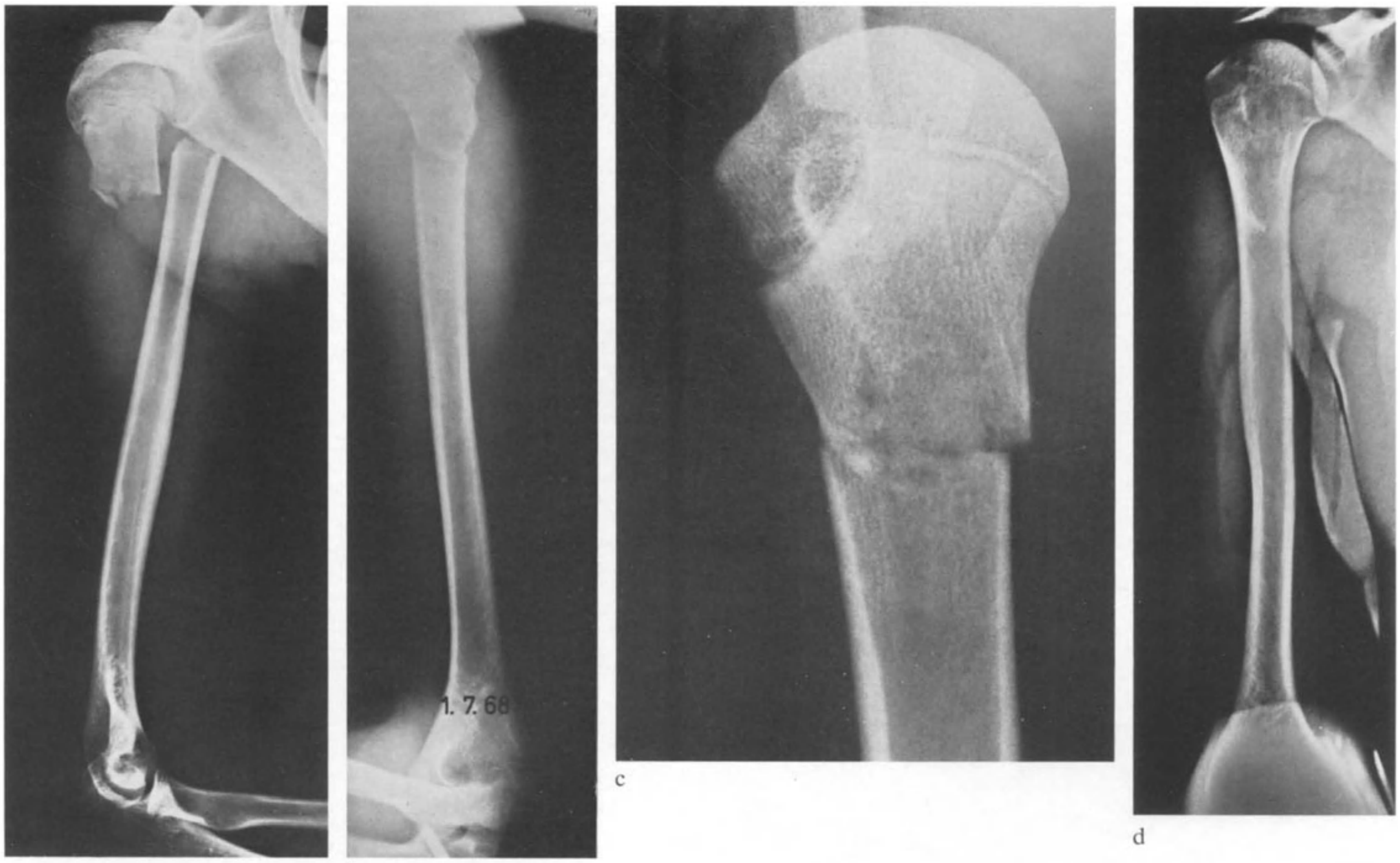
After puberty: Screws are used for fixation (Fig. 15). As long as the bone is growing, screws should not cross the epiphyseal plate, but should be restricted to fixation of the metaphyseal wedge. Only if closure of the epiphysis is due shortly can a screw be inserted into the head of the humerus; the wedge should always be fixed with a second screw. Two screws which are correctly inserted stabilize the fracture adequately.

Postoperative treatment includes a *Velpeau* bandage for 4 days. As soon as the fracture is stable, postoperative mobilization may be begun without difficulty. The screws are removed after 3 months.

2.3 Infratubercular Fractures of the Humerus

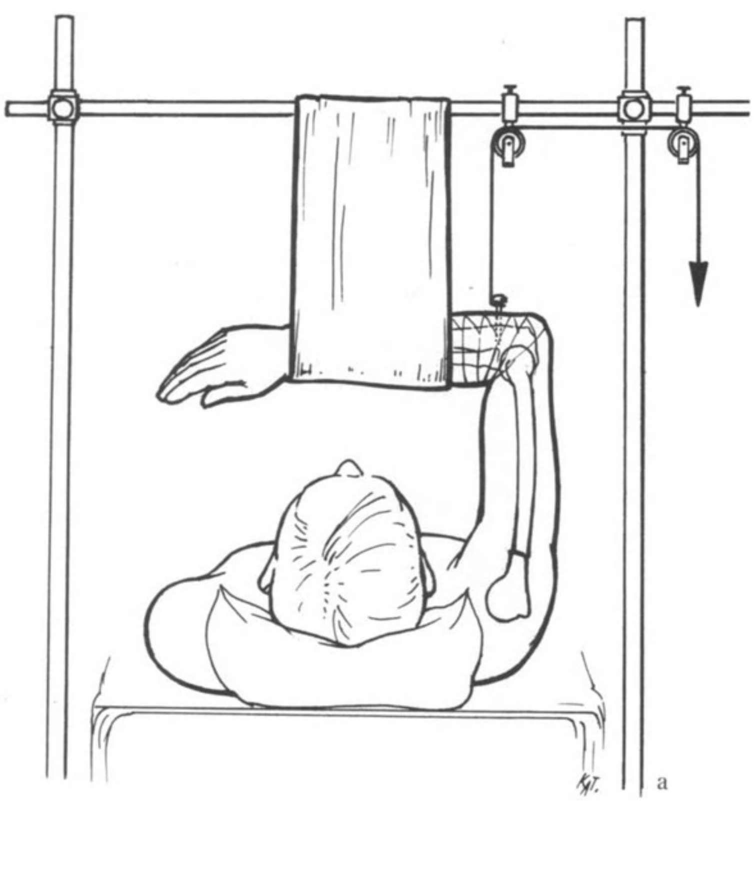
2.3.1 Pathological Anatomy

The fracture line lies distal to the epiphyseal plate and frequently crosses the surgical neck of the humerus transversely; frequently, there is shortening and displacement of the fragments by the full width of the shaft (Fig. 16). A *long proximal fragment* (Fig. 17) includes the insertions of pectoralis major, teres major, and latissimus dorsi; these cause adduction, flexion, and internal rotation.

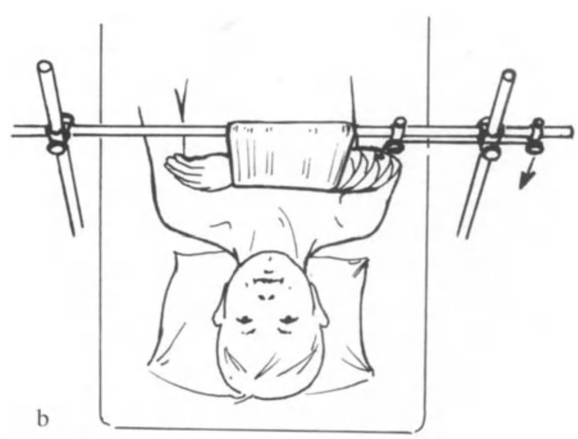


a b c d

Fig. 17a–d. *Infratubercular fracture with a long proximal fragment*. W.E., ♀, aged 13 years, No. 123360.
a) Long proximal fragment with severe dislocation of the distal fragment.
b) Reduction by vertical traction with an olecranon screw and positioning of the arm with the distal fragment in maximum inward rotation.
c) Roentgenogram to check reduction 3 days after the accident.
d) 5 years after the accident. Uneventful healing has taken place



a



b

Fig. 18a, b. *Vertical traction with a long proximal fragment*.
a) Vertical traction with an olecranon screw.
b) The distal humerus is in maximum physiological internal rotation. The thumb is pointing to the thorax at the level of the sternum

Because of this dislocation, in the a–p views the proximal fragment appears to be much shorter than it is. Its true length only becomes apparent in the transthoracic views or following reduction. Thus, in treating fractures of this type, the arm must be brought into and maintained in internal rotation.

A *short proximal fragment* does not go into internal rotation, since it does not include the insertions of the muscles mentioned previously. The arm is thus brought into and maintained in the neutral rotation position.

In addition to transverse infratubercular fractures, one occasionally sees short spiral or oblique fractures and, in children up to approximately 5 years of age, circumferential buckling and greenstick fractures.

In our series of cases, the infratubercular fractures were not restricted to any particular age group; they occurred at any age up to 16 years (Table 1).

2.3.2 Treatment

Nonoperative treatment

Greenstick fractures and circumferential buckling:

Immobilization: *Velpeau* bandage.

Duration of fixation: 2 weeks.

Dislocated fractures: Dislocated infratubercular fractures of the humerus are always treated as follows:

Reduction
(varies according to
the position of the
proximal fragment)

Vertical traction

Note: because of the danger of injury to the vessels and nerves which lie medial to the humerus, valgus angulation of the fracture should be avoided.

Dislocated fractures with a long proximal fragment: Reduction is carried out under general anesthesia by longitudinal traction on the flexed elbow and simultaneous flexion and inward rotation. At the same time, the proximal fragment can be helped into abduction by a hand placed under the axilla. The position is checked with the image intensifier.

Immobilization requires vertical traction with adhesive plaster or, better, with an olecranon screw. The arm is held in the end position of normal internal rotation (compare with the intact side) (Fig. 18).

Duration of traction: 1–3 weeks, depending on the age of the child. The shoulder is then fixed with a *Velpeau* bandage for 1–2 weeks.

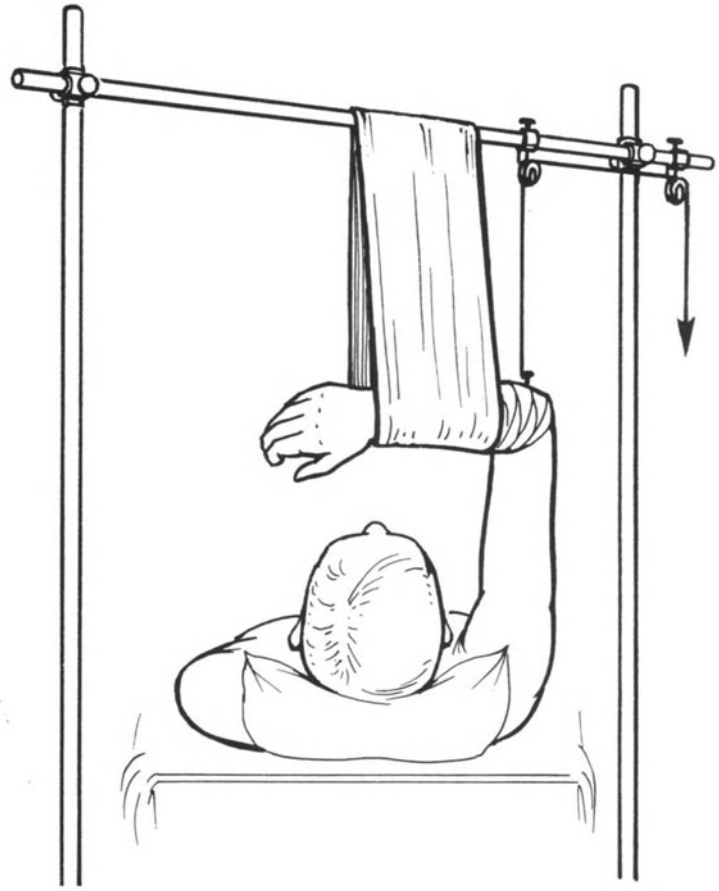
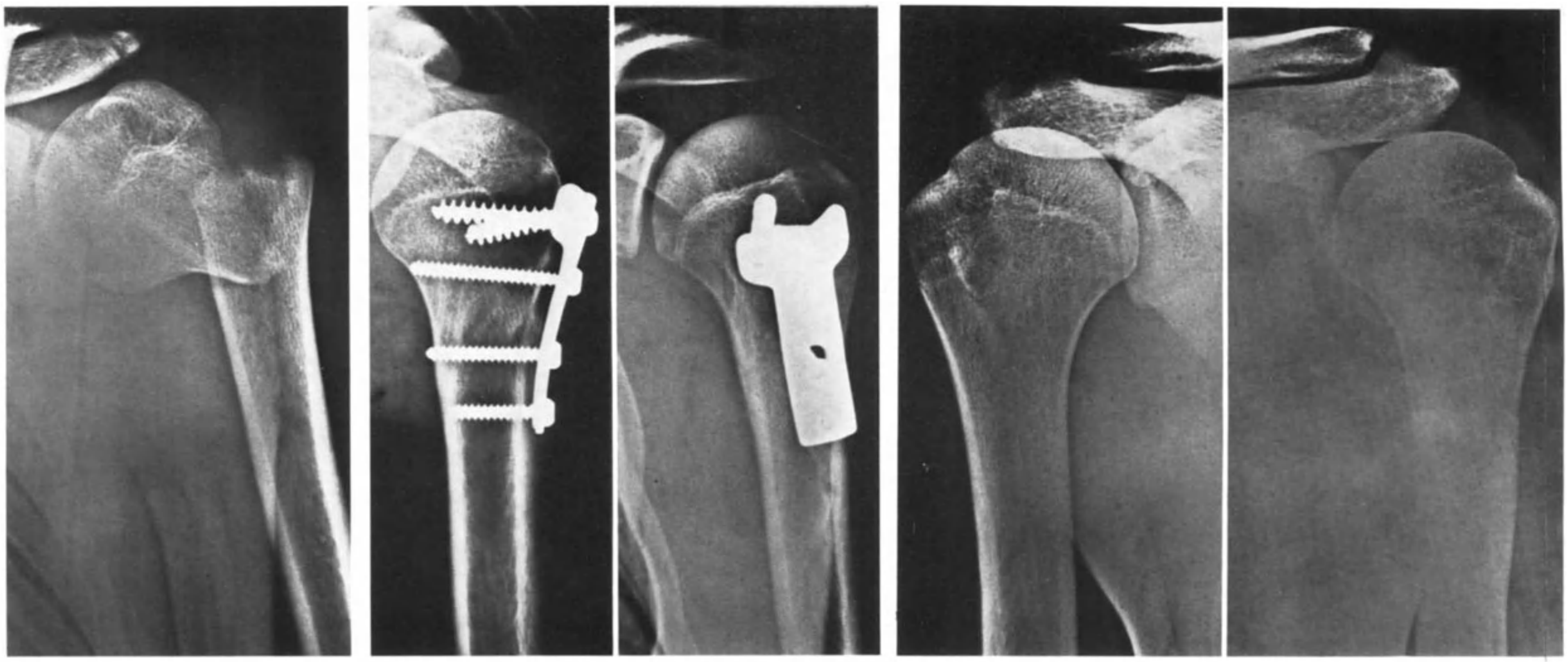


Fig. 19. *Vertical traction with a short proximal fragment.* The distal humerus is in the neutral rotation position, i.e., the thumb is pointing at the nose of the patient

Dislocated fractures with a short proximal fragment: Reduction is carried out under general anesthesia. Since the proximal fragment is not in excessive internal rotation, the manipulation required for reduction is the same as that used to reduce an epiphyseal separation. Longitudinal traction is applied to the elbow, which is flexed at a right angle, and at the same time the arm is brought into slight abduction, flexion, and external rotation. The position is checked with the image intensifier.

Immobilization is by vertical traction with adhesive plaster or, better, with an olecranon screw. In contrast to the previous type of fracture, the arm is suspended in neutral rotation (Fig. 19) (compare with the intact side).

Duration of traction: 1–3 weeks, depending on the age of the child. The shoulder is then fixed with a *Velpeau* bandage for 1–2 weeks. The hanging cast has hardly been used in our clinic. It is uncomfortable and places great demands on the child. In order that the hanging cast be effective, the child must sleep in a sitting position during the initial period of treatment (*Blount*) and it is not allowed to prop up or hold the arm. For these reasons, *Stewart* and *Hundley* also advise against the use of the hanging cast for



a b c

Fig. 20a–c. *Internal plate fixation of an irreducible infratubercular fracture of the humerus in an adolescent.* S.R., ♂, aged 16 years, No. 120142.
a) Closed reduction is impossible.
b) Anatomically precise open reduction followed by fixation with a small T-plate which is placed distal to the epiphyseal plate.
c) 2 years after the accident. The shoulders appear symmetrical and complete recovery has taken place

the treatment of fracture in children under 12 years of age.

Operative treatment
Surgery is seldom indicated, even for infratubercular fractures of the humerus. The indications are the same as those for fracture separations.

1. Fractures which cannot be reduced.
2. Old, malunited fractures which can no longer be reduced.
3. Excessive deformity in adolescents.
4. Open fractures. Here internal fixation is carried out to promote soft tissue healing.

Fixation of an infratubercular fracture in a lightly built adolescent is carried out with a semitubular plate; in the more powerfully built patient, the ASIF dynamic compression plate (DCP) is used. The plate is best placed on the ridge which runs down from the greater tubercle. If, for anatomic reasons in a growing adolescent, a screw has exceptionally to be inserted above the epiphyseal plate, it should never compress the latter. Furthermore, the plate should be removed immediately following healing of the fracture (Fig. 20).

Postoperative treatment: *Velpeau* bandage for 4 days, followed by active mobilization. The implant is removed after 3–6 months.

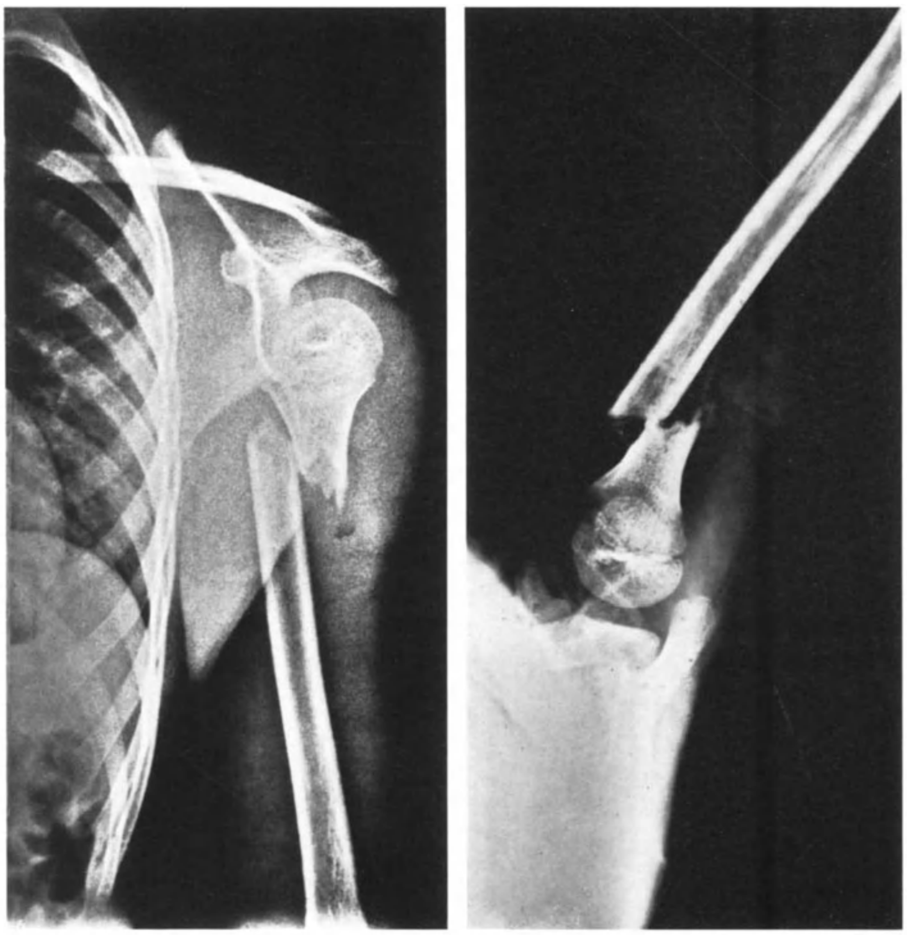
3 Prognosis

3.1 Fracture Healing

The fracture healing itself offers no problems, and pseudarthroses and necroses of the humeral head are almost unknown. Since *Aitken* Type II and III fractures of the epiphysis (*Salter* III and IV) hardly ever occur at the upper end of the humerus, there is no reason to expect progressive angulation due to growth disturbances in the epiphysis.

3.2 Primary Malunion

The younger the child, the better is the spontaneous correction of primary malunion. This is brought about by longitudinal growth (which, in the humerus, largely takes place at the proximal epiphyseal plate) and by the activity of the periosteum, which deposits bone on the concave side and resorbs it from the convex side (Fig. 21). This capacity for correction is dependent not only on the age of the child, but also on the degree of malunion. Severe angulation is not completely corrected. Thus, the sequelae of epiphyseal separations which are not reduced include very severe varus of the humerus (*Blount, Ehalt, Weil*). Further-




a b c

Fig. 21 a–c. *Spontaneous correction of a severe degree of dislocation following infratubercular fracture of the proximal humerus.* H.F., ♂, aged 6 years, No. 73665.
a) Roentgenogram taken immediately following the accident.
b) Treatment by vertical traction. The fracture has healed with correct axial alignment of the fragments and lateral displacement by almost the full width of the shaft.
c) Follow-up 8 years after the accident. Uneventful healing of the humerus fracture has taken place and the deformity has been spontaneously corrected by the circumferential growth of the bone

more, the residual varus and antecurvature deformities which result from incorrectly reduced fractures are well known; they usually affect function by limiting abduction. These residual deformities are not very serious, but they remain for the rest of the patient's life (*Judet*). In connection with the spontaneous correction of angular deformity, there has been prolonged discussion as to the degrees of residual deformity which are permissible following reduction of a fracture. *Blount* has published guidelines on this subject, i.e.,

Up to the age of 7 years, infratubercular fractures may be left with bayonet apposition, shortening of 1 cm, and angulation of 10°–20°.
From the 12th year of age onwards, fracture separations should have at least 50% bone contact and less than 10° angulation.
Bayonet apposition is permitted up to the 10th year of age.

In practice, radiographic assessment of the position of a fracture is frequently difficult, since with the fracture in traction or a *Velpeau* bandage, it is not always possible to obtain films in two axes which are exactly at right angles to each other, e.g., a–p and axial, or transthoracic. The deformity may be greater than it appears to be on the roentgenogram, and reduction which is thought to be satisfactory may be followed by a surprisingly disappointing result.

We have basically tried to reduce fractures as precisely as possible and have only relied on spontaneous correction in exceptional cases. It is probably for this reason that the residual deformities seen by us were largely insignificant (see Results).

4 Results

4.1 Number of Fractures Treated. Accompanying Injuries. Methods of Treatment

From 1961 to 1969, 53 fractures of the proximal humerus were treated in the Cantonal Hospital at St. Gall; 47 were treated nonoperatively and 6 operatively. We were able to follow-up 38 of these fractures. The fracture was open in two cases, and in one case, transient paresis of the median nerve resulted from an infratubercular fracture. The frequency of the different types of fracture and the age distribution are summarized in Table 1. Of the 38 patients whose fractures could be followed-up, 32 had been treated nonoperatively and 6 had been treated operatively (Table 2). The methods of treatment are shown in Tables 2 and 3.

Table 2. Methods of nonoperative treatment

Nonoperative treatment (32 cases)	
Reduction under general anesthesia	19
Velpeau bandage	16
Olecranon traction with screw	8
Olecranon traction with *Kirschner* wire before introduction of screw traction)	1
Traction with adhesive plaster	4
Shoulder spica (transferred from another hospital)	1
Hanging cast	2

Table 3. Methods of operative treatment

Operative treatment (6 cases)	
Kirschner wire fixation	1
Screw fixation of a fracture separation	2
Plate fixation of an infratubercular fracture	3
Complications	None

4.2 Results of Nonoperative Treatment

In five cases, the *range of movement* was restricted by up to 10°, particularly external rotation. In the remaining cases, shoulder joint movement was symmetrical.

Differences in length were found in 15 cases, but were not noticed by the patients themselves. In nine cases, there was lengthening and in six cases shortening of up to 15 mm.

Angular deformity: in 15 cases, slight S-shaped curvature of the humerus, varus angulation, and antecurvature were found (Fig. 22). As a result of longitudinal growth, apposition, and resorption, the angulation which was originally located at the site of the fracture is displaced towards the middle of the humerus. Severe degrees of varus angulation may simulate varus deformity of the elbow (Fig. 23). In two cases, valgus deformities of 5° and 10° were found.

Slight *symptoms* in the shoulder during sport were reported by only three patients. One woman patient complained of constant pain in the deltoid muscle, which resulted from scarring following a severely dislocated infratubercular fracture.

4.3 Results of Operative Treatment

The *range of motion* was symmetrical in five cases. In only one case internal rotation was increased by 20° owing to incorrect reduction.

Differences in length and *angular deformities* were present in none of the cases. One patient experienced *symptoms* when carrying loads.

5 Summary

Fractures of the proximal humerus are relatively rare in children. They are caused by falls or a blow on the shoulder. Intraarticular fractures or fractures

Fig. 22a–c. *Residual antecurvature.* K.N., aged 12 years, No. 101429.
a) Fracture.
b) Roentgenogram following reduction and initial union. The a–p film shows correct alignment, but the transthoracic film shows marked antecurvature just below the head of the humerus.
c) $3^1/_2$ years after the accident. The ranges of movement of the two shoulders are identical, but the roentgenogram shows marked antecurvature of the proximal third of the diaphysis

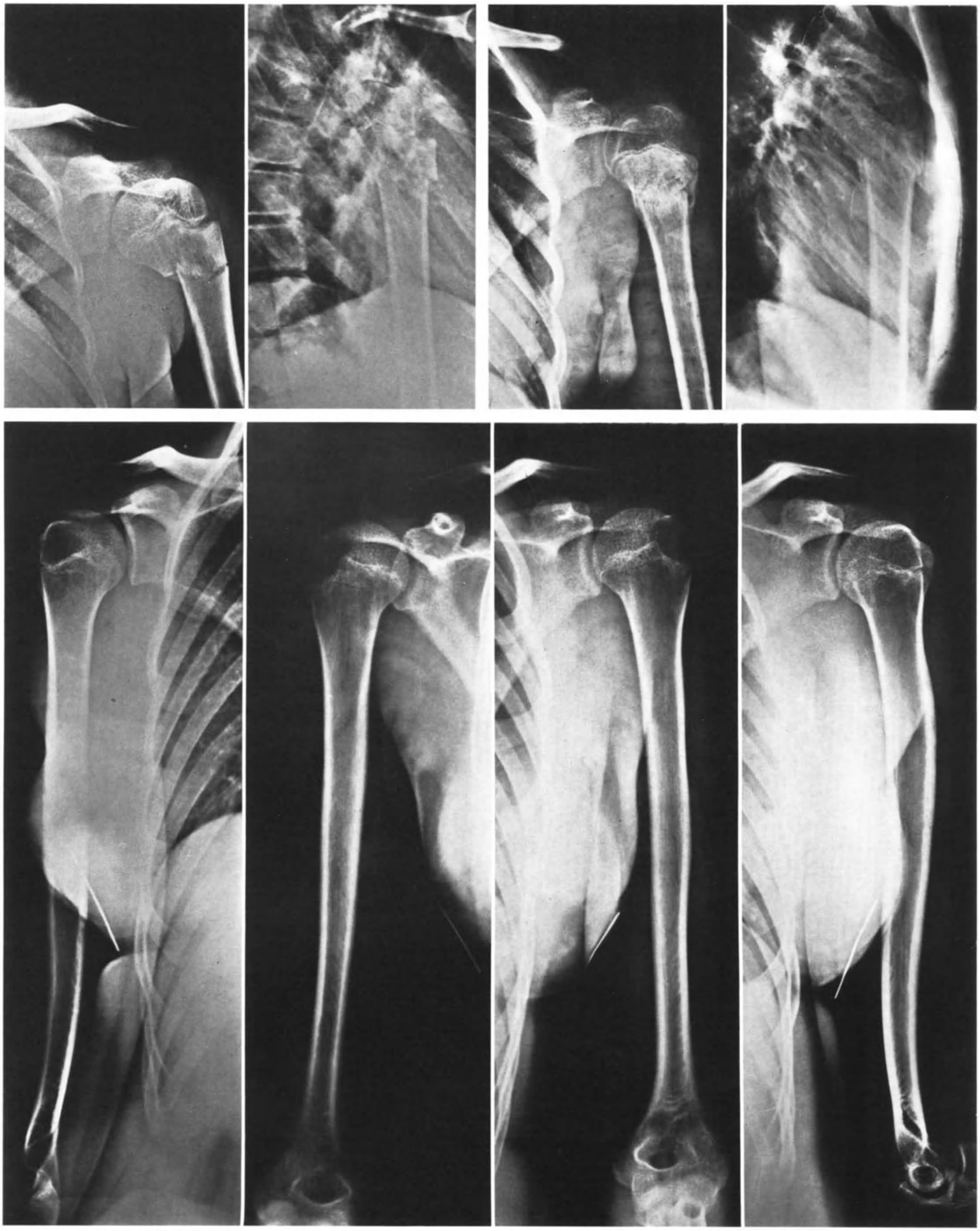


Fig. 22

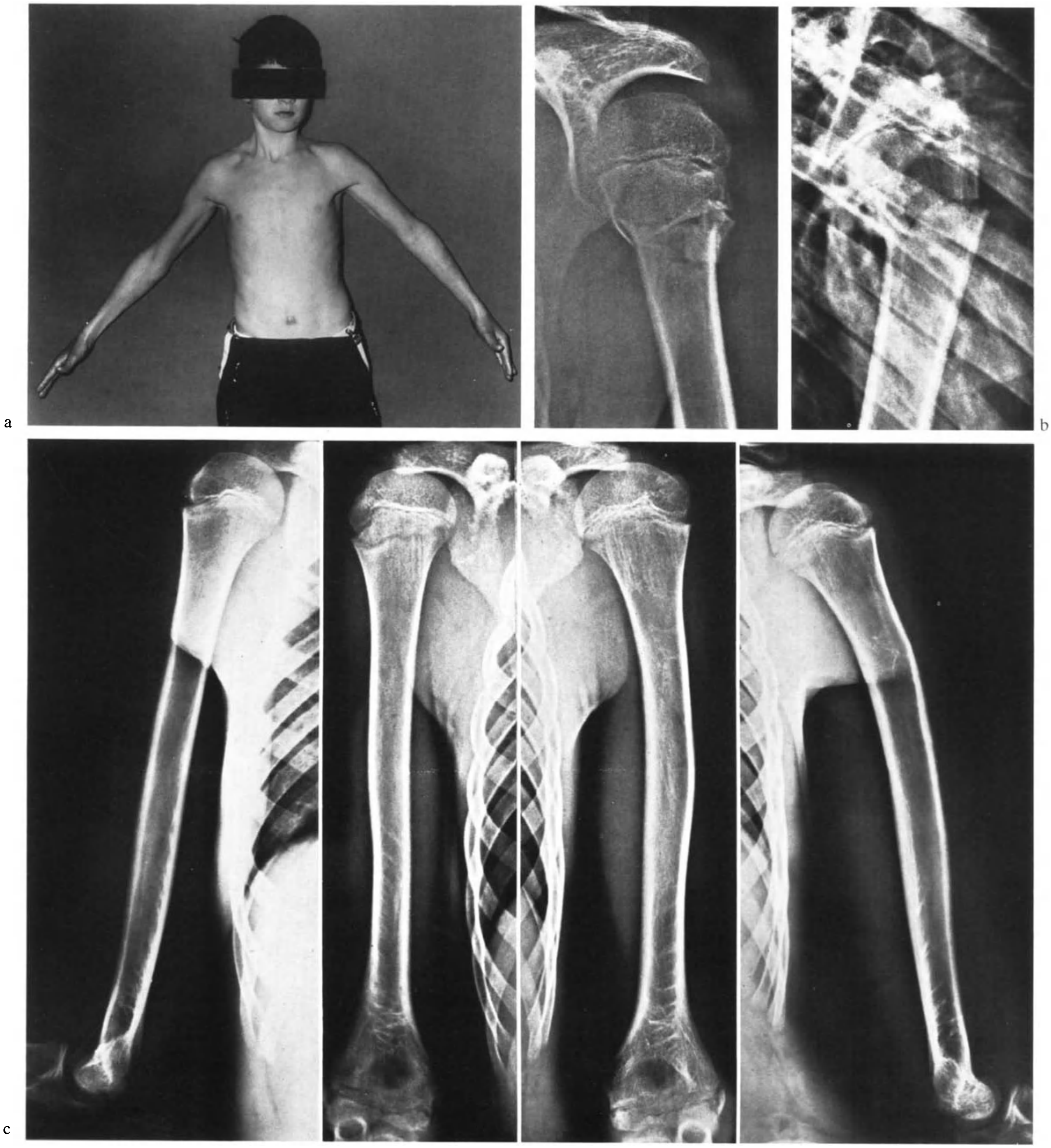


Fig. 23a–c. *Residual varus deformity*. H.W., ♂, aged 16 years. No. 108162.
a) Varus deformity of the elbow and shortening of the humerus on the left side following fracture of the humerus at the age of 12 years. The varus deformity of the elbow is virtual; in fact, the angulation is in the shaft of the humerus.
b) Infratubercular fracture of the proximal humerus at the age of 12 years with varus deformity.
c) 4 years after the accident. The varus deformity has moved distally along the humerus shaft and now simulates varus deformity of the elbow joint

which transect the growth cartilage do not occur. The fractures are classified morphologically as pure separations of the epiphysis, *Aitken* Type I fracture separations, and infratubercular fractures. The pathological anatomy and potential methods of treatment of each type of fracture are discussed.

Fracture healing is uneventful and fractures of the proximal humerus can generally be treated conservatively following closed reduction. Operative treatment is seldom indicated and is restricted to the following situations:

1. Excessive deformity in adolescents.
2. Fractures which cannot be reduced.
3. Old, malunited fractures which can no longer be reduced.
4. Open fractures.

Thirty-eight patients were followed-up, and the results of treatment of their fractures are described in terms of range of movement, difference in length, angular deformity, and subjective complaints.

6 References

Aitken, A. P.: Fractures of the Proximal Humeral Epiphysis. Surg. Chlin. N. Amer. **32**, 1573 (1963).

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Dameron, T. B., Reibel, D. B.: Fractures Involving the Proximal Humeral Epiphyseal Plate. J. Bone Jt Surg. **51 A**, 289 (1969).

Daubenspeck, K.: Geburtsverletzungen im Bereich des Schultergelenkes. In: Handbuch der Orthopädie (Hrsg. G. Hohmann, M. Hackenbroch, K. Lindemann), Bd. III, S. 293. Stuttgart: Thieme 1959.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Judet, J., Judet, R.: Fractures du col chirurgical de l'humerus. Acta orth. belg. **30**, 243 (1964).

Matzner, R.: Die Behandlung der Frakturen des Neugeborenen, des Säuglings und des Kleinkindes. Arch. orth. Unfall-Chir. **47**, 320 (1955).

Neer, C. S., Horwitz, B. S.: Fractures of the Proximal Humeral Epiphyseal Plate. Clin. Orthop. **41**, 24 (1965).

Renné, J., Weller, S.: Verrenkungen und Frakturen der oberen Gliedmaßen. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer 1974.

Riess, J.: In: Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Salter, R. B., Harris, R.: Injuries Involving the Epiphyseal Plate. J. Bone Jt Surg. **45 A**, 587 (1963).

Smith, F. M.: Fracture-Separation of the Proximal Humeral Epiphysis. A Study of cases seen at the Presbyterian Hospital from 1929-1953. Amer. J. Surg. **91**, 627 (1956).

Steward, M. J., Hundley, J. M.: Fractures of the Humerus. A Comparative Study in Methods of Treatment. J. Bone Jt Surg. **37 A**, 681 (1951).

Tondeur, G.: Les fractures récentes de l'épaule. Acta orthop. belg. **30**, 5 (1964).

Weber, B. G.: Indikationen zur operativen Frakturbehandlung bei Kindern. Chirurg **10**, 441-444 (1967).

Weil, S.: Der Humerus-varus. In: Handbuch der Orthopädie (Hrsg. G. Hohmann, M. Hackenbroch, K. Lindemann), Bd. III, S. 10. Stuttgart: Thieme 1959.

Fractures of the Shaft of the Humerus

P. Mehmann

CONTENTS

1 Introduction

Fractures of the shaft of the humerus are less common in children than in adults. They constitute 2%–5% of all fractures in children. According to *Renné* and *Weller*, they are even restricted to 5% of fractures of the arm. The greater frequency in our series of cases is probably ascribable to the increased danger associated with sport and road traffic.

Fractures of the shaft of the humerus usually result from *direct* violence, such as a fall onto the upper arm. This type of accident usually causes a transverse or oblique fracture. *Indirect* violence, such as a fall onto the hand or elbow, or placing the hand in a rotating laundry spin-dryer, more often causes torsional fractures. In our series of cases, the main causes of injury were road traffic, sport, and spin-dryers. Battered children and birth injuries are very seldom seen in our clinic (Fig. 1).

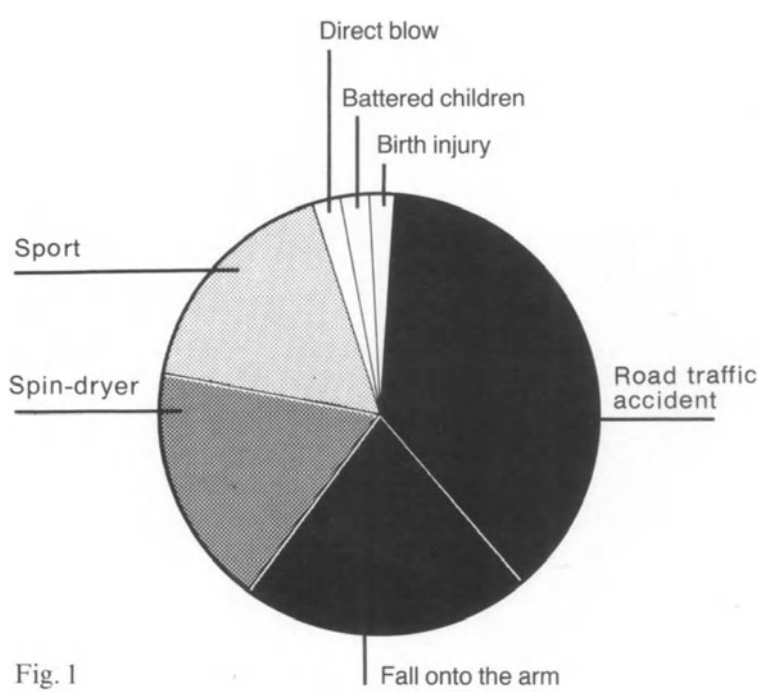


Fig. 1

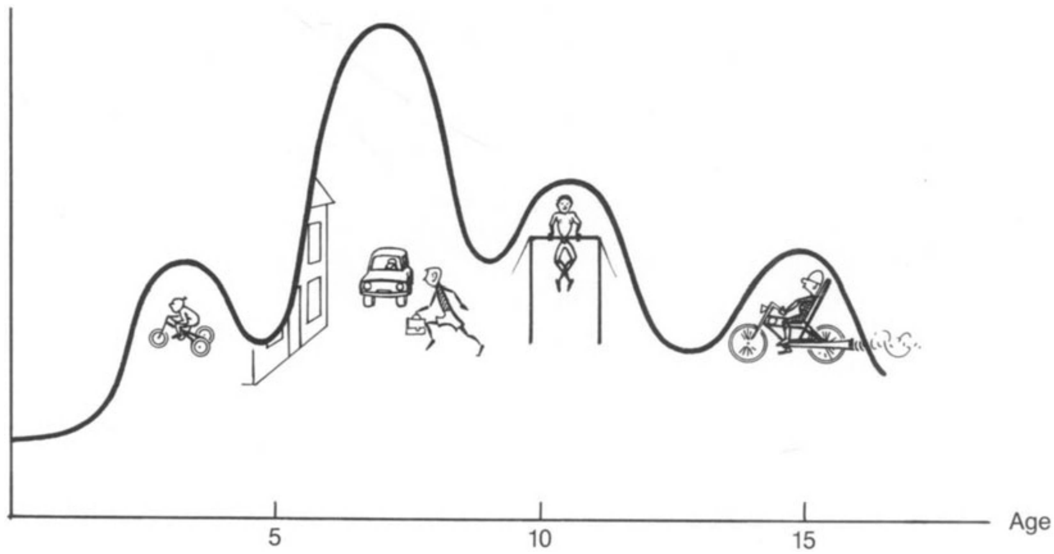


Fig. 2

According to *Pollen*, fractures of the humerus can occur at any age. The age distribution of our cases shows peaks at the toddler age, on starting school, around the age of 10 years, and on leaving school. These four increases in frequency correspond to the initial confrontation with road traffic, the child's first journeys to school and their associated dangers, commencement of sport at school, and increased participation in road traffic on leaving school (Fig. 2).

The humerus is more often broken on the left side than on the right, in a frequency ratio of 3:2. Open fractures of the shaft of the humerus are rare, as are injuries to vessels and nerves.

2 Types of Fracture and Treatment

We classify the fractures as transverse, short oblique, spiral, and comminuted. The basic pathological anatomy is the same in all types of fracture. The direction of the dislocation depends less on the degree of violence than on the level of the fracture. If the fracture is located in the distal or middle third of the humerus below the insertion of the deltoid muscle, the proximal fragment is pulled forwards and laterally by the deltoid, supraspinatus, and coracobrachialis muscles. At the same time, the distal fragment is pulled proximally by the biceps and brachialis muscles. On the other hand, if the fracture is situated in the proximal or middle third, above the insertion of the deltoid muscle, but below that of pectoralis major, the distal fragment is dislocated laterally and upwards by the deltoid, and the proximal fragment is brought into adduction and internal rotation by the pectoralis, latissimus dorsi, and teres major muscles (*Tachdjian*).

Fractures of the shaft of the humerus in children are generally treated nonoperatively. Operative stabilization is very seldom indicated, being restricted to cases of extremely severe soft tissue injury or lesions of vessels or nerves.

2.1 Transverse Fractures

Transverse fractures mainly result from falls onto the adducted arm. Depending on the degree of violence and on the age of the patient, a greenstick fracture or a dislocated transverse fracture may occur.

2.1.1 Greenstick Fractures

2.1.1.1 Pathological Anatomy

These fractures are extremely rare and are usually caused by relatively slight direct violence in a young child. The cortex is fractured on the convex side of the angulation and the periosteum is torn. In the shaft of the humerus, the angulation is usually on the lateral side. On the opposite side, the periosteum is intact and the underlying cortex is only slightly bent (Fig. 3). Very rarely one sees circumferential buckling of the shaft in the vicinity of the metaphysis, which is caused by indirect violence.

2.1.1.2 Treatment

Reduction: the greenstick fracture is completely broken under general anesthesia, since the angulation would otherwise recur as a result of the one-sided tension-band effect of the intact cortex and periosteum.

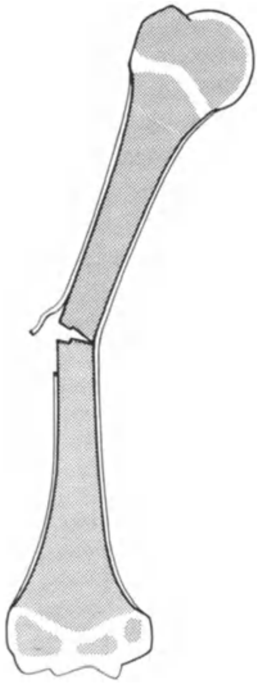


Fig. 3. *Greenstick fracture in the middle of the shaft*

Immobilization: depending on the age of the child, the upper arm is bound to the thorax with a bandage or is fixed with a *Velpeau* bandage. In older children, a plaster U-splint can be used with equal success (Fig. 4).

Duration of fixation: 3–6 weeks, depending on the age of the child.

2.1.2 Dislocated Transverse Fractures

2.1.2.1 Pathological Anatomy

Dislocated transverse fractures mainly result from direct trauma caused by a traffic accident or by a fall onto the adducted arm during sport. The periosteal cuff and the cortex are usually broken through completely, giving rise to the characteristic dislocation (Fig. 5). Open fractures with injury to nerves and vessels occurred in two cases in our series.

a b c

Fig. 4a–c. *Greenstick fracture in the middle of the shaft* F.M., ♀, aged 10 years, No. 172899.
a) Roentgenogram taken immediately following the accident.
b) Treatment: plaster U-splint for 4 weeks.
c) $3^1/_2$ years after the accident. The shoulders appear symmetrical and complete recovery has taken place

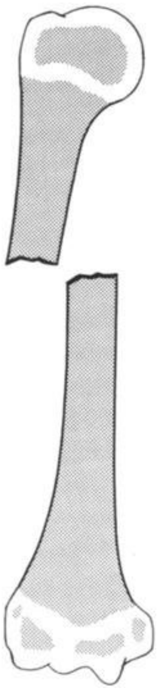


Fig. 5. *Dislocated transverse fracture of the shaft*

2.1.2.2 *Treatment*

Reduction: dislocated transverse fractures are reduced under general anesthesia. Anatomically precise reduction is unnecessary.

Immobilization: If the fracture remains stable following reduction, it is fixed with a plaster U-splint which is closely molded to the arm on the lateral side in order to prevent varus deformity.

If it is difficult to maintain reduction, or secondary dislocation occurs, traction is applied with an olecranon screw. A weight of 1–2 kg is used for 2–3 weeks. Great care should be taken to prevent distraction of the fracture. A correct rotation position of the fracture is assured only if the thumb points to the tip of the nose (Fig. 6). As soon as the fracture is more or less united and secondary dislocation is unlikely to occur, the upper arm is immobilized for a further 3 weeks with a plaster U-splint.

Duration of fixation: 3–6 weeks, depending on the age of the child.

a b c

d

Fig. 6a–d. *Dislocated transverse fracture of the shaft*. B.F., ♂, aged 12 years, No. 105660.
a) Roentgenogram taken immediately following the accident.
b) Treatment: Reduction under general anesthesia, followed by vertical traction with an olecranon screw.
c) 2 months after the accident. Bone union has taken place.
d) $3^{1}/_{2}$ years after the accident. Uneventful healing with no sequelae

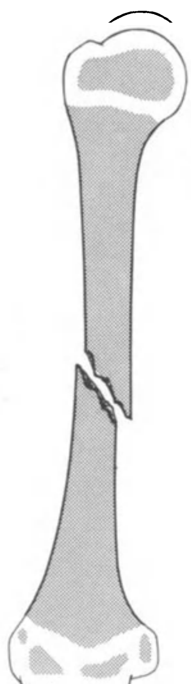
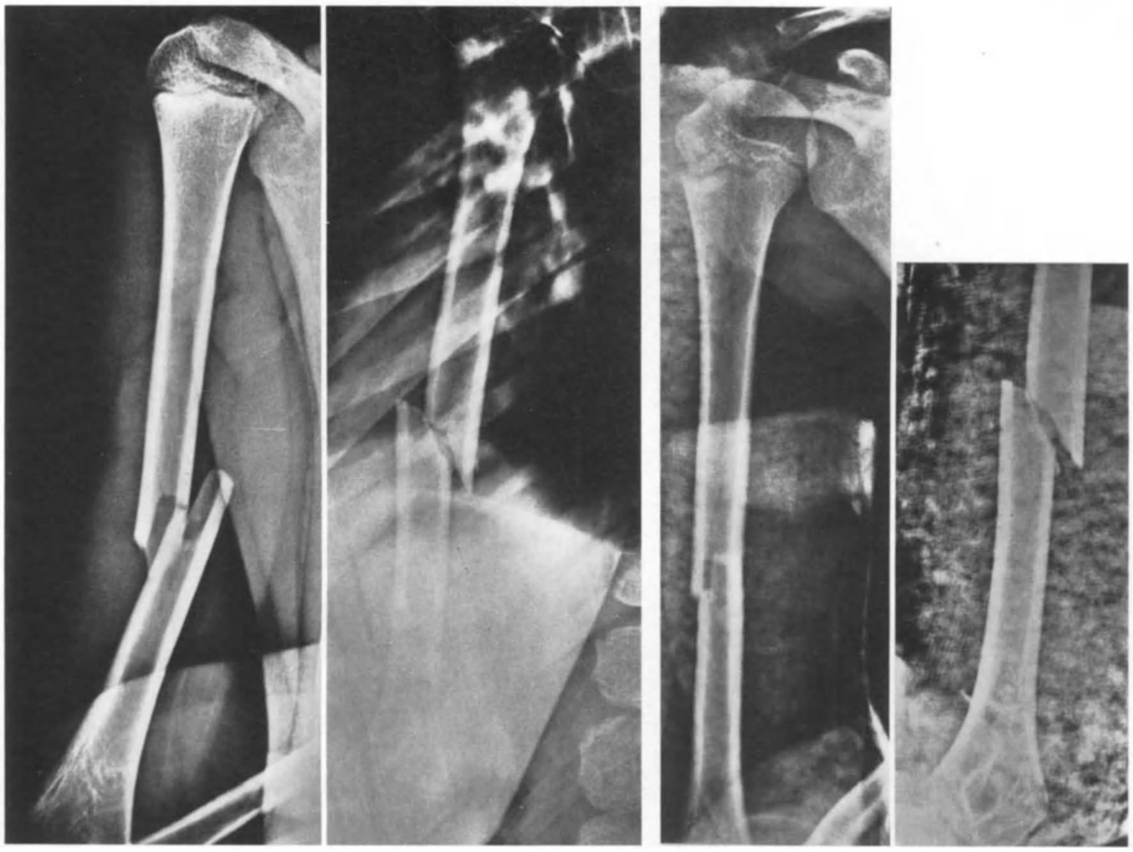
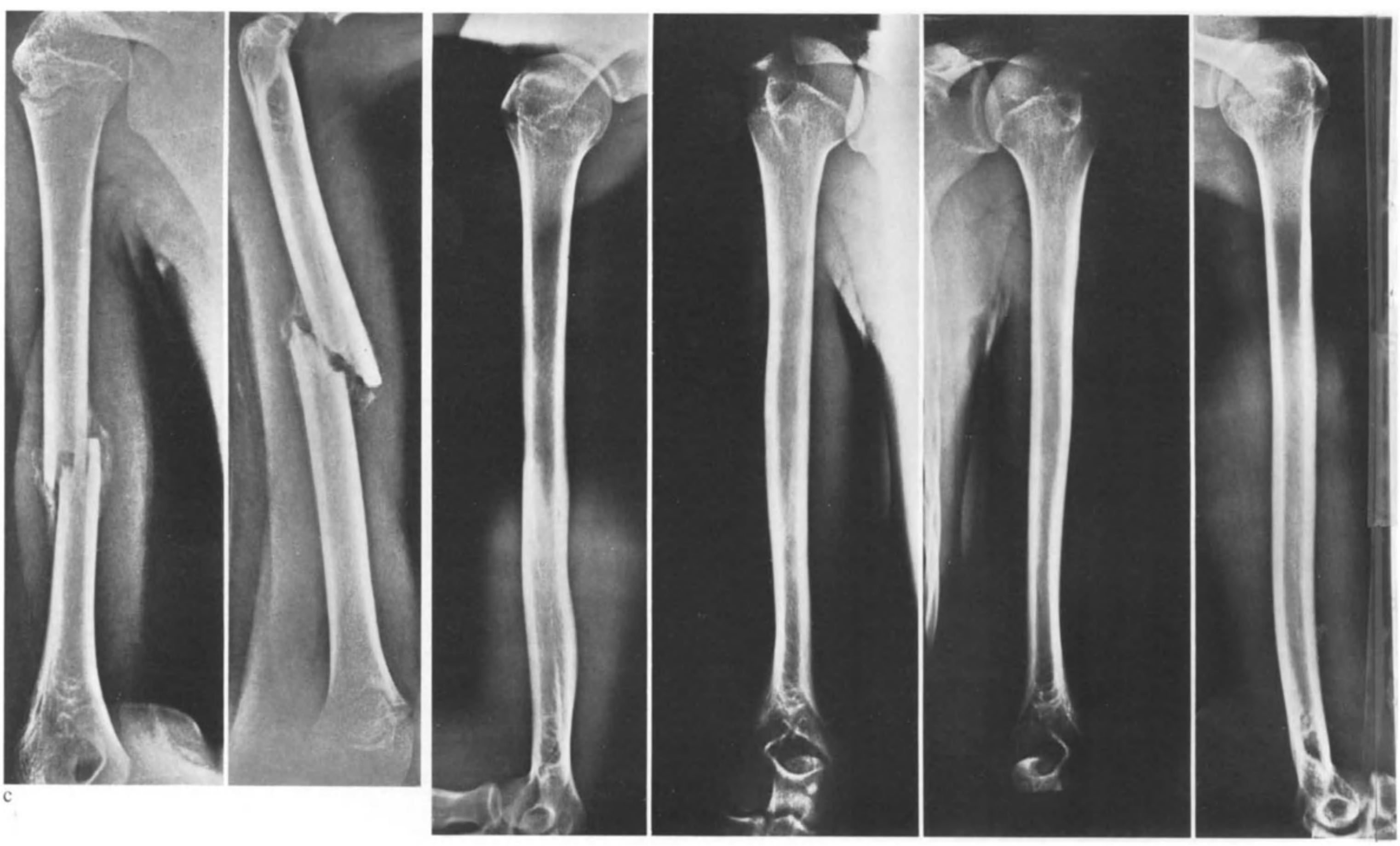


Fig. 7. *Oblique fracture of the shaft*



a b

Fig. 8a, b ▸



c

Fig. 8c, d

2.2 Oblique Fractures

2.2.1 Pathological Anatomy

Oblique fractures are also caused by direct violence, Their radiographic appearance is usually that of an angulation fracture without an angulation fragment. In rare cases, an undislocated angulation fragment may be seen on the roentgenogram. In this type of fracture, dislocation of the fragments almost always results, and the fracture line runs distally and medially. The direction of the dislocation largely depends on the site of the fracture (Fig. 7).

2.2.2 Treatment

Oblique fractures are, in principle, treated like transverse fractures.

Reduction and Immobilization: if the line of the oblique fracture is relatively long and the fracture is not markedly dislocated, reduction may be followed by fixation with a high, circular full-arm cast or a plaster U-splint (Fig. 8).

Reduction under general anesthesia with subsequent olecranon screw traction is only necessary if muscle has been pierced by a bone fragment or if there is marked secondary shortening.

Duration of fixation: 3–6 weeks, depending on the age of the child.

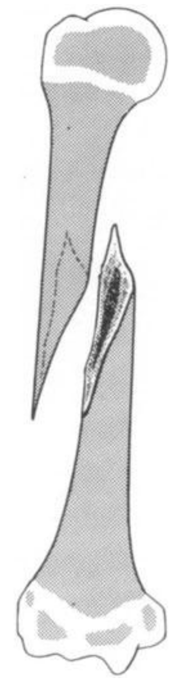
2.3 Spiral Fractures

2.3.1 Pathological Anatomy

These are usually simple spiral fractures without a butterfly fragment (Fig. 9). They mainly result from a fall onto the extended elbow or arm, or are caused by placing the hand in a rotating laundry spin-dryer. Accompanying injuries are determined here by the degree of violence, and in our records we found one case of perforation of the brachial artery.

Fig. 8a–d. *Oblique fracture of the shaft*. K.B., ♂, aged 10 years, No. 121298.
a) Roentgenogram taken immediately following the accident.
b) Treatment: reduction followed by application of a plaster U-splint.
c) 1 month after the accident. Bone union has occurred with good alignment of the fragments.
d) 5 years after the accident. The appearance of the shoulders is symmetrical

Fig. 9. *Spiral fracture*



2.3.2 Treatment

Immobilization: if dislocation is not marked, it is usually possible to fix the fragments with a plaster U-splint or a circular full-arm cast, without prior reduction (Fig. 10).

If there is considerable dislocation of the fragments, or the patient has multiple injuries, we prefer traction with an olecranon screw for 2–3 weeks followed by cast fixation for a further 2–3 weeks.

Duration of fixation: 3–6 weeks, depending on the age of the patient.

In certain cases, a long plaster cylinder has also been found to be of value if there is a tendency to retrocurvature. The patient carries the weight of the plaster cylinder himself, so that neither shortening nor lengthening is likely to occur (Fig. 11).

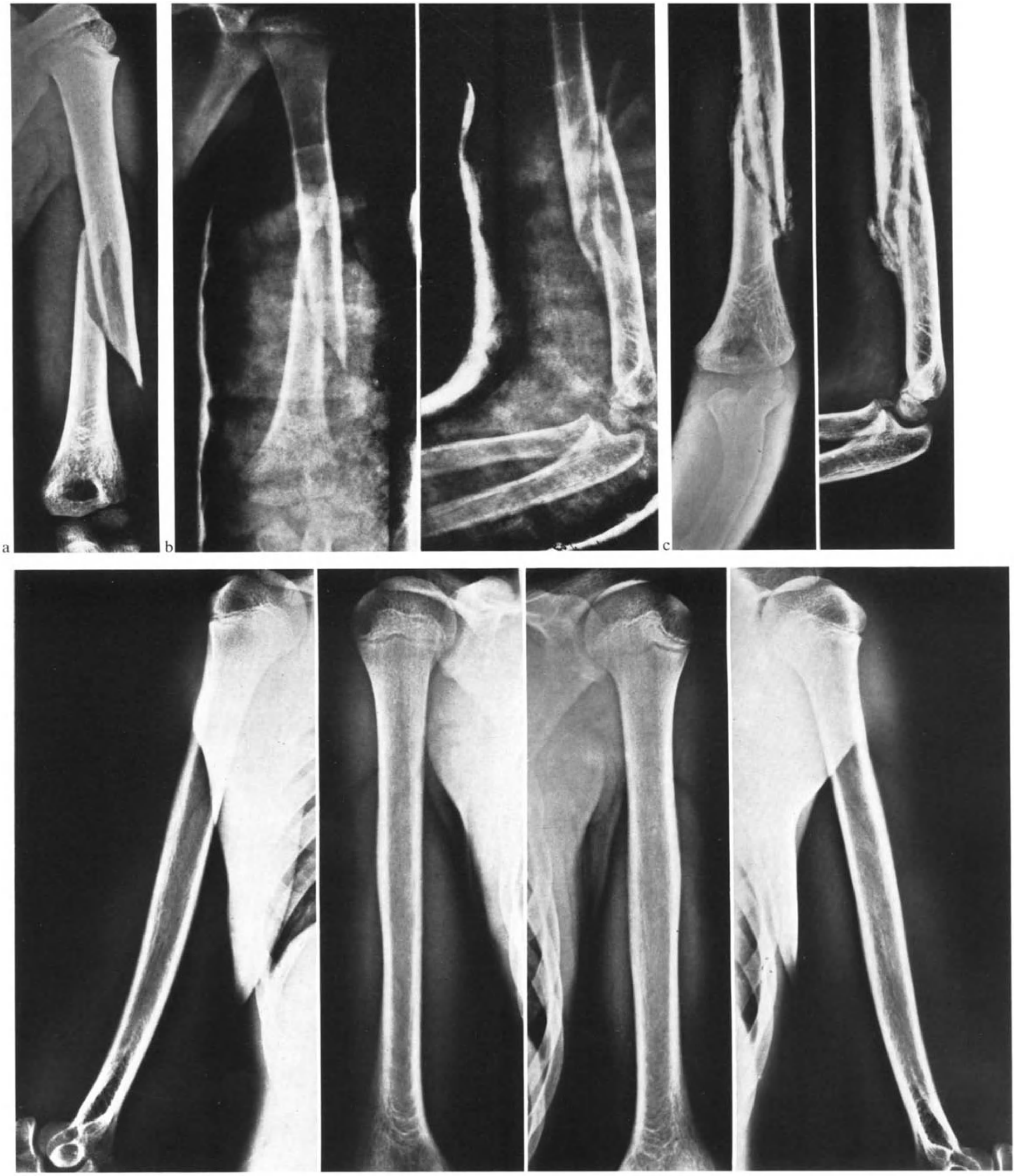
2.4 Comminuted Fractures

2.4.1 Pathological Anatomy

True comminuted fractures very rarely occur in children. Most are seen shortly before cessation of growth, being the result of extremely severe direct or indirect violence (Fig. 12).

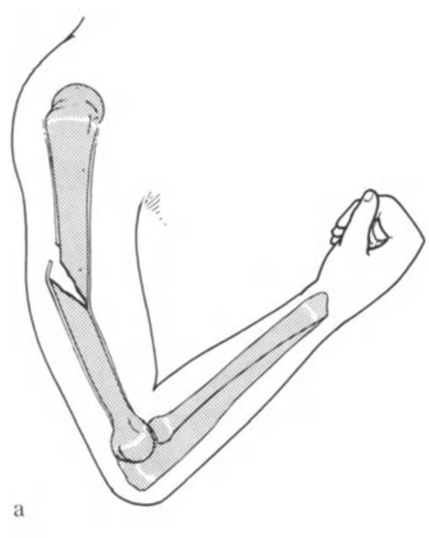
2.4.2 Treatment

Here too, we prefer nonoperative treatment. The correctly aligned arm is immobilized in a plaster U-splint or in full-arm cast. Again, if the fracture is very unstable, olecranon screw traction followed by cast fixation may be necessary.



a b c d

Fig. 10a–d. *Spiral fracture*. D.J., ♂, aged 13 years, No. 74774.
a) Roentgenogram taken immediately following the accident.
b) Treatment: Full-arm cast for 5 weeks.
c) Bone union has occurred 5 weeks later.
d) 8 years after the accident. Complete recovery has occurred with symmetrical shoulders



a

b

Fig. 11a, b. *Cast to correct tendency to retrocurvature.*
a) If there is a tendency to retrocurvature, the reduction can be maintained by keeping the elbow in extension. A cylindrical cast is used which is analogous to that used on the knee.
b) Z.F., ♂, aged 15 years, No. 130949. Spiral fracture which has been made to unite with correct alignment by keeping the elbow extended

Fig. 12. *Comminuted fracture (extremely rare)*

2.5 Open Fractures

2.5.1 Pathological Anatomy

Open fractures of the upper arm are rare. They are usually caused by severe direct or indirect trauma; depending on the direction of the traumatic force and on the level of the fracture, either the proximal or the distal fragment pierces the soft tissues and skin. Second- and third-degree open fractures are extremely rare.

2.5.2 Treatment

Following simple piercing of the skin (first-degree open fracture), the fracture can be reduced nonoperatively and the wound is then closed with the usual sterile precautions; the fracture is subsequently treated nonoperatively along the lines described above. The fracture may be reduced operatively if muscle is inter-

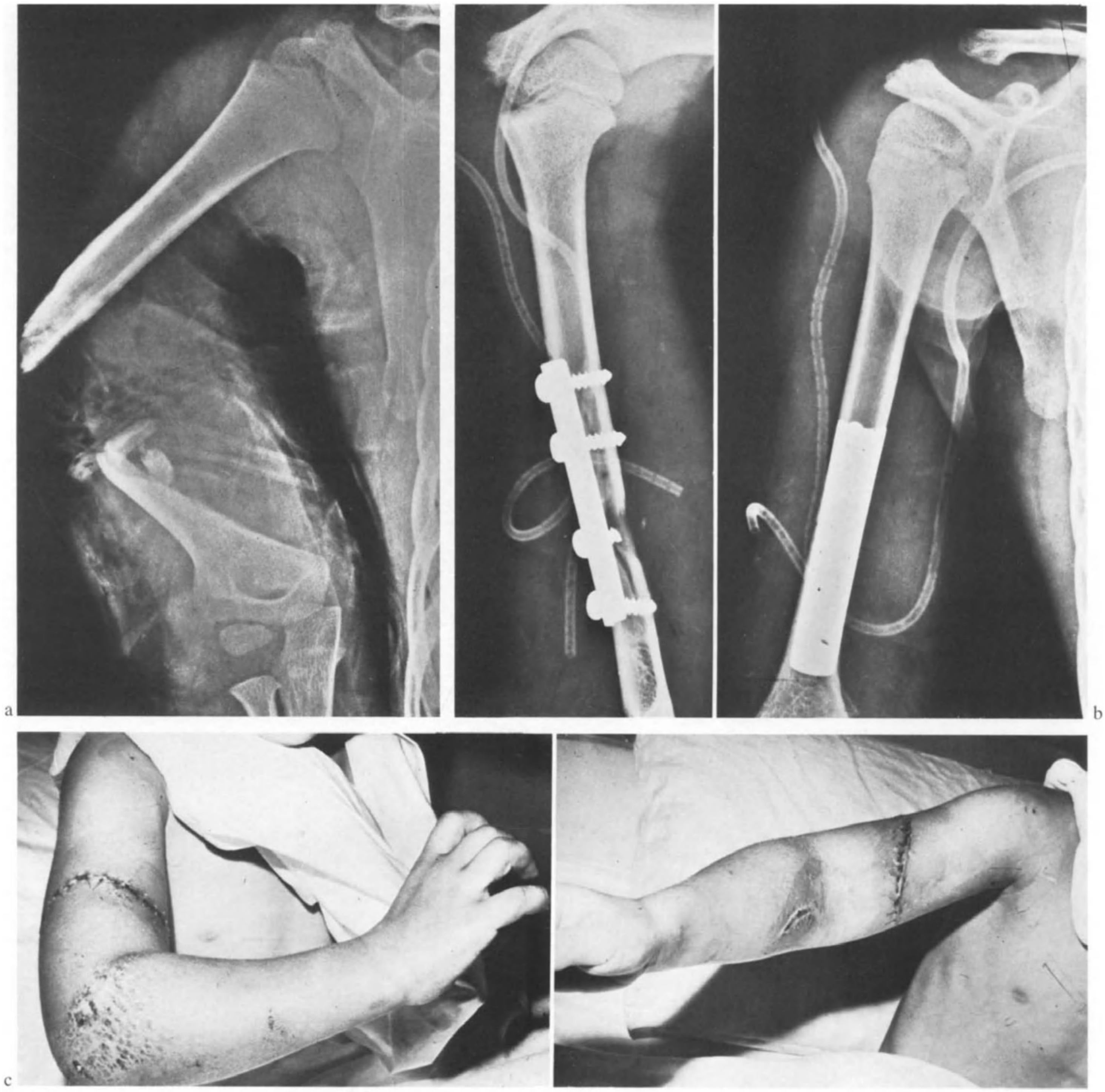


Fig. 13a–c

posed between the fragments but, here too, the subsequent treatment should be nonoperative if the soft tissues are not in a precarious condition. A fracture of the upper arm in a child must also be treated operatively if there is severe soft tissue injury. The internal fixation technique depends on the age of the patient and on the type of fracture. Operative stabilization of the fracture allows ideal treatment of the soft tissue injury, including meticulous debridement, examination of the neurovascular bundle, and, if necessary, suturing of nerves and vessels. The promotion of soft tissue healing by internal fixation is the best method of preventing infection. Furthermore, it eases the nursing care of patients with multiple injuries (Fig. 13).

3 Prognosis

3.1 Fracture Healing

Fractures of the shaft of the humerus do not usually present difficulties following correct nonoperative treatment. Bone union occurs within an average period

Fig. 13a–e. *Open fracture of the humerus.* H.E., ♂, aged 6 years, No. 99108.
a) Traffic accident with severely comminuted open fracture of the shaft of the humerus (third-degree open fracture).
b) Treatment: internal fixation with a minimum of implant material and extensive débridement of the soft tissues.
c) 14 days after the accident. Primary wound healing has taken place.
d) 12 weeks after the accident. The fracture has healed.
e) 1 year after the accident. Complete recovery has occurred


d e

Fig. 13d, e

of 6 weeks, and functional postoperative mobilization is therefore permissible. Anatomically correct reduction is normally followed by 0.5–2.0 cm increase in growth. The increase in length is seldom noticed by the patient. However, when traction is applied with an olecranon screw, care should be taken to prevent distraction of the fragments, since this lengthens the extremity and also prolongs healing. Pseudarthrosis did not occur in our series. Operative stabilization of a humerus fracture is only indicated if there is extremely severe soft tissue injury or damage to vessels or nerves. Simple, open fractures can also be treated nonoperatively following treatment and closure of the wound.

3.2 Primary Malunion

Initial shortening of 1–2 cm is acceptable, since increased growth normally occurs in the fractured bone. Angulation of greater than 20° should be avoided. Lesser degrees of angular deformity are usually corrected spontaneously by the subsequent growth of the bone, thus producing an aesthetically satisfactory final result. The only means of assessment of rotation deformity is by clinical comparison of the positions of two anatomic landmarks in the proximal and distal fragments, since no satisfactory radiological technique exists.

4 Results

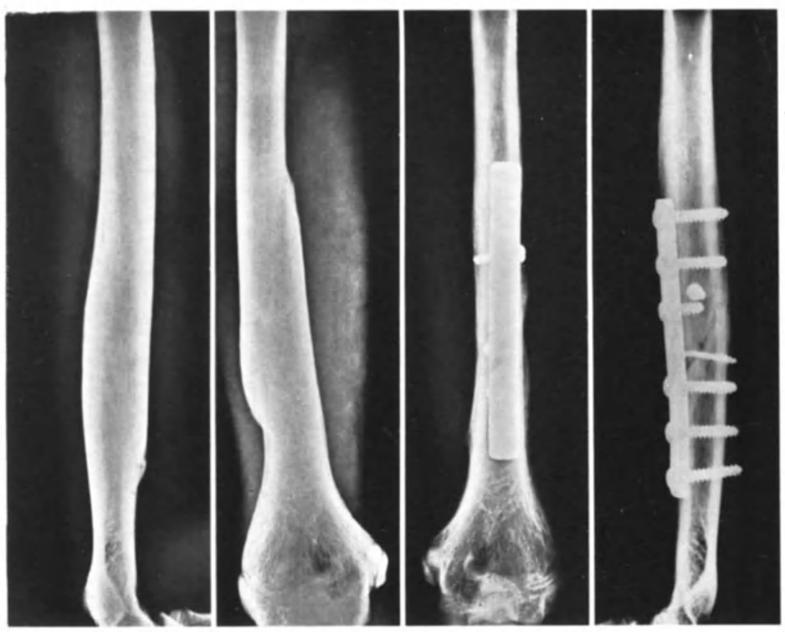
Between 1961 and 1974, 54 fractures of the shaft of the humerus were treated in our hospital. Fifty-one of them were treated nonoperatively and three operatively.

4.1 Results of Nonoperative Treatment

Twenty-two patients were treated by olecranon traction followed by a cast; 19 were treated initially with a cast; in nine cases, the fracture was immobilized with a *Velpeau* bandage or by adhesive plaster fixation. One patient was treated by simple mobilization without fixation.

In none of the cases in our series was radiographically detectable angulation present 5 years after the accident. In no case was rotation deformity found on clinical comparison of the two sides. In 60% of the cases, longitudinal growth was found to have increased; in 40%, it had decreased. The difference in length was never greater than 2 cm.

Damage to the radial nerve was not seen in our series. In one case, piercing of the brachial artery caused an incipient *Volkmann* contracture. Immediate surgical exposure of the brachial artery revealed a small perforation without severe damage to the intima.



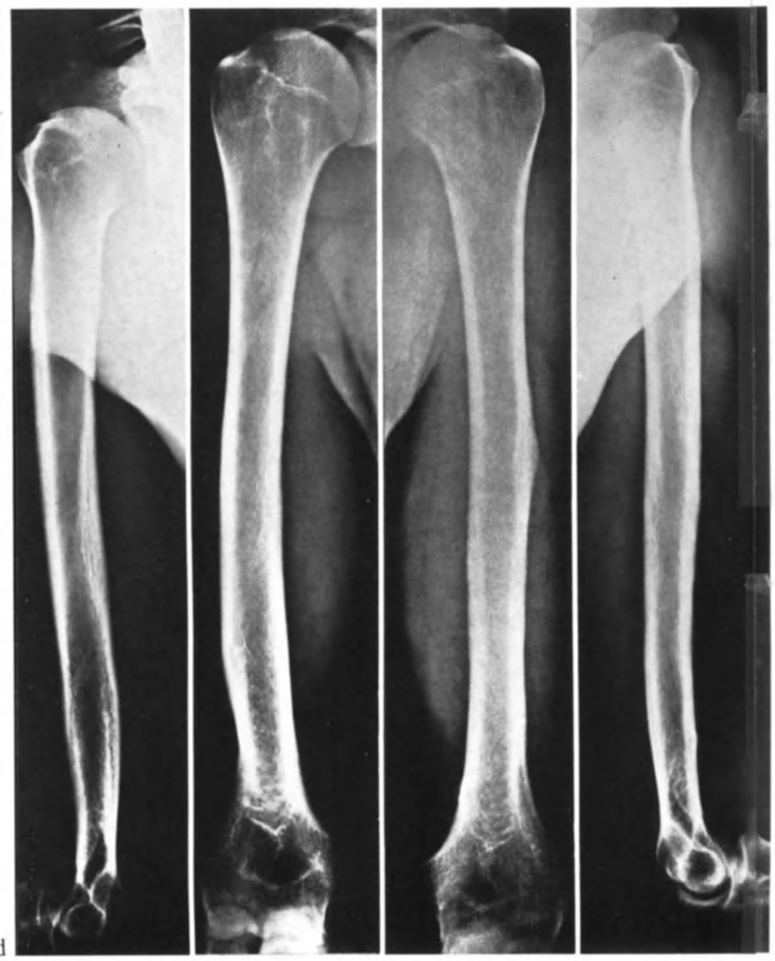


Fig. 14a–d. *Bilateral diaphyseal fracture of the humerus.* B.H., ♂, aged 12 years, No. 76125.

a) Bilateral diaphyseal fractures of the humerus: closed on the right and open (second degree) on the left.

b) Treatment: closed reduction and application of a full-arm cast on the right. Open reduction, internal fixation, and débridement on the left.

c) 3 months after the accident. The fractures have healed on both sides.

d) $7^1/_2$ years after the accident. Complete recovery has taken place

Development of the contracture was prevented by relaxation incision of the fascia, evacuation of the hematoma, and manual reduction of the fracture. At follow-up, there were no clinically evident sequelae apart from slight weakening of the radial pulse.

4.2 Results of Operative Treatment

Operative fixation was carried out in three cases. On one occasion, surgery was necessitated by extensive soft tissue injuries, and, on another, by an open fracture (Fig. 14). In the third case, there was extensive comminution and the epiphyses had almost closed.

Normal anatomy and function were restored in each case.

5 Summary

On the basis of our results, we can say that fractures of the shaft of the humerus, which are rare in children, generally heal uneventfully following correct nonoperative treatment, and that limitation of function is not to be expected. Surgery is seldom necessary, being mainly indicated for open fractures, suspected crushing, or trapping of the radial nerve, or damage to the brachial artery.

6 References

Pollen, A. G.: Fractures and Dislocations in Children. Edinburgh, London: Livingstone 1973.

Renné, J., Weller, S.: Verrenkungen und Frakturen der oberen Gliedmaßen. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer 1974.

Tachdjian, M. O.: Pediatric Orthopedics. Philadelphia-London-Toronto: Saunders 1972.

Fractures of the Medial Epicondyle

D. Pelet

CONTENTS

1 Introduction

Avulsion fracture of the medial epicondyle is a relatively frequent injury in children and in adolescents in whom the apophyseal plate has not yet closed. It is frequently combined with dislocation of the elbow.

On the flexor side of the elbow, the capsule and muscle are always torn and, therefore, some degree of dislocation of the fragment is always present. Nonoperative treatment of these fractures therefore results in malunion or pseudarthrosis, which may cause inflammation of the ulnar nerve. Pseudarthrosis is frequently accompanied by valgus deformity of the elbow joint with instability. The instability may also lead to irritation of the ulnar nerve. We are therefore of the opinion that a dislocated fragment requires open reduction and temporary internal fixation with a minimum of implant material if the normal anatomy and function are to be restored.

2 Classification

2.1 Nondislocated Fracture

This type of fracture of the medial epicondyle is extremely rare, since an avulsion mechanism is responsible (Fig. 1).

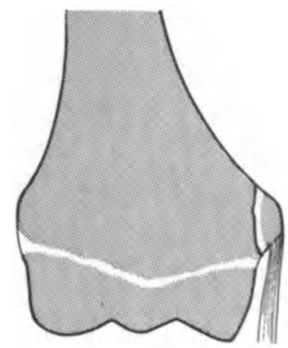


Fig. 1. *Nondislocated fracture*. This type is very rare because the flexor muscles almost always cause marked dislocation

2.2 Dislocated Fracture

The fragment is dislocated by the pull of the flexor carpi ulnaris and flexor digitorum muscles. The medial epicondyle may be pulled down below the level of the joint. There are two types of avulsion: pure separation of the apophysis, which is less common, and metaphyseal fracture of the apophysis, which is much more frequent (analogous to *Aitken* Type I fracture of an epiphysis) (Fig. 2).

The treatment and prognosis of the two types of fracture are identical.

2.3 Dislocation of the Medial Epicondyle into the Joint

In approximately a quarter of the cases, the medial epicondyle may remain trapped in the joint following dislocation and spontaneous reduction (Fig. 3). Surgery is always indicated in these cases (Fig. 4).

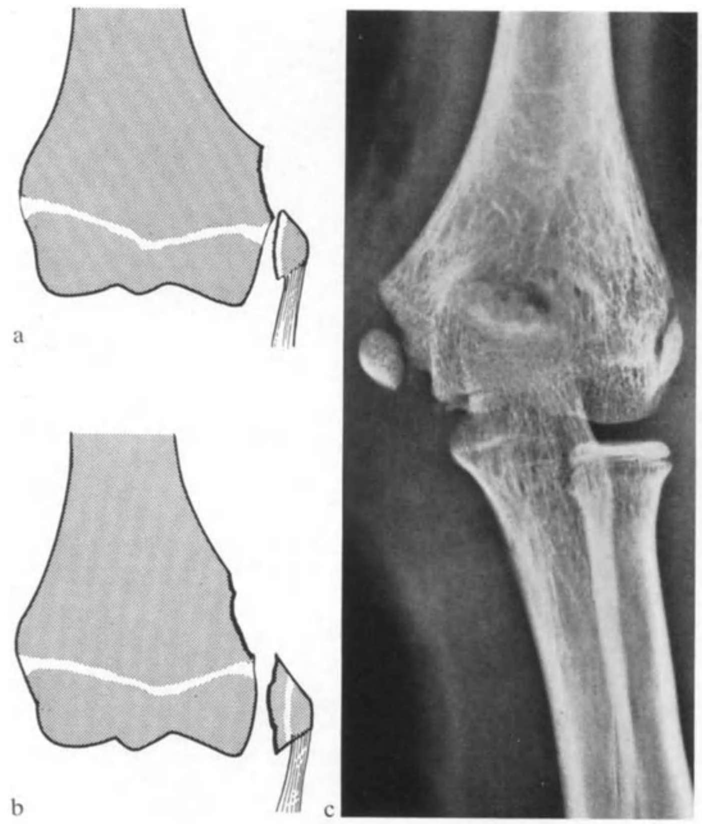


Fig. 2a–c. *Dislocated fracture.*
a) Simple separation of the traction epiphysis.
b) Metaphyseal avulsion of the traction epiphysis; this fracture may be purely metaphyseal or *Aitken* Type I.
c) B.L., ♀, aged 10 years, No. 112938. An example of *Aitken* Type I avulsion of the traction epiphysis

Fig. 3. *Trapping of the bone fragment in the elbow joint.* W.F., ♀, aged 7 years, No. 141616.
The medial epicondyle is completely dislocated into the elbow joint

2.4 Fracture of the Medial Epicondyle Combined with Dislocation of the Elbow

In 50% of cases, the fracture types 2.2 and 2.3 are combined with dislocation of the elbow joint. This dislocation is almost always in a backward and radial direction (Fig. 5). Anterior dislocation is very rare. The prognosis and any subsequent limitation of movement is determined by the extent of the soft tissue damage. Severe and prolonged dislocation is followed by calcification with subsequent limitation of movement.

2.5 Other, Rarer Combined Injuries

In very few cases, avulsion of the medial epicondyle is accompanied by other injuries, e.g., fracture of the olecranon (Fig. 6). The treatment is determined by the therapeutic principles appropriate to each of the component injuries.

3 Diagnosis

The diagnosis can almost always be made with two standard roentgenograms of the elbow. If it is unclear, comparison of stressed roentgenograms of the intact and injured elbows may provide further useful information; if avulsion has occurred, dislocation will be seen which was not revealed by the standard films. The apophyseal center of ossification is radiolucent up to the age of 4 years, so that stressed roentgenograms are necessary for the diagnosis of an avulsion fracture. If the joint can be made to open, surgical exploration and reattachment of the apophysis, which is still completely cartilaginous at this age, is indicated.

4 Treatment

We operated on almost all fractures of the medial epicondyle. A nondislocated fracture could be treated nonoperatively, but is extremely rare.

Fig. 4a–d. *Open reduction and internal fixation of a medial epicondyle which slipped into the elbow joint following avulsion.* R.A., ♂, aged 15 years, No. 72299.
a) Roentgenograms taken immediately following the accident. The medial epicondyle is missing from its usual position and a radiopaque shadow is seen in the joint.
b) Open reduction has been followed by internal fixation with a small lag screw.
c, d) 14 years after the accident. There are no residual signs of the fracture and the elbow joints are symmetrical

Fig. 5a–c. *Posterolateral dislocation with avulsion of the medial epicondyle.* L.F., ♂, aged 13 years, No. 165989.
a) Roentgenograms taken immediately after the accident.
b) The elbow joint after closed reduction of the dislocation followed immediately by fixation of the medial epicondyle with a lag screw.
c) 3 years after the accident. There are no sequelae

a

b

c

Fig. 6a–c. *Fracture of the medial condyle combined with fracture of the olecranon.* S.R., ♂, aged 12 years, No. 119988. a) Roentgenograms taken immediately after the accident. b) Treatment: Transfixation of the medial epicondyle with *Kirschner* wires; tension band osteosynthesis of the olecranon fracture.
c) 18 months after the accident. Normal growth and symmetrical ranges of elbow movement

The authors all agree that surgery is indicated if the fragment is trapped in the joint (Fig. 7). Surgical exploration and reduction is even indicated in cases in which treatment has been delayed, i.e., several weeks after the accident, since a fragment which has been folded into the joint will cause severe articular damage (Fig. 8).

In our opinion, open reduction and stabilization of a dislocated fragment are indicated even if the joint is not dislocated, since anatomically precise reduction and fixation are necessary to prevent medial instability. Anatomically precise reduction and fixation also prevent pseudarthrosis; although the latter is in itself harmless, it may cause symptoms in rare cases. Furthermore, it may give rise to irritation of the ulnar nerve. Internal fixation reliably prevents redislocation, a complication which we encountered subsequent to removal of the cast in a case of combined injury (Type 2.4) which was treated nonoperatively (Fig. 8).

If surgery is delayed, complete restoration of the normal anatomy and function is rarely possible, since permanent soft tissue damage will already have occurred and will frequently prevent anatomically correct reduction.

a b

c

Fig. 7a–c. *Dislocation of the elbow with displacement of the avulsed medial epicondyle into the elbow joint.* F.R., ♂, aged 11 years, No. 110655.
a) Roentgenograms taken immediately following the accident.
b) Treatment: Open reduction, ligament suture, transfixation of the medial epicondyle with *Kirschner* wires.
c) $9^1/_2$ years following the accident. No residual signs are discernible

We advise transposition of the ulnar nerve in all cases in which preoperative damage was present, even if the latter was restricted to slight hypesthesia in the area innervated. In cases of this type in which the nerve was simply exposed and freed rather than transposed, hypesthesia was still evident years later. In one case in which the nerve was not transposed, the neurological function subsequently worsened.

5 Operative Technique and Postoperative Treatment

Dislocation is reduced under general anesthesia prior to surgery. A slightly curved incision is made over the epicondyle, the hematoma is evacuated, and the avulsed fragment is exposed and extracted from the joint space. Anatomically correct reduction of the fragment and of the flexor muscle group and the ulnar collateral ligament is followed by internal fixation. In patients under 14 years of age, we use two *Kirschner*

Fig. 8 a–e. *Undetected displacement of the medial epicondyle into the joint*. P.R., ♀, aged 9 years, No. 153 567.
a) Dislocation of the elbow was diagnosed following the accident. Closed reduction was carried out under general anesthesia and a cast was applied.
b) The joint immediately redislocated following removal of the cast 1 month after the accident.
c) Comparative roentgenograms prior to surgical exploration and repair. The elbow joint is completely dislocated and the medial epicondyle is folded into the joint.
d) Surgical exploration and mobilization of the joint followed by transfixation of the medial epicondyle with a *Kirschner* wire.
e) 4 years and 9 months after the accident. The range of motion is severely limited and pain arises in the end position of joint movement. The radiological appearance is practically normal. An unsatisfactory result

a b c

Fig. 9a–c. *Operative technique in adolescents before puberty. Transfixation of the medial epicondyle with Kirschner wires.* K.V., ♂, aged 12 years, No. 181103.
a) Roentgenogram taken immediately following the accident.
b) *Kirschner* wire fixation.
c) 1 year after the operation. There are no residual signs of the fracture

a b

Fig. 10a, b. *Pseudarthrosis of the medial epicondyle.* W.A., ♀, aged 8 years, No. 130407.
a) Nonoperative treatment by cast fixation was carried out for 5 weeks.
b) 7 years after the accident. There is a slightly painful pseudarthrosis of the medial epicondyle with marked instability of the medial collateral ligaments and slight limitation of the range of joint motion. The medial epicondyle of the humerus projects markedly and its appearance is aesthetically displeasing

wires (Fig. 9) which are slightly bent. In older patients, we prefer a small lag screw (Fig. 5). The avulsed fragment should never be excised, since this frequently results in medial instability and, furthermore, there is a danger of causing disturbance of growth in the medial side of the elbow. If the preoperative nerve function was normal, the ulnar nerve should not be exposed unless it is fixed to the avulsed fragment. In the latter case, it must be freed. If there were signs of damage to the ulnar nerve prior to the operation, the nerve should always be exposed and transposed ventrally.

Following the operation, the elbow is immobilized at an angle of 90° in a full-arm cast for 3–7 weeks, the exact duration depending on the age of the child. The *Kirschner* wires are removed after an average of 6 weeks; screws are removed after 4–6 months.

6 Long-Term Results

From 1967 to 1972, 34 cases of avulsion of the medial epicondyle were treated by open reduction and internal fixation in our clinic. We were able to follow-up 27 children at an average of 6 years and 10 months following their accidents.

Increased valgus of the elbow was rarely seen and never exceeded 5°, a deformity which is of no clinical or aesthetic significance.

The range of movement was symmetrical in all the cases of isolated avulsion of the epicondyle. In the cases with additional dislocation of the elbow joint, slight limitations of flexion, extension, and pronation were found which never exceeded 10°. Limitation of movement was associated with radiographically visible calcification of the collateral ligaments.

Recovery from preoperative injury to the ulnar nerve was only complete in those cases in which the nerve was ventrally transposed at operation. In one case, postoperative worsening of preoperatively existing nerve damage occurred; here the ulnar nerve had not been ventrally transposed.

In no case did we find evidence of postoperative loss of function of a preoperatively intact ulnar nerve.

Pseudarthroses were found in four cases; three were caused by inadequate reduction and one resulted from delayed internal fixation. In these patients, there was slight instability of the ulnar collateral ligaments and the range of motion was somewhat reduced (Fig. 10).

One case ended with a poor result. An avulsion fracture of the medial epicondyle with dislocation of the elbow in a 9-year old girl was treated nonoperatively. The fragment remained dislocated and trapped in the joint. Seven weeks after the accident, open reduction and internal fixation were carried out. At follow-up, 5 years later, the range of movement was seriously restricted and the patient complained of recurrent pain (Fig. 8).

7 Summary

Following avulsion of the medial epicondyle and dislocation, successful restoration of the normal anatomy and function can be expected if anatomically precise reduction and perfect internal fixation are performed immediately, i.e., as an emergency operation. If preoperative injury to the ulnar nerve is present, the nerve should be exposed and ventrally transposed.

Supracondylar Fractures of the Humerus

F. MAGERL, H. ZIMMERMANN

CONTENTS

1 Distal End of the Humerus in the Child

At birth, the distal epiphysis of the humerus is still completely cartilaginous. The first epiphyseal center of ossification appears in the capitulum during the first year of life, and the second arises in the medial epicondyle between the 5th and 9th years. Ossification of the trochlea and of the lateral epicondyle may start in the middle of the 8th year, but that of the trochlea generally occurs somewhat earlier (11 years) than that of the lateral epicondyle (*Schmid* and *Halden*).

The centers for the capitulum, trochlea, and apophysis of the lateral epicondyle fuse with each other between the 13th and 16th years and unite with the diaphysis shortly afterwards (14th–16th year). The center for the medial epicondyle remains separate until it fuses with the diaphysis between the 14th and 18th years (*Lanz* and *Wachsmuth*).

An important parameter is the physiological valgus angle of the elbow joint which is formed by the longitudinal axes of the ulna and humerus (total cubital angle of *Fick*, carrying angle of the elbow). According to *Smith*, the carrying angles of the elbow joint in children aged 3–11 year are as follows:

Boys: mean angle 5.4°, variation 0°–11°,
Girls: mean angle 6.1°, variation 0°–12°.

When fracture healing has occurred and full extension of the elbow is possible, varus or valgus deformity can be detected by measurement of the carrying angle. During treatment, when the elbow cannot be fully extended, the angle of the distal fragment is measured by the method of *Baumann*, using the longitudinal axis of the humerus and a line which passes between the capitulum and the diaphysis (Fig. 1). According to *Baumann*, the difference between the angle α and 90° ($90° - \alpha$) corresponds to the physiological carrying angle. If, for example, the angle of the elbow on the intact side is 10° (=170°), the angle α should be 80°. In common with *Schlag* and *Halbe*, we have the impression that the angle α is frequently smaller than

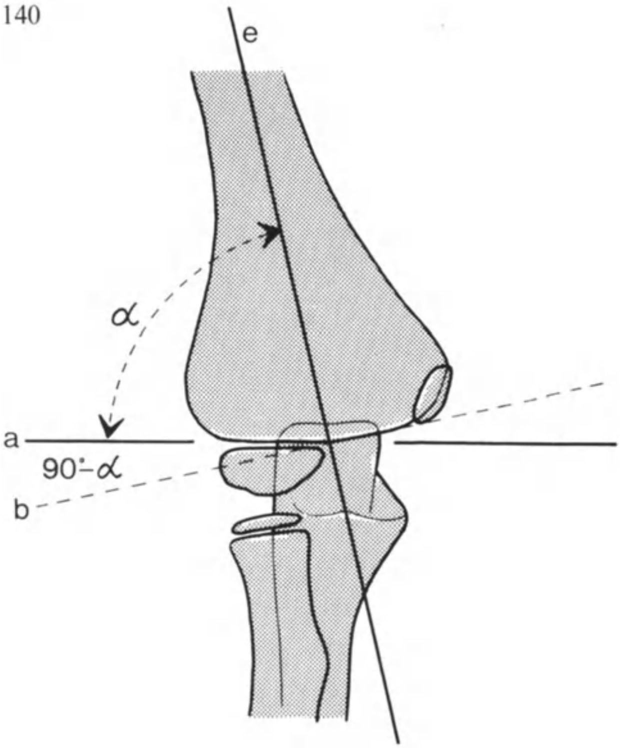


Fig. 1. *Baumann's line and α angle*. The longitudinal axis of the humerus (e) and Baumann's Line (a) intersect at an angle α. With the aid of *Baumann's* line, malposition of the distal fragment can be detected, even if the elbow is flexed. In many cases, the lower border of the humeral metaphysis on the medial side is also straight; thus, another line (b) is available for determination of the position of the fragments

that derived from the formula: angle of elbow $= 90° - \alpha$. We therefore check the angle α by radiographic comparison with the intact side.

In many cases, the lower border of the medial segment of the humeral metaphysis forms a straight line which can be used for the diagnosis of angulation of the distal fragment in the frontal plane (line b in Fig. 1).

In the sagittal plane the distal epiphysis of the humerus is tilted forwards (Fig. 2). The angle between the epiphyseal plate and the longitudinal axis of the humerus (diaphysis-epiphysis angle) is approximately 150° (=30°) (*Egyed*). *Katzmann* found a mean value of 30.6° in healthy children up to the age of 14 years, with variation from 25° to 39°.

2 Characteristics of Supracondylar Fractures

In the child, the mainly cartilaginous structures of the distal end of the humerus are elastic and the capsule is relatively tight. As a result of this, ligamentous injuries and intracapsular fractures are less common than extracapsular supracondylar fractures. The fractures, whose levels vary somewhat, are situated proximal to the epiphyseal plate and transect both metaphyseal columns and the olecranon, coronoid, and radial fossae which lie between them.

Kocher differentiates between two types of fracture: flexion fractures and extension fractures.

In adolescents, the fractures are almost all of the extension type. According to *Blount, Schulz*, and *Cassidy*, flexion fractures are found in less than 1% of cases. In our series, however, they were somewhat more frequent.

Extension fractures exhibit the following characteristics:

1. The plane of the fracture is horizontal or tilted so as to run in a ventral and distal direction.
2. The distal fragment is displaced backwards and proximally, as well as medially or laterally.
3. The distal fragment is tilted backwards, i.e., in "extension," and generally in varus.
4. The distal fragment is rotated, usually inwards.

The metaphysis has a flattened cross section and the fracture surfaces are therefore very narrow, particularly between the two metaphyseal columns. Fragmentation and plastic deformation sometimes render the fracture surfaces incongruent. If the fracture is dislocated, the anterior periosteum is torn, but the posterior periosteum is frequently only detached from the proximal fragment.

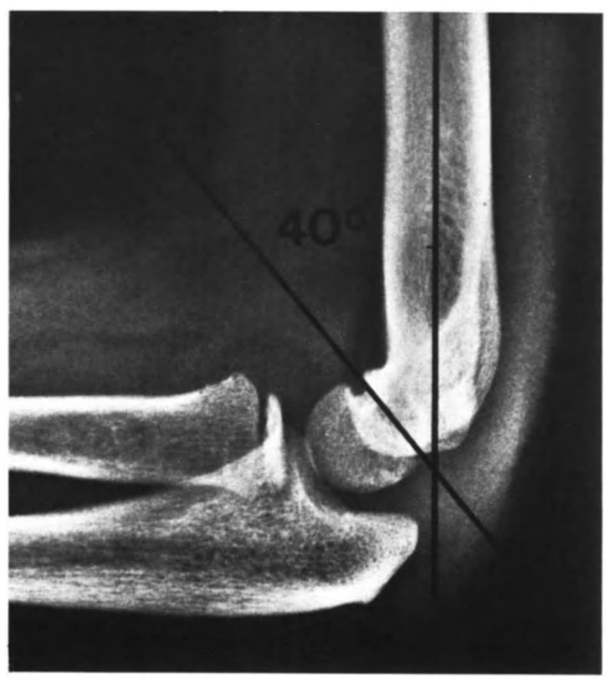


Fig. 2. *Angle between the epiphysis and diaphysis*. The distal epiphysis of the humerus is tilted in a volar direction. The included angle between the longitudinal axis of the humerus and the plane of the epiphyseal plate is 40° in this roentgenogram of the elbow of a healthy 9-year old boy

Supracondylar flexion fractures exhibit the following characteristics:

1. The plane of the fracture is horizontal or slopes distally and dorsally.
2. The distal fragment is displaced forwards and proximally, as well as medially or laterally (Fig. 12).

Supracondylar fractures are classified according to the degree of dislocation (*Lubinus, Felsenreich*). *Felsenreich* distinguishes three groups, as follows.

Group 1: Angulation slight or absent. Bone not completely broken through.
Group 2: Angulation of the fracture. Displacement of the fragments, which remain in contact with each other.
Group 3: Fragments displaced by the width of the bone with loss of contact between them.

Because the fracture surfaces are very narrow, supracondylar fractures of groups 2 and 3 tend to be unstable, the fragments tilting on each other like two boards which are placed together edgewise (Fig. 3). In oblique extension fractures, the fragments have the additional tendency to slip past each other.

The treatment of a supracondylar fracture depends very much on the condition of the dorsal periosteum. If the latter is intact, it can be used as a tension band to stabilize the fracture. The cuff-and-collar treatment recommended by *Blount* probably relies on the tension band effect of the dorsal periosteum (Fig. 4). The same is probably true of traction methods which use opposed traction (*Baumann, Dunlop, von Ekesparre*) (Fig. 7).

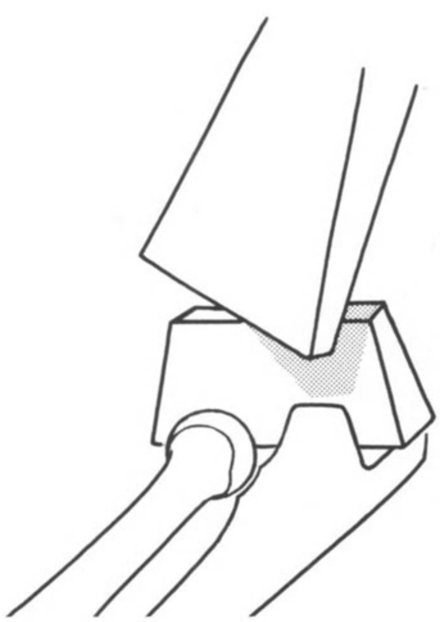


Fig. 3. *Tendency of extension fractures to dislocate*. The fracture surfaces are so narrow that a slight degree of rotation deformity suffices to allow tilting. Internal rotation and varus deformities usually result

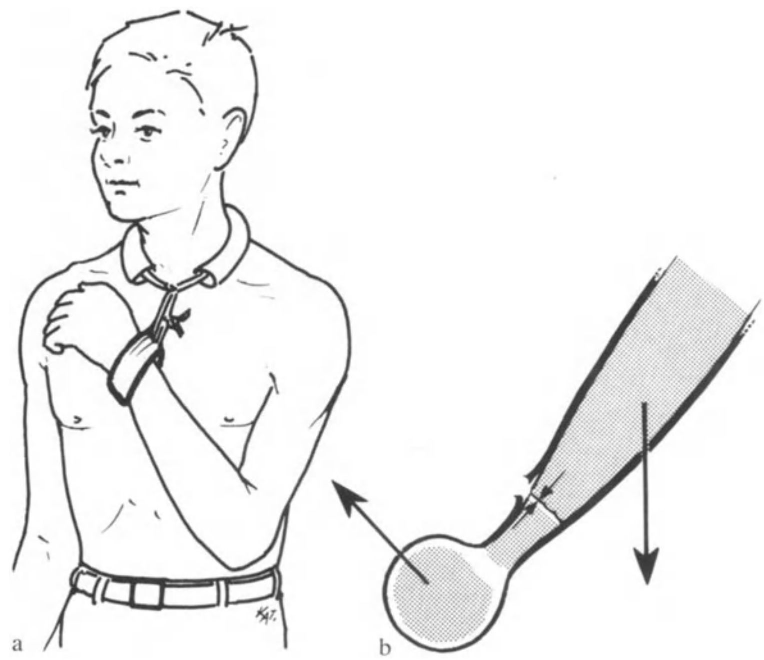


Fig. 4a, b. *Tension band effect of the intact dorsal periosteum*. a) Treatment by the *Blount* method with cuff and collar. b) If the forearm is suspended in the above manner, the weight of the upper arm exerts a bending moment on the fracture which is counteracted by the dorsal periosteum. The tension of the periosteum pulls the fracture surfaces together

If the dorsal periosteum is also torn, interfragmentary stability cannot be achieved by nonoperative methods. Traction only results in approximate reduction and positioning of the fragments, and the intact soft tissue cuff acts as a splint.

3 Accompanying Injuries

3.1 Open Fractures

Open fractures are rare. In the majority of cases, the skin is pierced on the medial side of the elbow joint.

3.2 Joint Capsule, Muscles

Extension fractures are frequently accompanied by tearing of the anterior joint capsule. If there is marked dislocation, severe injury to the brachialis muscle on the volar side may occur; the triceps tendon on the dorsal aspect usually remains intact. Severe scarring of the brachialis muscle or of the anterior capsule subsequently limits extension of the elbow.

3.3 Nerve Injuries

Nerve injuries are among the most frequent complications of supracondylar fractures. *Hördegen* found paralysis due to nerve injury in 17% of his cases; a mean frequency of 5%–8% was reported in the literature cited by him. The most frequent injury is that of the radial nerve, followed by the median nerve, combined paralysis, and the ulnar nerve, in that order.

3.4 Brachial Artery

Injuries to the brachial artery are less common. They may be direct injuries, such as compression, contusion, or division, caused by antecubital penetration of the proximal bone fragment. Indirect injury results from stretching of the vessel. If the artery is simply compressed, the blood flow returns to normal following reduction of the fracture. A frequent form of serious injury to the brachial artery is damage to the wall of the artery caused by excessive stretching, particularly tearing of the intima. The intima curls up and obstructs the blood flow. In addition, the blood flow is often reduced by the spasm which originates at the site of the vascular injury.

Division of the artery and trapping of the vessel between the bone fragments have been described in the literature, but we have not yet encountered injuries of this type.

3.5 Ischemic Muscle Necrosis and *Volkmann* Contracture

Any severe disturbance of the blood supply to a muscle may lead to ischemic necrosis of the muscle and thus give rise to a *Volkmann* contracture. Those muscle groups are particularly vulnerable which are enclosed in a tough fascia, such as the muscles of the forearm. If the capillaries or venules within these fascial compartments are compressed by edema or hematoma, the blood supply may be impaired, even if the arterial flow is unrestricted.

The development of ischemic necrosis is not dependent on the site of impairment of the vascular supply, be it arterial, venous, or capillary. The only determinant is the duration of the ischemia.

Closure of the brachial artery which is accompanied by interruption of the collateral blood supply due to arterial spasm causes necrosis of the muscle tissue within a few hours. Impairment of the capillary or venous circulation is tolerated by the muscle for somewhat longer periods, i.e., 24–48 h.

An excessively tight bandage restricts expansion of the forearm muscles and, thus, may cause a dangerous rise in intramuscular pressure in a manner similar to that of the tough fascia. Furthermore, marked flexion of the elbow joint is associated with the risk of edema formation due to obstruction of venous blood flow and lymph drainage.

Volkmann contracture results from replacement of the necrotic muscle by fibrous tissue. However, ischemia damages not only muscle, but also nerves, and it may therefore give rise to sensory deficit or motor palsy. In a fully-developed case of ischemic damage, the hand is completely deformed and useless.

Volkmann contractures are now rare, thanks to correct treatment and improved surveillance by hospitalization of patients who are at risk, but this complication still occurs. Among the patients followed-up by us, only one case was found, the contracture in this case being partial.

The symptoms and signs of impending ischemic muscle necrosis are: severe pain in the muscles of the forearm; painful limitation of the range of finger motion, particularly of extension; livid coloration of the hand; prominence of the superficial veins; paresthesia; loss of the radial pulse; and paralysis of the fingers and hand. These can be summarized as the five P's: pain, pallor, paresthesia, pulselessness, paralysis.

In our opinion, immediate surgery is imperative if there is angiographic evidence of vascular injury or if, following reduction of the fracture, the radial pulse is absent and the capillary blood flow is unsatisfactory. This caution is justified since experience, particularly that with the anterior tibial compartment syndrome, has shown that disturbances of function frequently follow ischemia which was thought to be insignificant.

If symptoms and signs of ischemia are accompanied by a palpable radial pulse, the possible causes should be immediately checked, e.g., excessive flexion of the elbow, a bandage which is too tight, dislocation of the fracture, hematoma. If the symptoms persist and are not relieved immediately on keeping the arm raised, extensive splitting or excision of the fascia is the only means of preventing muscle necrosis.

4 Causes and Mechanisms of Trauma

Extension fractures result from a fall on the hand with the elbow flexed. The force of the impact is transmitted by the bones of the forearm and causes backward dislocation of the lower end of the humerus (*Kocher*). According to *Lubinus*, backward dislocation of the lower epiphysis of the humerus may also result from a fall onto the flexed forearm. Furthermore, typical oblique extension fractures result from hyperextension of the elbow joint.

According to *Kocher*, torsion mechanisms are also involved in the causation of supracondylar fractures. It is well possible that the upper arm be held fixed by the powerful internal rotator muscles (latissimus dorsi and pectoralis major) during a fall, causing the distal fragment to be twisted off by an external rotation force. An impact on the elbow from behind, e.g., a fall onto the flexed elbow, results in a flexion fracture.

5 Frequency and Age Distribution

Supracondylar fractures of the humerus are among the most frequent fractures in children. In our series, they constitute 5.6% of all fractures of the extremities, thus being the fourth most frequent type of fracture.

Approximately 60% of all fractures in the region of the elbow joint are supracondylar (*Fahey*). They occur more frequently in boys than in girls.

Supracondylar fractures typically occur in children of school age. In the figures published by *Riess*, approximately 50% of supracondylar fractures occurred in children between 6–10 years of age, and 80.9% in those up to 18 years of age.

6 Treatment of Supracondylar Extension Fractures

The problems of treatment are associated less with reduction than with stabilization of the fragments. The problems arise in choosing a method which allows optimum stabilization of the fracture without impairment of the blood supply, and which also prevents edema. Of the numerous methods of treatment, the following are used in our clinic.

6.1 Group I Fractures

Group I fractures with insignificant swelling are immobilized for 3 weeks by the *Blount* cuff-and-collar method. Children who need to use the injured arm for dressing, writing, etc., are treated with a full-arm cast for the same period of time.

Treatment is ambulatory, with a radiological check at 1 week and at the end of treatment.

6.2 Noncomplicated Fractures of Groups 2 and 3

These fractures always necessitate the admission of the patient to a hospital, even if they appear to be simple injuries which are unlikely to present problems. The children are kept under in-patient surveillance for several days until one is sure that no complications have arisen.

In the absence of a clear indication for surgery, fractures of Groups 2 and 3 are treated by closed reduction under a general anesthetic. If there is some doubt as to whether the fracture will remain stable following reduction, preparations are made for the application of a traction device or for operation so that these procedures can be carried out under the same anesthetic without delay.

6.2.1 Closed Reduction

A correctly performed maneuver suffices for the reduction of the majority of fractures. If the first attempt at reduction fails, the manipulation is gently repeated. Interposed tissue may occasionally prevent reduction. In these cases, it is dangerous to force reduction by severe angulation of the fragments since this may not only cause further soft tissue damage, e.g., injury to the radial nerve, but may also increase the fragmentation of the bone ends and thus render subsequent treatment, including surgery, more difficult.

Closed reduction (Fig. 5) starts with the extraction of the proximal fragment from the brachialis muscle: the assistant holds the upper arm at the level of the axilla with both hands, while the surgeon grips and pulls on the supinated wrist of the patient with one hand and holds the elbow joint on the medial side with the other. The elbow should be flexed at an angle of approximately 30° in order to prevent nerves or the brachial artery from being stretched over the proximal fragment and damaged (*Watson-Jones*). When the proximal fragment has been extracted from the cubital region, the joint is extended somewhat (but not overextended) in order to reduce the tension on the dorsal periosteum. The longitudinal traction is maintained.

Any varus, valgus, or rotation deformities which remain are now corrected. The surgeon then presses the proximal fragment backwards with his thumb and displaces or tilts the distal fragment forwards with the remaining fingers. It is particularly important that the fragments be kept separated by longitudinal traction during this phase of reduction.

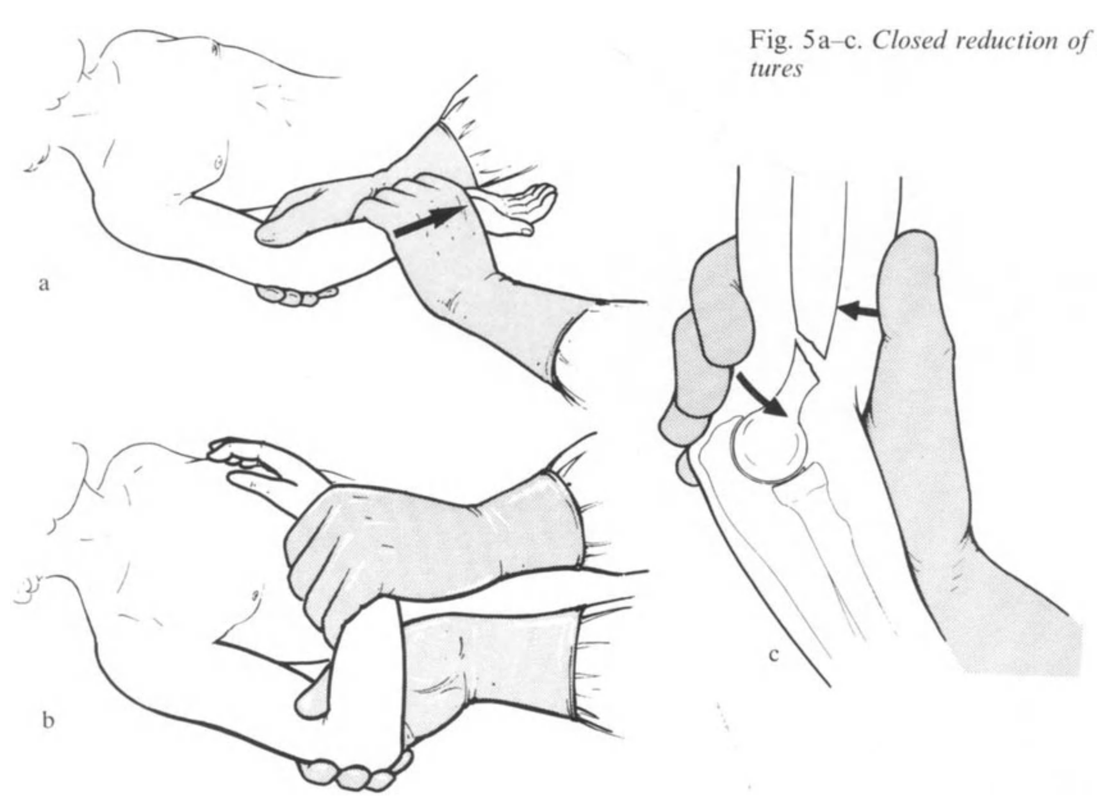


Fig. 5a–c. *Closed reduction of supracondylar extension fractures*

Finally, the surgeon holds the fragments firmly in the reduced position and flexes the elbow acutely. The reduction is then checked with a roentgenogram in this position.

The stability of the fracture, which is important for subsequent treatment, is assessed by careful movement of the elbow joint and by placing the forearm against the body.

6.2.2 Guidelines for Treatment

a) *Fracture stable when flexed at an acute angle.* If swelling insignificant: treatment with collar-and-cuff (*Blount*) for 3–4 weeks (Fig. 6). As a rule, this only applies to Group 2 fractures.
If swelling considerable: treatment by the *Baumann* method, vertical traction being applied with counterpull (Fig. 7). Alternatively, surgery may be necessary in order to stabilize the fracture.

b) *Fracture also stable with the elbow flexed at a right angle.* If swelling insignificant: Fixation with a slightly padded, split full-arm cast with the forearm in midpronation. Immobilization for about 4 weeks (Fig. 8).
If swelling considerable: treatment by vertical traction without counterpull, or by operative stabilization.

c) *Fracture easily reducible, but unstable; swelling allows positioning of the elbow at a right angle.* Treatment by vertical traction, with counterpull if necessary, or by operative stabilization.

6.2.3 Vertical Traction

A number of traction techniques with vertical or horizontal positioning of the upper arm have been described (*Baumann, von Ekesparre, Dunlop*). We prefer *Baumann*'s method of vertical traction (Fig. 9). The traction is applied directly to the bone and does not stress the skin. Furthermore, the positioning of the fragments is easily controlled and is less influenced by the movements of the child in bed than is the case with horizontal traction. The traction is applied to a cortical screw which is inserted into the ulna just distal to the coronoid process (*Fahey; Müller, Allgöwer, Willenegger*) (Fig. 7). The firmly fixed screw is a less effective portal of entry for bacteria than a *Kirschner* wire which is constantly rotating and sliding back and forth.

The vertical traction cord runs over a frame which is parallel to the forearm (Fig. 9). In order to prevent the fragment tilting, particularly in varus, as the child slides up and down in bed, the vertical traction cord should be made as long as possible. The child should lie at the upper end of the bed during the initial adjustment of the frame.

The vertical traction is adjusted so that the pull just suffices to lift the shoulder off the bed. Counter-

Fig. 6a–c. *Example of treatment by the Blount method.* I.D., ♀, aged 8 years, No. 121121.
a) Left-sided Type II extension fracture with insignificant swelling.
b) Following reduction, the fracture is stable with the elbow joint in acute flexion. Immobilization for 4 weeks.
c) $1^{1}/_{2}$ years later. The anatomy and function of the elbow joints are symmetrical

pull, if required, is applied to the forearm with adhesive plaster and to the upper arm with a sling. In each case, 1–1.5 kg countertraction suffices. The final position of the arm is as follows: the elbow is flexed at a right angle; the forearm is directed caudocranially, corresponding to the midrotation position of the upper arm at the shoulder joint; the thumb points to the face.

Duration of traction: 14–18 days.

Subsequent treatment: full-arm cast for 2–3 weeks.

The results of treatment by traction are completely satisfactory. However, this method increases the daily nursing care considerably and the child has to remain in bed. For this reason, operative techniques, such as open or percutaneous fixation with drilled-in *Kirschner* wires are nowadays frequently preferred.

6.3 Operative Treatment

"Intransigent" fractures and those involving injury to nerves or to the brachial artery have almost since time immemorial been regarded as indications for surgery. Already some considerable time ago good results were obtained by open reduction and wire suturing or fixation with nails or screws (*Baumann*), but nevertheless operative methods were reserved for exceptional cases, not least of all because of the risk of infection. However, the situation has been radically changed by technical advances (aseptic and antiseptic methods, corrosion-resistant implants, X-ray image intensifiers) and by standardized and less traumatic surgical procedures (*Witt, J. Böhler*), so that nowadays in problem cases, operative treatment is more likely

Fig. 7a–c. *Example of treatment by vertical traction.* S.P., ♂, aged 8 years, No. 106752.
a) Left-sided Type III extension fracture with marked swelling.
b) Vertical traction was applied with countertraction, since the reduced fracture was only stable with the elbow fully flexed. The appearance of a thin callus layer after 2 weeks (*arrow*) is a sign that the dorsal periosteum was lifted away from the bone, but not torn.
c) Symmetrical elbows 3 years after the accident with the exception of marked acceleration of growth in the epiphyseal centers of ossification of the left elbow joint

Fig. 8a–c. *Example of treatment with a circular full-arm cast.* P.U., ♀, aged 11 years, No. 119318.
a) Left-sided Type II fracture bordering on flexion type. Insignificant swelling.
b) Slight overcorrection with valgus deformity. Immobilization for 4 weeks.
c) Anatomically and functionally symmetrical elbows 1 year after the accident

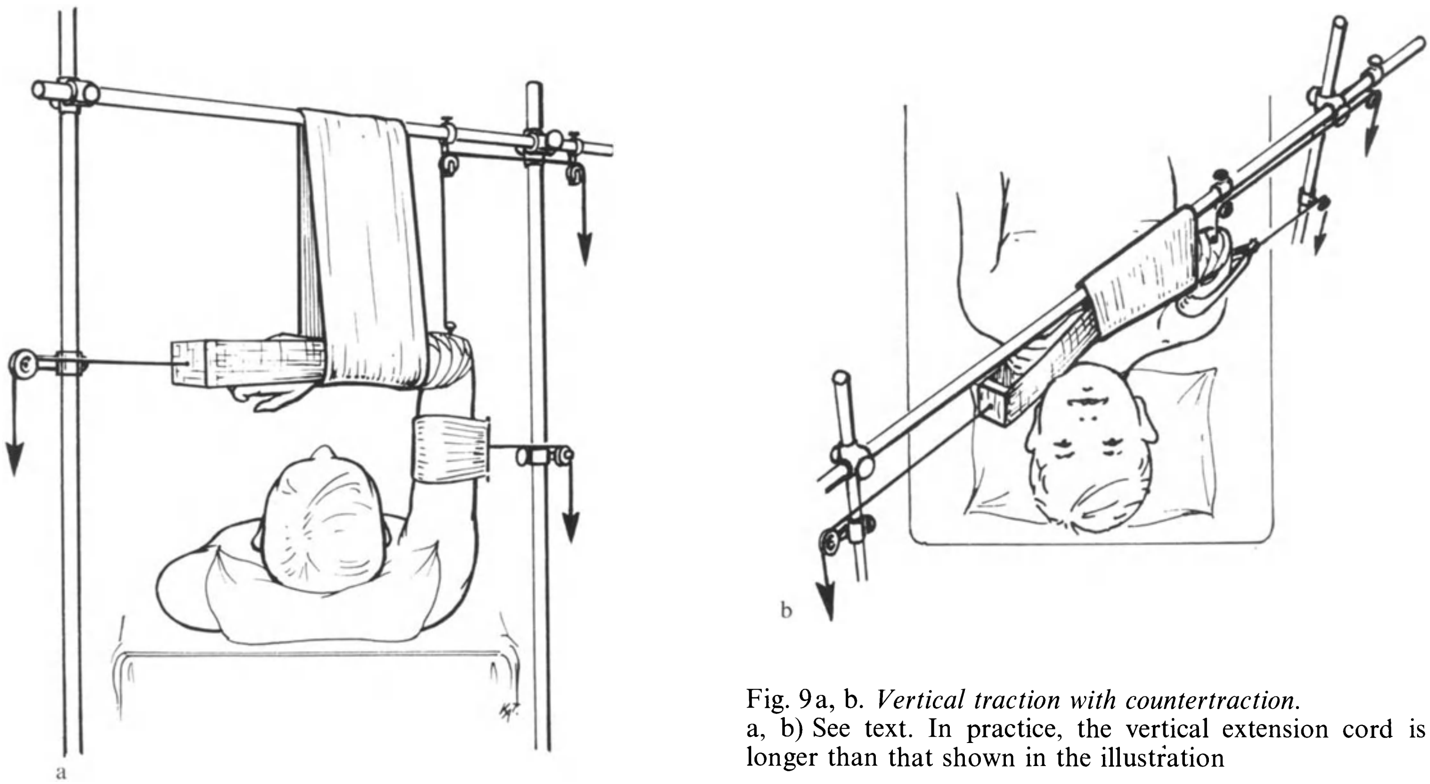


Fig. 9a, b. *Vertical traction with countertraction.*
a, b) See text. In practice, the vertical extension cord is longer than that shown in the illustration

to produce a satisfactory end result than nonoperative management.

6.3.1 Indications for Operative Treatment

We recognize the following indications for surgery:

a) Injury to the brachial artery; absence of the radial pulse following closed reduction.
b) Incipient *Volkmann* ischemia despite correct non-operative treatment.
c) Primary nerve injury.
d) Open fractures.
e) Extensive fracture hematoma. Severe swelling of the elbow region.
f) Fractures which cannot be satisfactorily reduced by closed manipulation.

The operation is performed on an emergency basis under general anesthesia. A pneumatic tourniquet is applied. During the operation, hematomas are evacuated, tissue debris are removed, and hemostasis is secured. Crushed nerve trunks are carefully exposed, protected during reduction of the fracture, and then returned to their original sites following removal of blood and tissue debris from the latter.

Experience in vascular surgery is necessary for the assessment and treatment of injuries to the brachial artery. Above all, the surgeon should be on the look-out for intimal lesions, which frequently extend way beyond the externally visible injury and which may induce thrombotic occlusion of the vessel. In such cases, it is imperative that a segment of the artery be resected which includes the whole of the intimal lesion; this segment is then replaced by a vein graft.

6.3.2 Operative Technique and Approaches

Lateral Approach. The patient lies supine. A longitudinal incision is made over the lateral epicondyle and the lateral margin of the humerus is exposed behind the lateral intermuscular septum. The fracture is exposed under the periosteum and reduced under direct vision. It is then fixed with two crossed *Kirschner* wires (Fig. 10). One *Kirschner* wire is inserted through the proximal fragment into the medial column of the metaphysis; this *Kirschner* wire lies behind the lateral muscle septum so that it does not exert pressure on the radial nerve. The second *Kirschner* wire is drilled through the lateral epicondyle and the lateral column into the proximal fragment. It passes through the cortex, leaving no more than the tip projecting. The ends of the *Kirschner* wires are bent round and buried under the skin.

Medial and Lateral Exposure. If satisfactory reduction is not possible using the lateral approach, an additional short longitudinal incision through which reduction can be completed is made over the medial epicondyle. In such a case, both *Kirschner* wires are drilled in through the epicondyles.

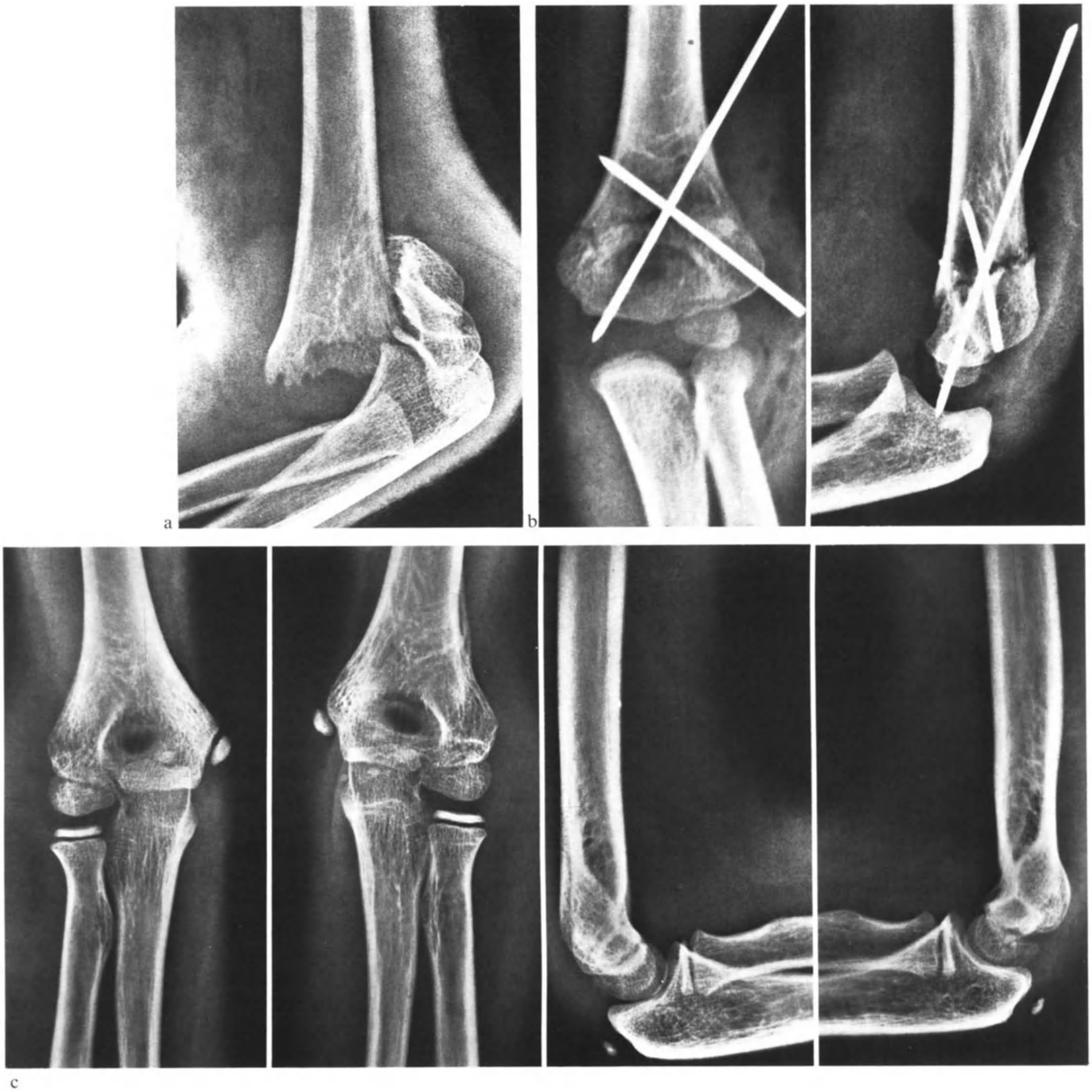


Fig. 10a–c. *Example of internal fixation by crossed Kirschner wires introduced from the lateral side.* H.R., ♂, aged 5 years, No. 82853.
a) Left-sided Group III extension fracture with severe swelling.
b) Radiological check during the operation.
c) Anatomically and functionally symmetrical elbows 6 years after the operation

Dorsal Approach. Dorsal approaches are only suitable for fractures which are not accompanied by injuries to vessels or nerves. The advantage common to all the dorsal approaches lies in the position of the arm, which eases reduction of the fracture. We no longer make a longitudinal incision through the triceps tendon, since this may easily result in injury to the branch of the radial nerve which supplies the deep head of triceps and the anconeus muscle. Instead, we prefer the combined dorsal approach (*Magerl*) which is carried out as follows:

The patient lies prone. The upper arm is placed on a short board; the elbow is flexed at a right angle and the forearm hangs down freely. A midline skin

Fig. 11 a–c. *Example of the insertion of both Kirschner wires through the epicondyles using a dorsal approach.* N.A., ♀, aged 8 years, No. 168547.
a) Right-sided Type III extension fracture.
b) 6 weeks after the accident. The fracture has healed following anatomically precise reduction.
c) Follow-up 1 year later. Accelerated growth and slight cubitus varus on the right side. Elbow function is perfect

incision is made and the triceps tendon and both epicondyles are exposed. The area of the fracture under the triceps tendon is then bared, first working from the lateral epicondyle and the lateral border of the humerus and then from the medial epicondyle. Great care is taken to avoid injury to the ulnar nerve. The fragments are stabilized in the manner described above, using crossed *Kirschner* wires which are drilled in through the epicondyles (Fig. 11).

6.3.3 Postoperative Treatment

A split, padded, full-arm cast is applied and the arm is kept raised until the swelling has subsided. The skin sutures are removed after 10–12 days. Four to 6 weeks after the operation, the cast can be taken off, the *Kirschner* wires are removed through stab incisions, and normal mobilization is begun.

Fig. 12a–c. *Example of the operative treatment of a flexion fracture*. R.J., ♂, aged 13 years, No. 74997.
a) Left-sided flexion fracture with displacement of the fragment by the full width of the shaft in an anterior and lateral direction.
b) Open reduction and stabilization with crossed *Kirschner* wires (see text).
c) Anatomically and functionally symmetrical elbows 7 years later

7 Treatment of Supracondylar Flexion Fractures

According to the method of *Watson-Jones,* these fractures are reduced and immobilized with the elbow completely extended. Immobilization with the joint in this position presents problems, however, and the method is not used in our clinic. If a reduced flexion fracture shows no tendency to dislocate with the elbow flexed at a right angle, a conventional full-arm cast is applied. Otherwise, we prefer open reduction and fixation. The operative technique is the same as that described for extension fractures (Fig. 12).

8 Treatment Following Fracture Healing

Following the completion of fracture healing, the mobility of the elbow joint is normally limited. Nevertheless, no special treatment is necessary. The joint recovers its normal range of motion rapidly and spontaneously if the child forgets the injury and uses the arm normally. Any attempt to accelerate this process, however well meant, usually has the opposite effect. This particularly applies to passive exercises, which cause pain and reflex inhibition of muscle movement; the child becomes frightened and mistrustful and ends by protecting the injured arm from movement.

9 Fracture Sequelae

9.1 Posttraumatic Myositis Ossificans in the Brachialis Muscle

Posttraumatic myositis ossificans of the brachialis muscle appears to be a very rare complication of supracondylar fracture of the humerus in the child. We, too, have not seen a single case to date.

9.2 Contracture of the Capsule

Fibrous contracture of the anterior joint capsule and adhesions to the similarly scarred surface of the brachialis muscle may permanently limit extension of the elbow joint, even in an adolescent. In severe cases, the range of movement may be improved by excision of the anterior capsule.

9.3 Restriction of Movement Due to Malunion

Antecurvature or retrocurvature (increase or decrease of the angle between the epiphysis and diaphysis, shown in Fig. 13) causes a shift in the range of flexion-extension movement of the elbow. Thus, for example, antecurvature reduces the range of flexion and increases that of extension. The shift in the range of flexion corresponds to the change in the angle between the epiphysis and the diaphysis, except when one of the fossae is filled in by a projecting fragment, callus, or scar tissue. Relative antecurvature often occurs, but this form of malunion is particularly frequently accompanied by flattening of the olecranon fossa so that nevertheless the range of extension is reduced, i.e., the olecranon process cannot fit deeply into the olecranon fossa. Flexion may be initially limited by projection of the proximal fragment into the coronoid or radial fossa as a result of rotation deformity. The subsequent resorption of the spur of the proximal fragment is accompanied by a progressive increase in the range of movement. Bone shelves which project above the fossae do not usually cause significant limitation of flexion of the elbow joint.

9.4 Malunion

The significance of deformity in the parasagittal plane (epiphysis-diaphysis angle) and in the horizontal plane (rotation) has already been mentioned. The following remarks concerning these types of deformity may be added.

As far as can be ascertained, spontaneous correction of the angle between the epiphysis and the diaphysis or of rotation deformity do not occur during subsequent growth.

Rotation deformity is evidenced radiologically by difference in width of the fragments and by the ventral overhang of the proximal fragment. The incongruity of the fragments is smoothed out by resorption and deposition of bone and becomes invisible with the passage of time (Fig. 13). Severe rotation deformity then only becomes evident if the ranges of rotation movement in the shoulder joints are compared.

Cubitus varus. The types of deformity previously mentioned manifest themselves indirectly. In contrast, varus angulation of the elbow is immediately obvious to the patient, his relatives, and the doctor. In the majority of cases, the problem is purely an aesthetic one. Patients rarely complain of pain on loading the elbow or of weakness, and only do so if there is severe varus deformity.

Varus deformity, or varisation of the carrying angle, is still a surprisingly frequent sequel of supracondylar fracture of the humerus in children. According to *Schlag* and *Halbe*, for example, frequencies ranging from 9% to 57% are reported in the literature. In our own case material, varus deformity was found in approximately 47%.

It is largely agreed that varus deformity of the elbow results from tilting of the distal fragment. The person mainly responsible for recognizing this fact was *Baumann,* who disproved the widely accepted idea that varus deformity resulted from a difference in growth rates. *L. Böhler* called attention to the part played by pronation and supination of the forearm in the pathogenesis of varus elbow.

The cause of varus elbow is varus angulation of the distal fragment. The internal rotation deformity acts, so to speak, as a pacemaker, since the distal fragment of a transverse fracture can only tilt as a result of rotation (Fig. 3). *Graham* demonstrated that, if the fracture surfaces are inclined, rotation in the plane of the fracture suffices to induce varus angulation of the elbow, and that this effect is proportional to the degree of inclination of the fracture surfaces.

The arguments that varus deformity is caused mechanically are so convincing that further discussion might be considered to be superfluous. However, the results of our own investigations once more suggest that growth processes could well be involved in the development of varus deformity of the elbow in the child. We were particularly surprised by the high rate of varus deformity following fractures whose angular

Fig. 13a–d. *An example of rotation deformity, antecurvature, and remodelling of fracture fragments*. B.R., ♀, aged 6 years, No. 107623.
a) Right-sided Type II extension fracture with valgus, antecurvature, and rotation deformities. The rotation deformity can be deduced from the difference in the width of the fragments on the lateral film. A corner of the proximal fragment projects on the ventral side like a nose.
b) Unchanged position of the fragments in a cast 1 week after the accident.
c) Remodelling of the fragments is already well under way 6 weeks after the accident. Bone is being deposited on the dorsal aspect and resorbed from the ventral side. The "nose" is already much smaller.
d) There are no longer any signs of rotation deformity 2 years after the accident. The enlargement of the diaphysis/epiphysis angle on the right side is a sign of residual antecurvature deformity

alignment appeared to be good or even perfect at the time of union (Fig. 11). Similar observations were reported by *Kutscha-Lissberg* and *Rauhs*: of 40 nondisplaced supracondylar fractures, ten healed with angular deformity in the frontal plane. The deformity in these ten cases, as well as that following reduction of other fractures, remained constant following removal of the plaster cast. The authors therefore concluded that misalignment of the fragments had occurred subsequent to reduction and that growth disturbances were not responsible for the deformity.

We still have no satisfactory explanation for the varus angulation of the metaphysis which is so frequently seen. It must be assumed that latent misalignment or secondary dislocation are mainly responsible. In many cases, however, with the aid of *Baumann*'s line and the longitudinal axis of the ulna distal to the fracture, varus deformity could be demonstrated for which the only likely explanation is increased growth of the epiphyses on the radial side (capitulum humeri, capitulum radii) and, perhaps, inhibition on the medial side by the firmly anchored ulnar collateral ligament (Fig. 14). Thus, in principle, varus angulation due to growth seems to be possible, at least in the region of the centers of ossification of the elbow joint, where it is limited to 5°–10°. However, angulation due to growth would accentuate that due to malunion or secondary dislocation of the fracture. This provides a better explanation of the frequency and severity of posttraumatic varus deformity of the elbow than malunion of the distal fragment alone.

Treatment of Deformity. Supracondylar osteotomy is indicated for the correction of varisation of the carrying angle of the elbow if the latter is aesthetically very displeasing or causes symptoms, and also for loss of flexion or extension caused by malunion. The osteotomy should be carried out before the cessation of growth, since the complication rate is lower in adolescents than in adults (*Magerl*).

10 Own Results

From 1962 to 1968, we treated 65 supracondylar fractures of the humerus in children and adolescents. The cases were followed-up in 1969.

A. Nonoperative Treatment

Number of cases:	33
Ages:	1–13 years (mean age: 6.6 years)
Sex distribution:	16 girls, 17 boys

Fig. 14a

Fracture side:	15 right, 18 left
Fracture types:	31 extension fractures, 2 flexion fractures
Open fractures:	None
Injuries to nerves or vessels:	None

Methods of treatment and degrees of dislocation (*Felsenreich* classification):

Cuff and collar:	7 (five first degree, two second degree)
Upper arm cast:	15 (4 first degree, 9 second degree, two third degree)
Vertical traction:	11 (6 second degree, 5 third degree)
Total:	33 (first degree: 9 second degree: 17 third degree: 7)

Results of Treatment

Followed-up:	32
Duration of follow-up:	1–7 years (mean: 3.1 years)
Symptoms	None: 30; Slight: 2

Range of movement:

Same on both sides:	20
Flexion limited:	8 (up to 10°: 6, up to 15°: 2)

b c

d

Fig. 14a–d. *Varus deformity of the elbow, partly caused by abnormal growth*. S.P., ♂, aged 9 years, No. 88575.
a) Left-sided Type III supracondylar extension fracture.
b) Radiological check during the operation. Anatomically precise reduction.
c) Radiological check 4 weeks after the operation. The fracture has united, but the fragments have separated somewhat along the line of the *Kirschner* wire on the radial side. The resulting varus tilt of the distal fragment amounts to approximately 10°. There is no rotation deformity. It is not yet possible to measure the carrying angle as the elbow cannot be fully extended.
d) 5 years after the operation, the carrying angles are 164° on the right side and 186° on the left. Using the *Baumann* Line, it can be shown that there is approximately 12° of varus tilt in the region of the metaphysis. This roughly corresponds to the degree of redislocation of the fragments seen 4 weeks after the operation. The remaining 10° of varus deformity are located distal to the metaphysis of the humerus and can only be accounted for by asymmetrical growth in the epiphyseal centers of ossification. The enlargement of the epiphyseal centers of ossification provides evidence of the stimulation of growth

Extension limited:	6 (up to 10°: 5, up to 15°: 1)

Change in carrying angle of elbow:

Varisation:	5°–10°: 12, up to 15°: 3
Valgisation:	5–10°: 3

Change in diaphysis-epiphysis angle:

Increase (antecurvature):	5°–10°: 6, up to 15°: 4
Decrease (retrocurvature):	5°–15°: 2

Accelerated growth on the side of the fracture:

Enlargement of the epiphyseal centers of ossification:	18 (not assessable: 4)
Lengthening of the arm (up to 1.5 cm):	7

B. Operative Treatment

Number of cases:	32
Ages:	4–14 years (mean age 8.5 years)
Sex distribution:	11 girls, 21 boys
Fracture side:	13 right, 19 left
Fracture types:	31 extension fractures 1 flexion fracture
Degrees of dislocation (*Felsenreich*)	Grade 2:3 Grade 3:29
Open fractures:	1
Pareses	6 (radial nerve:4 median nerve: 1 ulnar nerve: 1
Incipient ischemia:	2
Additional fractures of the same arm:	3 cases (1 open olecranon fracture and fracture of the distal forearm; 2 fractures of the distal forearm)

Results of Treatment

Followed-up:	32
Duration of follow-up:	1–7 years (mean: 3.5 years)
Postoperative complications:	None
Symptoms:	None: 30 Slight: 2

Range of movement:

Same on both sides:	23
Flexion limited:	7 (up to 10°:4, up to 15°:3)
Extension limited:	4 (up to 10°: 2, up to 15°: 2)

Change in carrying angle of elbow:

Varisation:	5°–10°: 5, up to 15°: 5, up to 20°: 2, 22°: 1
Valgisation:	Over 5°: 0

Change in diaphysis-epiphysis angle:

Increase (antecurvature):	5°–10°: 3, up to 15°: 4
Decrease (retrocurvature):	over 5°: 0

Accelerated growth on the side of the fracture:

Enlargement of the epiphyseal centers of ossification:	22 (not assessable: 6)
Lengthening of the arm (up to 2 cm):	9
Residual paresis:	1 (residual paresis of the radial nerve)
Partial *Volkmann* contracture:	1

In the discussion on the causes of cubitus varus in §9.4, reference is made to results of our own. These were derived from the investigation of 26 supracondylar fractures which united with apparently perfect alignment. Nine of these fractures were treated nonoperatively (4 fissures) and 17 operatively. In 16 cases, varisation of 5°–20° occurred. Valgisation of the carrying angle occurred in only two cases (less than 10°).

11 Summary

Supracondylar fractures of the humerus are typical fractures of school-age children. The extracapsular *Aitken* Type I fractures are classified in three groups according to the degree of dislocation. Injuries to the surrounding tissues mainly involve the neighboring nerve trunks, the radial nerve being that which is most frequently affected. The resulting paralysis is usually reversible. Injuries to the brachial artery and ischemic muscle necroses are much less common, but have serious consequences.

The treatment of the fracture is determined by its stability following reduction, by the accompanying injuries in the vicinity, and by the degree of swelling (fracture hematoma).

Simple, stable fractures are suitable for nonoperative treatment if the degree of swelling is such that complications are unlikely to arise. Operative treatment is to be preferred for all other types of fracture. The individual methods of treatment and their indications are discussed in detail. Approximately half the cases are treated operatively, and the rest conserva-

tively. For the operative stabilization of these fractures, we prefer open fixation with drilled-in *Kirschner* wires. No significant postoperative complications have occurred to date. In our series of cases, the results of operative and nonoperative treatment are approximately the same, even though surgery was almost exclusively reserved for Group 3 fractures and for those with complications. Subjective complaints rarely result from these fractures, and those which arise are not serious. The range of movement is the same on both sides in approximately two-thirds of the cases, and is limited by not more than 15° in the remaining patients. On a less satisfactory note, varisation of the carrying angle of the elbow occurred in almost half the cases, even following fractures which appeared to have been correctly united when union took place.

The causes of cubitus varus are discussed in this chapter. Supracondylar fractures of the humerus could be regarded as completely benign if it were not for the danger of *Volkmann's* ischemic contracture, and if the problem of posttraumatic cubitus varus were completely solved.

12 References

Baumann, E.: Über Regenerationserscheinungen am verletzten Ellbogen. Schweiz. med. Wschr. **54**, 1057 (1924).

Baumann, E.: Beiträge zur Kenntnis der Frakturen am Ellenbogengelenk. Bruns Beitr. klin. Chir. **146**, 1 (1929).

Baumann, E.: Grundsätzliches über die Zugbehandlung der Knochenbrüche. Z. Unfallmed. Berufskrankh. 1953, 3–16.

Baumann, E.: Zur Behandlung der Knochenbrüche am Ellenbogengelenk. Langenbecks Arch. Chir. **295**, 300 (1960).

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Blount, W. P., Schulz, I., Cassidy, R. H.: Fractures of the elbow in children. J. Amer. med. Ass. **146,** 699 (1951).

Böhler, J.: Gekreuzte Bohrdrähte, ein einfaches Prinzip der Osteosynthese. Arch. orthop. Unfall-Chir. **47**, 242 (1955).

Böhler, J.: Frische Ellenbogenverletzungen. Verh. dtsch. orthop. Ges. **45**, 349 (1958).

Böhler, L.: Die Technik der Knochenbruchbehandlung, 12.–13. Aufl., Bd. I. Wien: Maudrich 1951.

Böhler, L.: Behandlung der supracondylären Oberarmbrüche bei Kindern und Jugendlichen. Mschr. Unfallheilk. **64**, 1 (1961).

Dunlop, J.: Transcondylar fractures of the humerus in childhood. J. Bone Jt Surg. **21**, 59 (1939).

Egyed: Zit. n. Katzmann.

v. Ekesparre, W.: Die Behandlung der suprakondylären Humerusfraktur im Kindesalter. Dtsch. med. J. **9**, 168 (1958).

Fahey, J. J.: Fractures of the elbow in children. The American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Vol. XVII, p. 13. St. Louis: Mosby 1960.

Felsenreich, F.: Kindliche suprakondyläre Frakturen und posttraumatische Deformitäten des Ellenbogengelenkes. Arch. orthop. Unfall-Chir. **29**, 555 (1931).

Graham, H. A.: Supracondylar fractures of the elbow in children, Part 1 and 2. Clin. Orthop. **54**, 85 (1967).

Hördegen, K. M.: Neurologische Komplikationen bei kindlichen supracondylären Humerusfrakturen. Arch. orthop. Unfall-Chir. **68**, 294 (1970).

Katzmann, H.: Zur Behandlung suprakondylärer Oberarmfrakturen bei Kindern. Zbl. Chir. **90**, 2089 (1965).

Kocher, Th.: Beiträge zur Kenntnis einiger praktisch wichtiger Fracturformen. Basel und Leipzig: Carl Sallmann 1896.

Kutscha-Lissberg, E., Rauhs, R.: Frische Ellenbogenverletzungen im Kindesalter. Hefte zur Unfallheilkunde, H. 118. Berlin-Heidelberg-New York: Springer 1974.

v. Lanz, T., Wachsmuth, W.: Praktische Anatomie, 2. Aufl., Bd. I/3. Berlin-Göttingen-Heidelberg: Springer 1959.

Lubinus: Ueber den Entstehungsmechanismus und die Therapie der suprakondylären Humerusfrakturen. Dtsch. Z. Chir. **186**, 289 (1924).

Magerl, F.: Ein dorsaler kombinierter Zugang zum Humerus. Hefte zur Unfallheilkunde, krankh. **114**, S. 20. Berlin-Heidelberg-New York: Springer 1972.

Magerl, F.: Ellenbogenfraktur beim Erwachsenen–ein dorsaler kombinierter Zugang zum Humerus. Z. Unfallmed. Berufskrankh. **2**, 59 (1973).

Magerl, F.: Suprakondyläre Korrekturosteotomien am Humerus bei Erwachsenen. Z. Unfallmed. Berufskrankh. **2**, 87 (1973).

Müller, M. E., Allgöwer, M., Schneider R., Willenegger, H.: Manual of Internal Fixation, 2nd edition. Heidelberg-Berlin-New York: Springer 1979.

Riess, J.: Der suprakondyläre Oberarmbruch. In: Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Schlag, G., W. Halbe: Die gedeckte Bohrdrahtosteosynthese des stark verschobenen kindlichen suprakondylären Oberarmbruches. Mschr. Unfallheilk. **74**, 97 (1971).

Schmid, F., L. Halden: Die postfetale Differenzierung und Größenentwicklung der Extremitätenknochenkerne. Fortschr. Röntgenstr. **71**, 975 (1949).

Smith, L.: Deformity following supracondylar fractures of the humerus. J. Bone Jt Surg. **42 A,** 235 (1960).

Watson-Jones: Fractures and Joint Injuries, 5the Ed., Vol. II. Edinburgh, London and New York: Churchill Livingstone 1976.

Witt, A. N.: Zur operativen Behandlung der supracondylären Humerusfrakturen im Kindesalter. Chirurg **26**, 488 (1955).

Fractures of the Elbow

H. ZIMMERMANN

CONTENTS

1 Introduction

Fractures of the elbow joint in children may occur at any age. They usually result from indirect violence, such as a fall onto the outstretched hand. The force may act axially on the joint, or it may be directed obliquely and thus tend to produce valgus or varus angulation, flexion, or hyperextension. The nature of the resulting injury is also determined by the angle of the elbow and the position of the forearm during the accident. Thus, for example, pronation abolishes the physiological valgus angulation of the elbow and changes the direction of the force from valgus to varus. An axial impact drives the capitulum and the trochlea apart, producing a T(Y)-shaped fracture. The fracture gapes proximally and the fragments are tilted in the frontal plane owing to the pull of the collateral ligaments and that of the flexor and extensor muscles (Fig. 1).

The most frequent trauma mechanism is that of *valgus angulation*. The force may be direct or indirect.

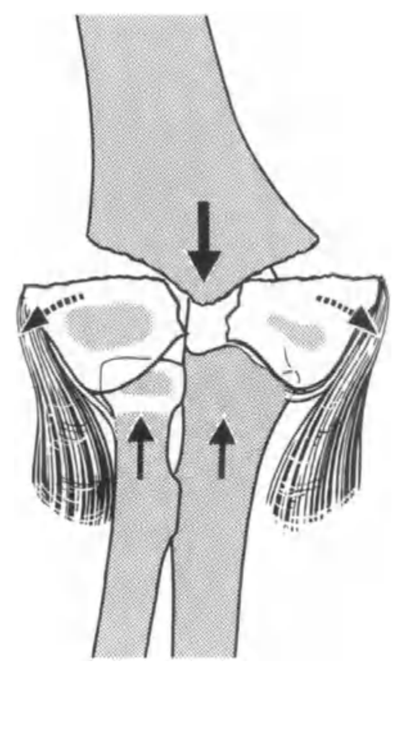
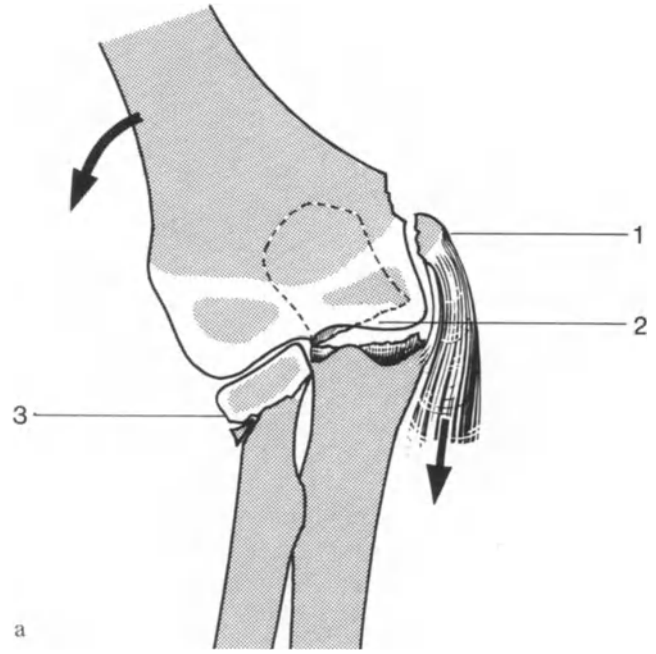


Fig. 1. *Axial compression fracture of the distal humerus.* Purely axial compression causes a T-shaped fracture and drives the capitulum of the humerus and the trochlea apart



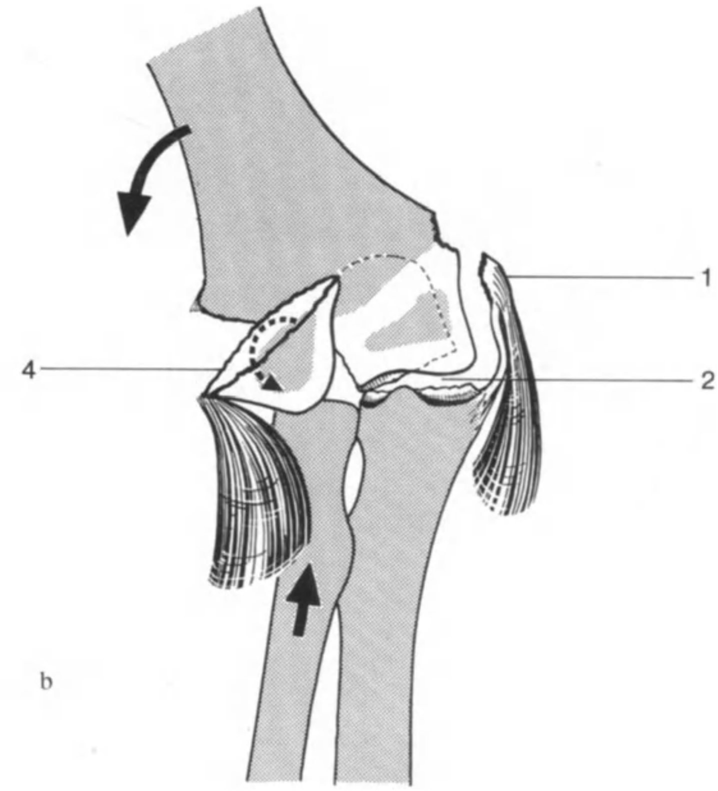


Fig. 2a, b. *Valgus compression fracture*. (*1*) Avulsion of the medial epicondyle; (*2*) Fracture of the olecranon; (*3*) Fracture of the neck of the radius; or (*4*) Fracture of the lateral condyle

The fractures are classified as follows (Fig. 2):

1. Avulsion of the medial epicondyle.
2. Fracture of the olecranon, either on its own or combined with injury to the head of the radius.
3. Bending fracture of the neck of the radius.
4. Fracture of the lateral condyle.

2 Types of Fracture and Treatment

Fractures of the elbow joint create many more problems than diaphyseal fractures. Apart from involving the joint, the fracture passes through the epiphyseal plate, and the risks of growth disturbance and joint incongruity are therefore considerable. The elbow joint is a complicated structure, and any change in its anatomy compromises its biomechanical function. Treatment should completely eliminate joint incongruity, since the latter might otherwise adversely affect articular action. Angular deformity has less serious consequences than in the lower limb, which bears weight. However, this type of deformity, especially cubitus varus, is aesthetically displeasing. Cubitus valgus occasionally causes progressive mechanical irritation of the ulnar nerve with corresponding paresis. It should always be remembered that every injury to the elbow involves danger to the vascular supply of the forearm and hand. In an extreme case, ischemic contracture (*Volkmann*) occurs and results in severe disablement, the affected hand being rendered useless.

If a fracture of the elbow is to be treated operatively, the procedure should if possible be carried out on an emergency basis, since a fracture hematoma which is only a few hours old suffices to initiate calcification and stiffening of the elbow joint. The elbow joint of a child is incompletely ossified and is therefore only partially visible on a roentgenogram. The centers of ossification become visible one by one (see Fig. 3). In order to diagnose a fracture, it is frequently necessary to make comparable roentgenograms of the opposite, intact elbow.

The intraarticular fractures of the elbow joint are classified morphologically as follows:

1. Fractures of the lateral condyle.
2. Fractures of the medial condyle.
3. T(Y)-fractures or comminuted fractures of the distal humerus.
4. Fractures of the olecranon.
5. Fractures of the head of the radius.

2.1 Fractures of the Lateral Condyle

2.1.1 Pathological Anatomy

The fracture is caused by a fall onto the hand with the elbow extended (*Tachdjian*). This results in valgus angulation and lateral compression, so that the lateral

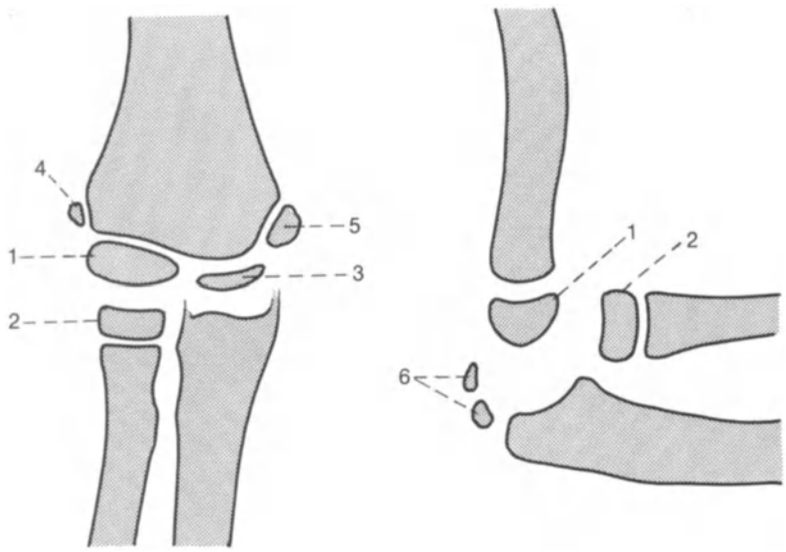


Fig. 3. *Centers of ossification of the elbow joint.* (*1*) Capitulum of the humerus (from the eighth month onwards); (*2*) Head of the radius (from the fifth year onwards); (*3*) Trochlea (from the seventh year onwards); (*4*) Lateral epicondyle (from the eleventh year onwards); (*5*) Medial epicondyle (from the fifth year onwards); (*6*) olecranon (from the eighth year onwards)

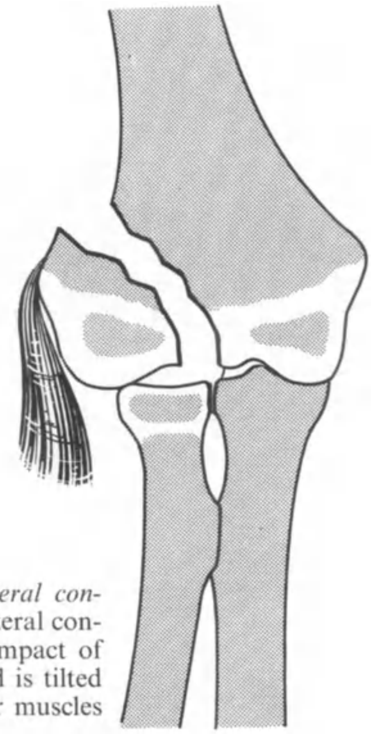


Fig. 4. *Fracture of the lateral condyle of the humerus.* The lateral condyle is driven off by the impact of the head of the radius and is tilted by the pull of the extensor muscles of the fingers and hand

condyle is punched off by the head of the radius (Fig. 4). The same fracture may be caused by *varus angulation,* but in this case, the lateral condyle is avulsed. Together with supracondylar fractures of the humerus, these fractures constitute the commonest form of elbow injury (18.5%, according to *Blount*). The fracture line commences just medial to the capitulum of the humerus and passes obliquely upwards and laterally so as to completely transect the epiphyseal plate, thus constituting an *Aitken* Type III injury. Thus, there is a risk of subsequent growth disturbance. The fragment may be larger and include part of the trochlea (Fig. 5). The degrees of dislocation seen radiologically vary enormously; rotations of up to 180° have been described (*Dameron* and *Reibel*). In some cases, the diagnosis may be extremely difficult, and comparable roentgenograms of the intact side should always be made.

2.1.2 Treatment

Since even slight displacement of the fragments leaves a step in the joint surface and leads to growth disturbance (Fig. 6), anatomically precise reduction is necessary. Closed reduction and cast fixation is associated with a risk of subsequent redislocation (due to the pull of the extensor muscles of the forearm) and valgus deformity of the elbow. *Nonoperative* treatment is therefore only suitable for fissures without displacement of the fragments.

Operative Treatment: For the above reasons, open reduction and fixation is basically indicated for fresh fractures, even if the degree of displacement is only slight.

Operative procedure: lateral approach between the anconeus and brachialis muscles, the joint being opened on the ventral side. Careful exposure and precise reduction of the condyle, which is fixed with two thin diverging *Kirschner* wires (Fig. 7). The ends of the wires are bent round and the skin is sutured.

Postoperative treatment: Dorsal, full-arm plaster splint for 12 days, followed by removal of the skin sutures and application of a circular full-arm cast with the elbow flexed at a right angle. The latter is worn for 4 weeks. The wires are removed after 6 weeks.

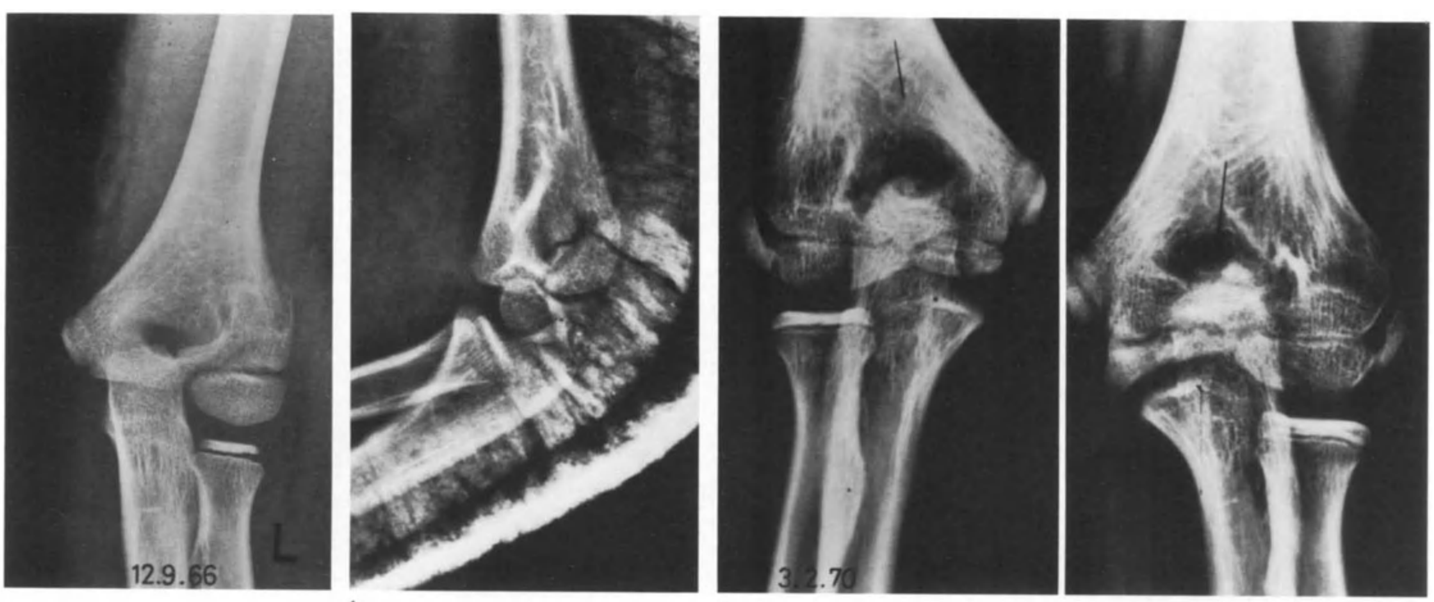
Duration of fixation: 6 weeks.

2.1.3 Prognosis

Fractures which are not reduced lead to severe deformity of the joint, and usually result in pseudoarthrosis with valgus angulation, limitation of the range of movement, and paresis of the ulnar nerve (Fig. 8) (*Renné* and *Weller, Kutscha* and *Rauhs, Tachdjian, Chigot, Ehalt, Pollen*). Treatment by supracondylar osteotomy with simultaneous forward transposition of the ulnar nerve then has to be considered.

a b

Fig. 5a, b. *Fracture of the capitulum of the humerus with partial fracture of the trochlea.* B.J., ♂, aged 6 years, No. 121171.
a) 3 week old fracture which is still dislocated.
b) 2 years after nonoperative treatment. The valgus angle of the elbow is increased by 5°. The damage to the trochlea has led to gross deformation of the articular surface of the humerus with fusion of the trochlear epiphysis



a b c

Fig. 6a–c. *Fracture of the lateral condyle with minimum dislocation followed by growth disturbance.* B.C., ♀, aged 9 years, No. 107149.
a) Roentgenogram taken immediately after the accident.
b) As the dislocation was only slight, surgical exploration and repair was not carried out. The fracture was immobilized with a cast.
c) 4 years after the accident. Fusion of the trochlear and capitular epiphyses has given the trochlea a ridge shape, which is accentuated by comparison with the intact side

Fig. 7a–c. *Anatomically precise reduction of a fracture of the lateral condyle*. Sch. C., ♂, aged 7 years, No. 111507. a) Severely dislocated fracture of the lateral condyle. b) 2 months after open reduction and fixation with *Kirschner* wires. Perfect union of the fracture. c) 1 year after the accident. Complete recovery

Fig. 8a–d. *Fracture of the lateral condyle which was not reduced.* H.W., ♂, aged 21 years, No. 79355.

a) A fracture of the lateral condyle at the age of 8 years was initially treated by immobilization with a cast. 13 years later, there is severe valgus deformity, pseudarthrosis of the capitulum of the humerus, paresis of the ulna nerve, and 40° loss of extension.

b) Treatment: Varus osteotomy.

c) 1 year after the operation. The osteotomy has united, the function of the joint has improved, and the ulnar paresis has decreased in severity.

d) $9^1/_2$ years following corrective osteotomy. Slight overcorrection with significant improvement in function and only slight residual ulnar paresis

Table 1. Lateral condylar fractures (1961–1969).

Name	Age	Years until follow-up	Treatment	Flexion/ Extension difference	Pronation/ Supination difference	Valgus difference	Difference in radius lengths
1. G. R.	4	8	Osteosynthesis	0	0	0	0
2. A. W.	6	0	Osteosynthesis	?	?	?	?
3. R. H.	9	8	Osteosynthesis	0	0	− 4°	+3 mm
4. B. W.	11	8	Osteosynthesis	0	0	−10°	+3 mm
5. H. M.	6	7	Osteosynthesis	0	0	− 2°	0
6. W. R.	8	6	Osteosynthesis	−10/0	0	−17°	0
7. M. C.	4	5	Osteosynthesis	0	0	−12°	+4 mm
8. S. H.	6	4	Osteosynthesis	0	0	0	0
9. B. C.	9	4	nonoperative	0	0	0	0
10. G. W.	10	3	Osteosynthesis	0	0	− 4°	0
11. F. S.	11	0	Osteosynthesis	?	?	?	?
12. H. E.	7	2	Osteosynthesis	− 5/0	0	0	–
13. B. J.	6	2	nonoperative	−10/10	0	+ 5°	−3 mm
14. P. Ph.	4	2	Osteosynthesis	0	0	0	–
15. Sch. Ch.	7	2	Osteosynthesis	0	0	0	0
16. J. K.	7	1/2	Osteosynthesis	0	0	0	0

Fig. 9a–c

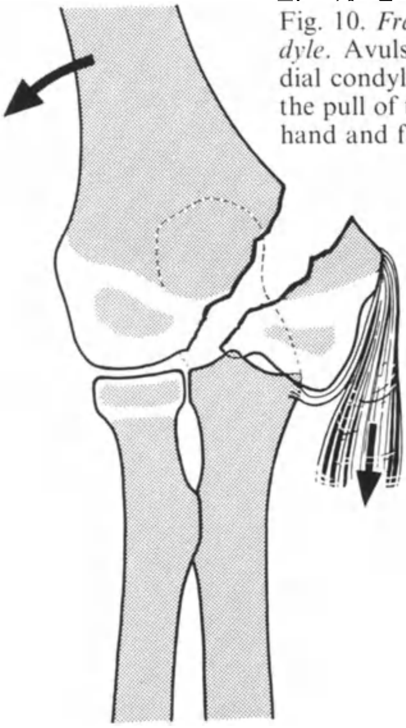


Fig. 10. *Fracture of the medial condyle*. Avulsion fracture of the medial condyle which is then tilted by the pull of the flexor muscles of the hand and fingers

Following precise reduction, growth may be accelerated somewhat on the radial side and thus cause slight cubitus varus (Fig. 9). This results from hyperemia in the area of the fracture with corresponding stimulation of the radial side of the epiphyseal plate. As long as the exposure of the distal fragment does not involve extensive denudation of the bone, there is no danger of necrosis of the lateral condyle.

2.1.4 Results (Table 1)

Sixteen patients were treated between 1961 and 1969. Two had nondislocated fractures and were treated nonoperatively, and 14 required operation. In none of the cases did infection, pseudarthrosis, paresis of the ulnar nerve, or closure of the lateral epiphyseal plate occur. In three cases, flexion was reduced by 5°–10°, and 2°–12° varus was found in half of the fractures which had been operated on. In three children, the longitudinal growth of the radius had increased by 3–4 mm; this was almost certainly due to stimulation of the proximal epiphyseal plate.

Fig. 9a–c. *Fracture of the lateral condyle with subsequent varus deformity of the elbow*. M.C., ♀, aged 4 years, No. 93627.
a) Wedge fracture of the lateral condyle.
b) Operative reduction and *Kirschner* wire fixation.
c) 5 years after the accident. There is slight varus deformity of the elbow (12°) as a result of increased growth of the capitulum of the humerus. The latter was caused by the hyperemia which accompanies fracture healing

a b c

Fig. 11a–c. *Combination of avulsion of the medial condyle with transverse supracondylar fracture of the humerus*. H.V., ♂, aged 10 years, No. 123429.
a) Roentgenogram taken immediately following the accident.
b) Treatment: Open reduction and internal fixation with *Kirschner* wires.
c) $1^1/_2$ years after the accident. The joint congruence has been restored. There is slight widening of the distal humerus. Joint function is normal

2.2 Fractures of the Medial Condyle

2.2.1 Pathological Anatomy (Fig. 10)

This type of fracture very rarely occurs in children. It was found in only 1.3% of the elbow injuries reported by *Kutscha* and *Rauhs* in their series of cases. No characteristic trauma mechanism has been described, and in the literature, fractures of this type have been ascribed both to direct (*Baumann*) and to indirect (*Chigot*) violence. In the latter case, avulsion fracture probably occurs as a result of the application of a pure valgisation force to the elbow. The injury may occur on its own or may be combined with a supracondylar fracture of the humerus (Fig. 11). The fracture always crosses the growth cartilage and it damages the trochlea, which is the most important component of the hinge joint.

2.2.2 Treatment

Operative Treatment: Because the fracture involves the joint and the proliferative cell layer of the epiphyseal plate, treatment should be aimed at anatomically precise reduction.

Operative procedure: Medial skin incision. The trochlear fragment is carefully exposed, reduced so as to render the joint surface congruent, and fixed with *Kirschner* wires (Fig. 11).

Postoperative treatment: Posterior, full-arm plaster splint until wound healing is advanced, and then a circular full-arm cast with the elbow flexed at a right angle. The *Kirschner* wires are removed after 6 weeks.

Duration of fixation: 6 weeks.

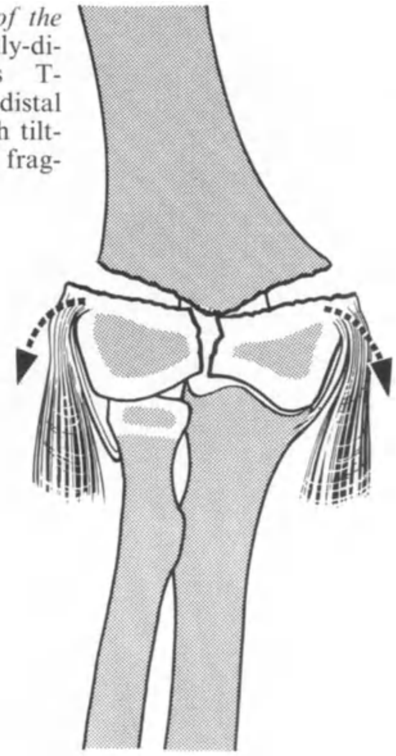


Fig. 12. *T(Y)-fracture of the distal humerus.* An axially-directed impact causes T-shaped fracture of the distal end of the humerus with tilting of the two condylar fragments

2.3 T(Y)-Fractures or Comminuted Fractures of the Distal Humerus

2.3.1 Pathological Anatomy

Comminuted fractures of the condyles are also very rare. They are caused by the axially directed force which results from a fall onto the outstretched arm. The radius and ulna transmit the axial force directly to the condyles and drive them apart. The fragments are then tilted by the pull of the flexor and extensor muscles and collateral ligaments which are directly attached to them. The fracture line always transects the epiphyseal plate (Fig. 12), and perfect reduction of the fragments is therefore a prerequisite of restoration of the original anatomy and function.

2.3.2 Treatment

Operative Treatment: The aims of treatment are the restoration of joint congruence and the obliteration of the gap in the epiphyseal plate prior to healing. These can only be achieved by open reduction and fixation (Fig. 13).

Operative procedure: The patient lies prone. A dorsal, S-shaped skin incision is made which skirts the olecranon. The triceps tendon is split so as to expose the olecranon fossa. The trochlea and the capitulum are then fitted together precisely and joined with a transverse screw. Finally, the two joint components are fixed to the metaphysis of the humerus with *Kirschner* wires.

Postoperative treatment: Posterior, full-arm plaster splint for 2 weeks. The skin sutures can then be removed and a circular full-arm cast is applied with the elbow flexed at a right angle. The metal is removed after 6 weeks.

Duration of fixation: 6 weeks.

2.4 Fractures of the Olecranon

We differentiate between two types of fracture which may occur on their own or be combined with a fracture or dislocation of the head of the radius.

2.4.1 Avulsion Fractures of the Olecranon

2.4.1.1 Pathological Anatomy (Fig. 14)

The tension of the triceps muscle which results from a fall onto the flexed elbow causes avulsion of the olecranon and distraction of the fragments. If the displacement is only slight, diagnosis may have to be based on the clinical findings and comparative roentgenograms. Trauma which tends to produce valgus angulation will cause an oblique fracture which is fre-

a b c


Fig. 13a–c. *T (Y)-fracture of the distal humerus.* G.H., ♂, aged 11 years, No. 134032.
a) T-shaped comminuted fracture.
b) Treatment: internal fixation by transverse screw fixation of the trochlea and capitulum, followed by *Kirschner* wire fixation of the supracondylar component.
c) 1 year after the accident. Complete recovery has taken place. The only residual sign of the fracture is the slight supracondylar widening of the humerus seen on the roentgenogram

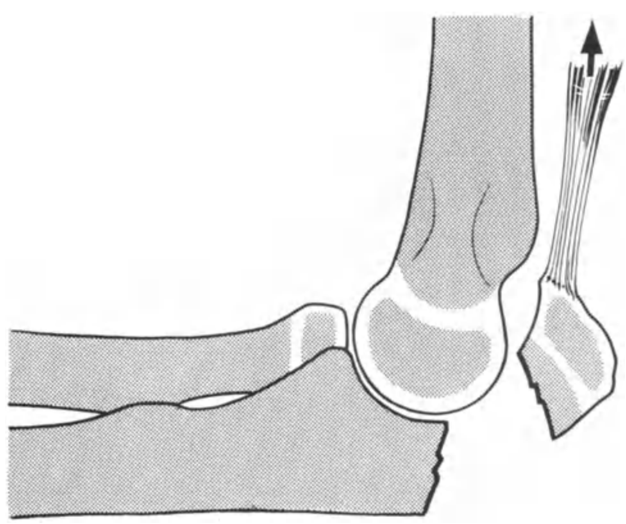


Fig. 14. *Avulsion fracture of the olecranon.* The proximal fragment is dislocated by the triceps muscle

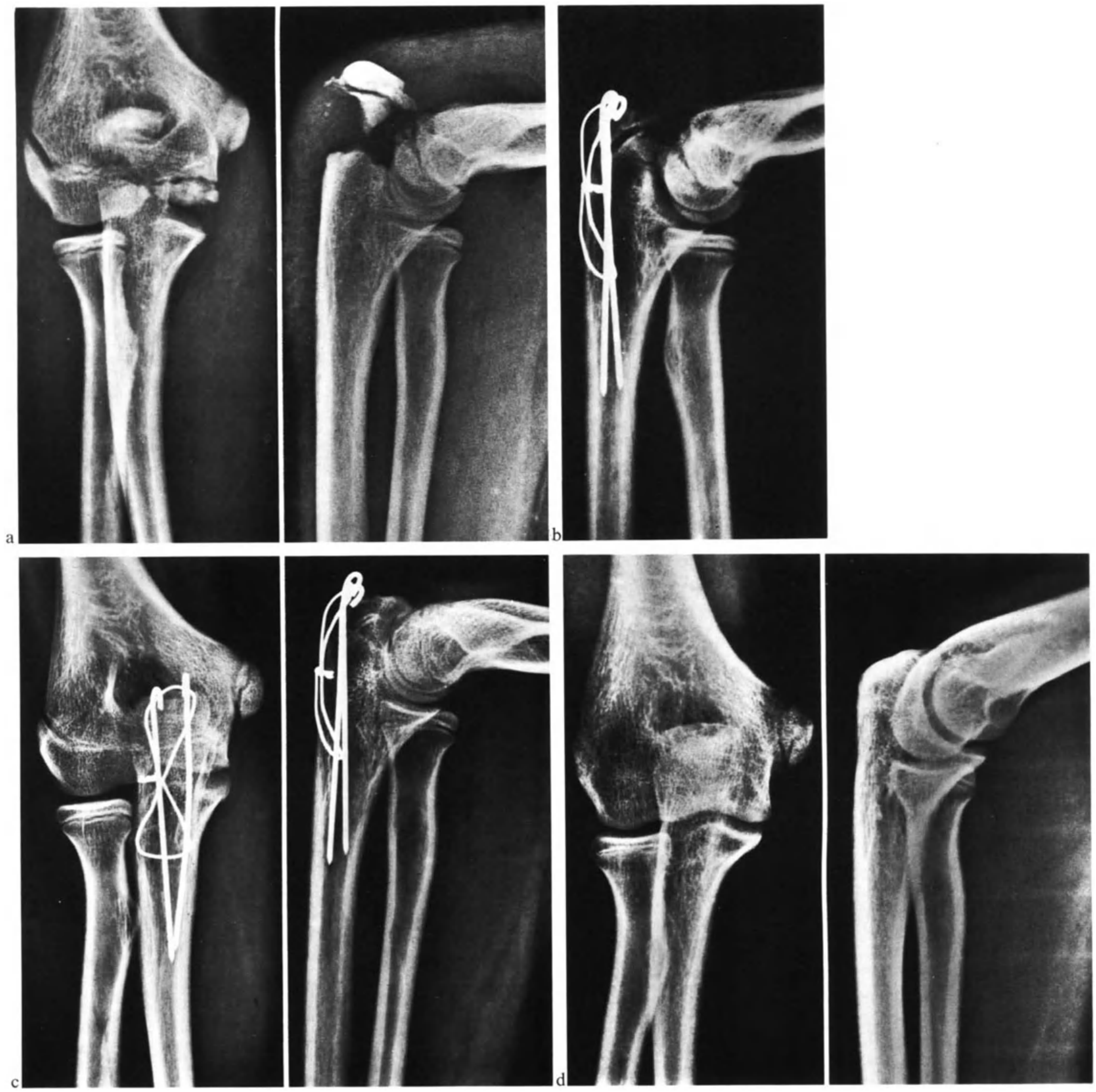


Fig. 15a–d. *Avulsion fracture of the olecranon.* K.B., ♂, aged 14 years, No. 184223.
a) Roentgenograms taken immediately following the accident.
b) Postoperative roentgenogram following tension-band osteosynthesis.
c) 3 months later. Perfect fracture healing.
d) 1 year after the accident. Full recovery has taken place

a b c

Fig. 16a–c. *Oblique fracture of the olecranon.* W.J., ♂, aged 13 years, No. 71273.
a) Roentgenogram taken immediately following the accident.
b) 16 weeks after internal fixation. The fracture has united.
c) 5 years and 10 months following the accident. Complete recovery has taken place

quently accompanied by injury to the head of the radius.

2.4.1.2 Treatment

Nonoperative Treatment: If a fracture of the olecranon is not dislocated, the periosteum is largely intact and the fracture hematoma is small. Subsequent dislocation of the fracture is therefore unlikely to occur, so that nonoperative treatment suffices.

Immobilization: Circular full-arm cast with the elbow slightly flexed.

Duration of fixation: 4 weeks.

Operative Treatment: If the fragments have been drawn apart, joint congruence has to be restored by open reduction and stabilization.

Operative procedure: The patient lies prone. A dorsal, S-shaped skin incision is made which skirts the olecranon on the lateral side. The fragments are reduced and fixed by tension-band osteosynthesis, using two axial *Kirschner* wires and a figure-of-eight cerclage wire (*Weber*). The ends of the *Kirschner* wires are bent round and buried between the fibers of the triceps tendon (Fig. 15). Screw fixation is used for an oblique fracture (Fig. 16).

Postoperative treatment: Posterior, full-arm plaster splint until wound healing is well advanced. Since this type of internal fixation is quite stable, the subsequent treatment includes active, normal use of the arm. The implants are removed after 6 weeks.

Duration of fixation: 2 weeks.

2.4.1.3 Prognosis

Pseudarthrosis occurs if the fracture is not reduced and stabilized. Irritation of the ulnar nerve may result from hypertrophic callus formation.

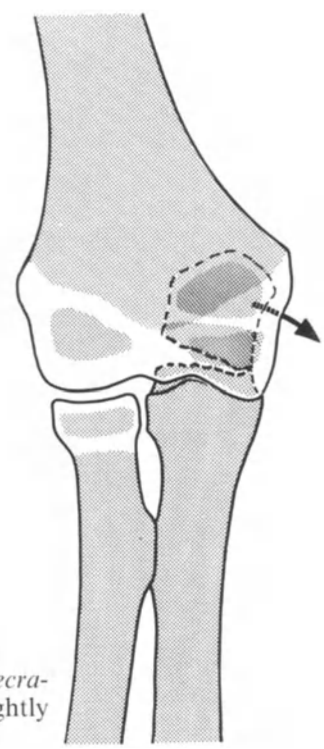
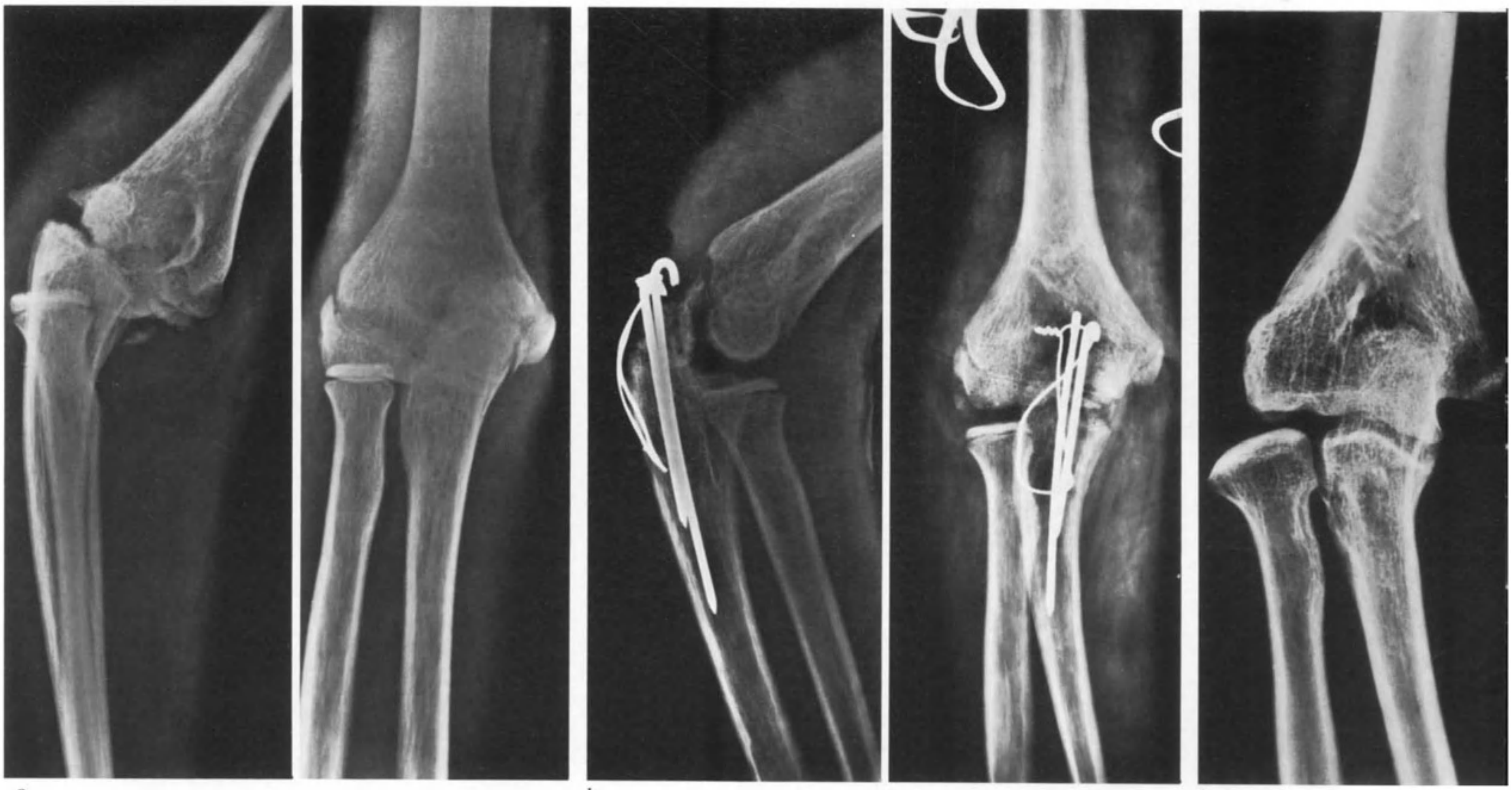


Fig. 17. *Varus fracture of the olecranon.* The fragments are only slightly dislocated



a b c

Fig. 18a–c. *Varus fracture of the olecranon with dislocation of the head of the radius*. O.P., ♀, aged 12 years, No. 76037.
a) Roentgenograms taken immediately following the accident.
b) Treatment: Open reduction and tension-band osteosynthesis of the transverse fracture of the olecranon. The head of the radius has been restored to its normal position relative to the capitulum of the humerus.
c) 5 years after the accident. Varus angulation of the olecranon has occurred as a result of abnormal growth, with lateral subluxation of the head of the radius, decreased range of rotation movement, and a painful elbow

2.4.2 Angulation Fracture of the Olecranon

2.4.2.1 Pathological Anatomy

This injury is very rare. It is possibly caused by direct trauma, or may result from abnormal bending loads applied to the elbow joint (Fig. 17).

2.4.2.2 Treatment

Operative Treatment: The varus deformity which is always present cannot be completely corrected by non-operative methods. Experience has shown that angulation of this type may increase during subsequent growth.

Operative procedure: Reduction and fixation by tension-band osteosynthesis.

Postoperative treatment: Dorsal full-arm plaster splint until wound healing is complete. The cast is then removed and free movement of the arm is allowed. The metal is removed after 6 weeks.

Duration of fixation: 2 weeks.

2.4.2.3 Prognosis

Varus deformity may recur despite anatomically precise reduction and correct internal fixation. This induces lateral subluxation of the head of the radius, resulting in a painful elbow joint with a limited range of motion (Fig. 18). Varus angulation of the ulna

Fig. 19a–e. *Posttraumatic varus deformity of the elbow with dislocation of the head of the radius. Tendency to recurrence.* H.L., ♀, aged 3 years, No. 142980.
a) 1 year after the accident which probably resulted in fracture of the olecranon. Varus deformity of the proximal ulna is present, with dislocation of the head of the radius.
b) Corrective osteotomy of the ulna with reduction of the head of the radius. Temporary fixation with a percutaneous *Kirschner* wire.
c) 3 years after osteotomy. The deformity has recurred and there is lateral subluxation of the head of the radius.
d) Further corrective osteotomy of the ulna. The head of the radius has been restored to its correct position in relation to the capitulum of the humerus.
e) 6 months following the second corrective osteotomy. There are no signs of recurrence

and dislocation of the head of the radius may even recur following corrective osteotomy (Fig. 19); the reasons for this are unknown.

2.4.3 Results (Table 2)

Of the total of 13 patients (1961–1969), six had an isolated fracture of the olecranon. The others included seven combined injuries, five fractures of the neck of the radius, one avulsion fracture of the medial epicondyle, and one case of rupture of the ulnar collateral ligament. Three nondislocated fractures were treated nonoperatively, and the remaining ten required surgery. The isolated fractures of the olecranon were followed by recovery of normal joint function, but the combined injuries resulted in losses of up to 30° of flexion or extension. One patient suffered two fractures of the olecranon within a period of 6 months. Following the second accident, there was backward dislocation of the elbow in addition to the pre-existing varus deformity. This deformity subsequently in-

Table 2. Olecranon fractures (1961–1969).

Name	Age	Years until follow-up	Additional injuries	Treatment	Flexion/ Extension difference	Special remarks
1. L. V.	11	6	–	Osteosynthesis	0	
2. W. J.	13	$5^1/_2$	–	Osteosynthesis	0	
3. B. P.	15	$5^1/_2$	–	Osteosynthesis	0	
4. O. P.	12	$5^1/_2$	Refracture and backward dislocation of forearm	Osteosynthesis	−20/−15	Subluxation of head of radius
5. F. B.	11	4	Neck of radius (Judet IV) and ulnar collateral ligament	nonoperative	0/−35	
6. G. B.	12	3	Neck of radius (Judet II)	Osteosynthesis	0	
7. Sch. R.	10	1	–	Osteosynthesis	0	
8. S. S.	4	0	–	nonoperative	?	
9. Sch. R.	12	$1^1/_2$	Medial epicondyle	Osteosynthesis	0	
10. H. E.	4	1	Neck of radius (Judet IV)	nonoperative	−30/0	
11. St. B.	12	1	–	Osteosynthesis	0	
12. M. J.	14	1	Neck of radius (Judet III)	Osteosynthesis	0	
13. N. P.	12	1	Neck of radius (Judet IV)	Osteosynthesis	−30/0	

creased, resulting in lateral subluxation of the head of the radius and painful reduction of joint motion.

2.5 Fractures of the Head of the Radius

On the basis of their pathological anatomy, these fractures are divided into:

Fractures of the neck of the radius, and
Oblique fractures of the head of the radius, involving the epiphyseal plate (= wedge fractures).

2.5.1 Fractures of the Neck of the Radius

2.5.1.1 Pathological Anatomy

An axial impact on the elbow joint causes compression fracture or fracture dislocation of the neck of the radius. Because of the valgus angulation, the deformed head of the radius is always directed laterally. The fragment may take up any pronation or supination position, the latter being dependent on the position of the radius at the time of the accident (Fig. 20). The fracture lies distal to the epiphysis, which thus remains intact. In a manner similar to the head of the femur, the head of the radius derives its blood supply from vessels in the joint capsule, which is attached distally to the neck (Fig. 21), and also via the periosteal vessels. Every fracture of the neck of the radius thus endangers the vascular supply to the proximal fragment, which includes the proximal epiphysis and the growth cartilage of the epiphyseal plate. Here, the *degree of dislocation* plays a decisive part. We use the *Judet* classification (Fig. 22) and take into account two factors, i.e.,

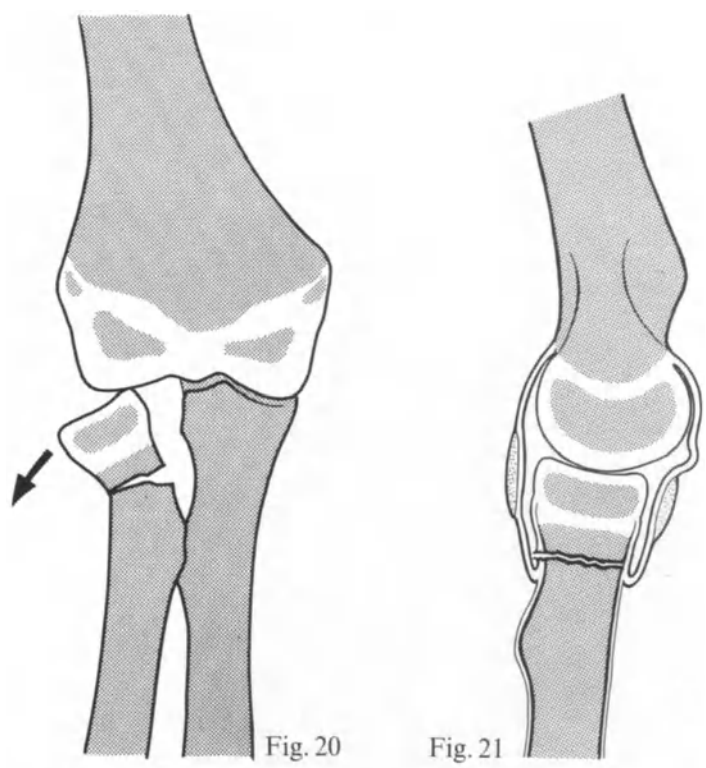


Fig. 20. *Fracture of the neck of the radius.* The head of the radius is tilted to a varying degree

Fig. 21. *Blood supply of the head of the radius.* Fracture of the neck of the radius may involve damage to the periosteal vessels which supply the proximal epiphysis

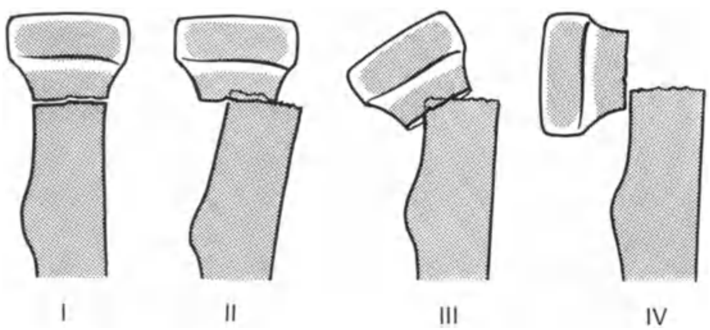


Fig. 22. *Judet classification of fractures of the neck of the radius.* Stage I: no tilt. Stage II: up to 30°. Stage III: 30°–60° tilt with a variable degree of dislocation. Stage IV: complete dislocation with 60°–90° tilt

Dislocation: this allows the occurrence and extent of damage to the vascular supply to be deduced. Tilt: this gives an indication of the function of the radius as a rotating rod.

Type I: Dislocation slight or absent. Tilt slight or absent.

Type II: Dislocation up to half the width of the shaft. Tilting up to 30°. The synovial capsule and the periosteum are only partially torn.

Type III: Variable degree of dislocation with variable degree of interfragmentary contact. Tilt: 30°–60°.

Type IV: Dislocation complete. Tilt: 60°–90°. The annular ligament is ruptured.

This classification is of practical relevance, since the treatment and prognosis are type-dependent.

2.5.1.2 Treatment

Types I and II. Reduction under general anesthesia is only carried out in severe Type II cases. Slight initial malunion is corrected by subsequent growth (Fig. 23).

Immobilization: Circular full-arm cast with the elbow flexed at a right angle.

Duration of fixation: 2–3 weeks.

Type III. Basically, closed reduction is first attempted under a general anesthetic: the arm is repeatedly pro-

a b

Fig. 23a, b. *Stage II fracture of the neck of the radius.* B. St., ♂, aged 12 years, No. 107155.
a) Slight tilt. No reduction.
b) 3 years and 4 months after the accident. The angulation, which was not reduced immediately after the accident, has corrected itself spontaneously. Normal joint function

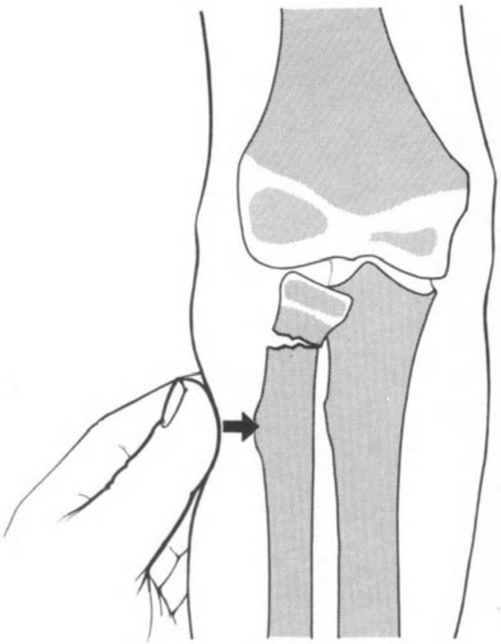


Fig. 24. *Maneuver for reduction of Stage II and Stage III fractures of the neck of the radius.* The fracture is positioned under the image intensifier so that its convex side faces laterally. It can then be converted to a Stage I or Stage II fracture by pressure of the thumb on the apex

a b

Fig. 25a–d. *Stage IV fracture of the neck of the radius.* F.B., ♀, aged 11 years, No. 103087.

a) Roentgenogram taken immediately following the accident.

b) Open reduction and transarticular percutaneous transfixation with a *Kirschner* wire.

c, d) 3 years and 8 months after the operation. The head of the radius is slightly widened following an episode of partial necrosis. Supination was found to be limited by 35° on comparison with the intact side. No symptoms are present

nated and supinated under the image intensifier until the angulation appears on the radial side. The fracture is then reduced by pressure with the thumb on the apex, thus converting it to Type I or II (Fig. 24). If reduction in this manner is unsuccessful, open reduction is carried out under the same anesthetic (see Type IV).

Immobilization: Full-arm cast, which must be split if there is marked swelling.

Duration of fixation: 4 weeks.

Type IV. This type of fracture always requires operative treatment. Anatomically precise reduction and stabilization are absolutely necessary to ensure optimum conditions for revascularization of the head of the radius.

Operative procedure: The joint is opened by the *Kocher* method. Precise reduction and transarticular *Kirschner* wire fixation are carried out (Fig. 25), and the ends of the annular ligament are brought together. Excision of the head of the radius is contraindicated in children because of the increase in valgus deformity and distal radio-ulnar incongruence (Fig. 26).

Postoperative treatment: Dorsal full-arm plaster splint, which is replaced by a full-arm circular cast after 2 weeks. Removal of the metal after 4 weeks.

Duration of fixation: 4 weeks.

2.5.1.3 Prognosis

As a rule, Types I–III do not lead to abnormal remodelling, since the periosteum and the synovial capsule are only partially torn and the blood supply is not excessively compromised. Growth in the epiphyseal plate is not inhibited; it may even be excessive (Fig. 27) and cause an abnormal increase in the length of the radius. Type IV fractures with complete disengagement of the head of the radius are associated with interruption of the blood supply to the head and epiphyseal plate. Either total or partial necrosis can therefore be expected. If anatomically precise reduction is possible, the blood supply of the radial head may be partially restored from the distal side and thus

c
Fig. 25c, d
d

a
b

Fig. 26a, b. *Adverse results of resection of the head of the radius*. S. P., ♂, aged 22 years, No. 135029.
a) 8 years after resection of the head of the radius in another hospital following fracture of the radial neck. Severe valgus deformity of the elbow (22°) is seen on comparison with the opposite side.
b) Markedly disproportionate length of the ulna on the side of the fracture

be followed by a good clinical result (Fig. 25). The head of the radius always takes on a more or less bulbous shape, and the longitudinal growth of the bone is reduced in comparison to the intact side. Together with the necrosis, deformity which is left uncorrected limits the rotatory movement of the radial head (Fig. 28).

2.5.2 Oblique Fracture of the Head of the Radius, Involving the Epiphyseal Plate (=Wedge Fracture)

2.5.2.1 Pathological Anatomy (Fig. 29)

This is an *Aitken* Type III injury with transection of the proliferative zone and formation of a step in the joint surface. Since the head of the radius is still

a b c

Fig. 27a–c. *Stage III fracture of the neck of the radius with increased growth.* B. A., ♂, aged 7 years, No. 107020.
a) The fresh fracture.
b) Treatment: closed reduction so as to convert the fracture to Stage I, followed by immobilization with a cast.
c) 4 years and 4 months later. The development of the epiphyseal center of ossification on the side of the fracture is more advanced than on the intact side. Slightly increased longitudinal growth of the radius

a b c

Fig. 28a–c. *Incompletely reduced Stage IV fracture of the neck of the radius.* D.W., ♂, aged 11 years, No. 114140.
a) Dorsal dislocation of the elbow with Stage IV fracture of the neck of the radius and paresis of the radial nerve.
b) Roentgenogram taken following immediate incomplete reduction and internal fixation with a *Kirschner* wire.
c) 2 years and 8 months after the accident. Marked partial necrosis of the head of the radius. There is complete loss of supination, but pronation is normal. The paresis of the radial nerve has regressed completely

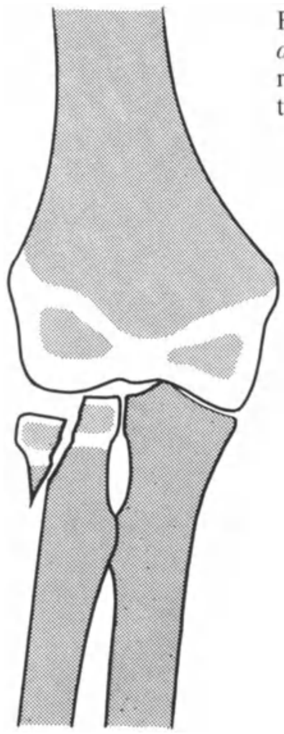


Fig. 29. *Wedge fracture of the head of the radius.* A wedge-shaped fragment of variable size is driven off the head of the radius

largely cartilaginous in the child, it is not completely delineated in a roentgenogram. The fragment which has broken away is therefore always much larger than might be expected from its radiographic appearance.

2.5.2.2 Treatment

Operative Treatment: The fragment which has broken away has to be refixed, since it otherwise hinders joint movement (Fig. 30). Small fragments which cannot be stabilized are removed.

Operative procedure: The fragment is exposed via a *Kocher* incision. The wedge-shaped fragment is brought into the operative field by pronation and supination. After careful reduction, it is temporarily fixed with a fine *Kirschner* wire. This is followed immediately by permanent fixation with an ASIF small-fragment lag screw.

Postoperative treatment: Dorsal full-arm plaster splint for 2 weeks. Further immobilization is unnecessary. The metal is removed after 3–6 months.

Duration of fixation: 2 weeks.

a b c

Fig. 30a–c. *Wedge fracture of the head of the radius.* H.P., ♀, aged 11 years, No. 127749.
a) The fresh fracture.
b) $2^1/_2$ months after open reduction and internal fixation with a lag screw.
c) 1 year and 6 months after the accident. Symmetrical ranges of elbow movement with no residual symptoms

Table 3. Fractures of the head of the radius (1961–1969).

Name	Age	Years until follow-up	Treatment	Stage before/after reduction	Flexion/ extension difference	Pronation/ supination difference	Radius difference	Valgus difference
1. R. K.	11	6	Osteosynthesis	II/II	0	−15/0	−5 mm	+4°
2. B. S.	12	4	nonoperative	II/II	0	0	+7 mm	0
3. G. B.	12	5	nonoperative	II/II	0	0	?	?
4. Z. M.	16	1	nonoperative	II/I	0	0	?	0
5. A. B.	7	7	Osteosynthesis	III/I	−10/0	−20/0	0	0
6. B. A.	7	4	nonoperative	III/I	0	0	+3 mm	0
7. M. S.	6	3	nonoperative	III/I	0	0	0	0
8. M. J.	12	1	Osteosynthesis	III/I	0	0	0	+4°
9. K. M.	14	1	nonoperative	III/I	0	0	+4 mm	0
10. G. Ch.	13	1	Osteosynthesis	III/I	0	−20/0	?	?
11. F. S.	11	1	Osteosynthesis	III/I	0	−20/0	?	?
12. F. B.	11	4	Osteosynthesis	IV/I	0	0/−35	−4 mm	0
13. D. W.	9	3	Osteosynthesis	IV/II	0	0/−90	?	+6°
14. N. P.	12	2	Osteosynthesis	IV/I	0/−10	−30/0	0	0
15. H. E.	3	1	Osteosynthesis	IV/I	0	−30/0	?	0
16. H. P.	11	2	Osteosynthesis	Chip fracture	0/−10	0	−3 mm	+3°

2.5.3 Results (Table 3)

From 1961–1969, 15 fractures of the neck of the radius and one wedge fracture were treated, six of them non-operatively and ten operatively. Limitation of flexion or extension was found in only three cases; in none of these did the deficit exceed 10°. A marked reduction of supination was found in Case 13, in which a severe dislocation had been left unreduced. Four children showed slight valgus angulation of the elbow (3°–6°) as a result of slightly reduced longitudinal growth of the radius.

3 Summary

Fractures of the elbow joint in children and adolescents should be taken very seriously, since joint incongruence and disturbances of growth result from failure of the fracture to heal in the anatomically correct position.

All fractures which transect the joint surface of the distal humerus require open reduction and internal fixation, even if they appear to be only slightly dislocated. The same applies to olecranon fractures with dislocation of the fragments.

Fractures of the neck of the radius are treated non-operatively or operatively so as to bring about healing with correct axial alignment. Wedge fractures are very rare and require anatomically correct reduction and screw fixation.

In each case, the subsequent treatment includes cast fixation with the elbow joint flexed at a right angle. In children, fixation with a cast is not deleterious, and physiotherapy is therefore usually unnecessary.

4 References

Baumann, E.: Ellenbogen, spezielle Frakturen und Luxationslehre. Stuttgart: Thieme 1965.

Baumann, E.: Distale Oberarmbrüche beim Kind. Chir. Praxis **4**, 317 (1967).

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Chigot, P. L., Estève, P.: Traumatologie infantile. Paris: Expansion scientifique 1958.

Dameron, T. B., Reibel, D. B.: Fractures involving the proximal humeral epiphyseal plate. J. Bone Jt Surg., **51 A**, 71 (1969).

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Kutscha, E., Rauhs, R.: Frische Ellenbogenverletzungen im Wachstumsalter. Hefte zur Unfallheilkunde, Heft 118. Berlin-Heidelberg-New York: Springer 1974.

Pollen, A.: Fractures and Dislocations in Children. Edinburgh, London: Churchill & Livingstone 1973.

Renné, J., Weller, S.: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer 1974.

Tachdjian, M.: Pediatric Orthopedics. Philadelphia: Saunders 1972.

Weber, B. G.: Grundlagen und Möglichkeiten der Zuggurtungsosteosynthese. Chirurg **35**, 81 (1964).

Shaft Fractures in the Forearm

F. Freuler, B.G. Weber, Ch. Brunner

CONTENTS

1 Introduction

Diaphyseal fractures of the forearm comprise up to 20% of all injuries to the upper extremity according to reported data (*Renné* and *Weller*). Seventy-five percent of the fractures occur in the distal third (including those in the vicinity of the wrist joint), 18% in the middle third, and 7% in the proximal third (*Blount*).

Fig. 1. *Diaphyseal greenstick fractures in the forearm.* L.N., ♀, $3^1/_2$ years, No. 90855.
Fall from a tricycle. Dorsal angulation of the fracture

Fig. 2a–c. *Angulation of the fracture recurs if the periosteum is left intact.* E.L., ♀, aged 5 years, No. 189096.
a) Greenstick fracture of the distal third of the diaphysis with volar angulation.
b) Reduction under anesthesia. The dorsal intact periosteum was not disrupted during reduction. The fracture was immobilized with a cast and the axial alignment of the fragments is satisfactory.
c) Following removal of the cast 6 weeks after the accident, the volar angulation of the fracture is seen to have recurred as a result of the tension of the intact dorsal periosteum

The most frequent *type of accident* is a fall onto the outstretched arm. It causes fractures of the *middle* and *distal third* of the arm, with typical angulation of the fragments in a ventral direction. Angulation in a dorsal direction is much rarer, and results from a fall on the hand with the wrist in volar flexion (Fig. 1). Depending on the magnitude of the trauma causing the deformation, a greenstick fracture may occur, leaving the periosteum intact, or the fragments may be completely dislocated and the periosteum torn. If the wrist is hyperextended and in marked radial abduction at the time of impact, the shaft of the radius may be fractured with disruption and dislocation of the radio-ulnar joint (*Galeazzi* fracture). This type of fracture is extremely rare in children and is at most seen in adolescents. Fractures of the *middle third* are frequently caused by direct trauma, which may produce an isolated fracture of the radius or ulna. These cases may also involve greenstick or dislocated fractures, depending on the degree of violence. With increasing age, greenstick fractures become less common, and the fractures seen in adolescents are almost exclusively dislocated; this is due to differences in the properties of the bone and also to differences in the type of accident.

The trauma mechanisms associated with fractures of the proximal third are, as in the case of the elbow injuries, more varied. A fall onto the forearm with the elbow flexed may cause an isolated fracture of the ulna with dislocation of the head of the radius (*Monteggia* fracture).

2 Fracture Types and Treatment

Since the treatment is determined by the site of the fracture, the following classification has proved itself useful:

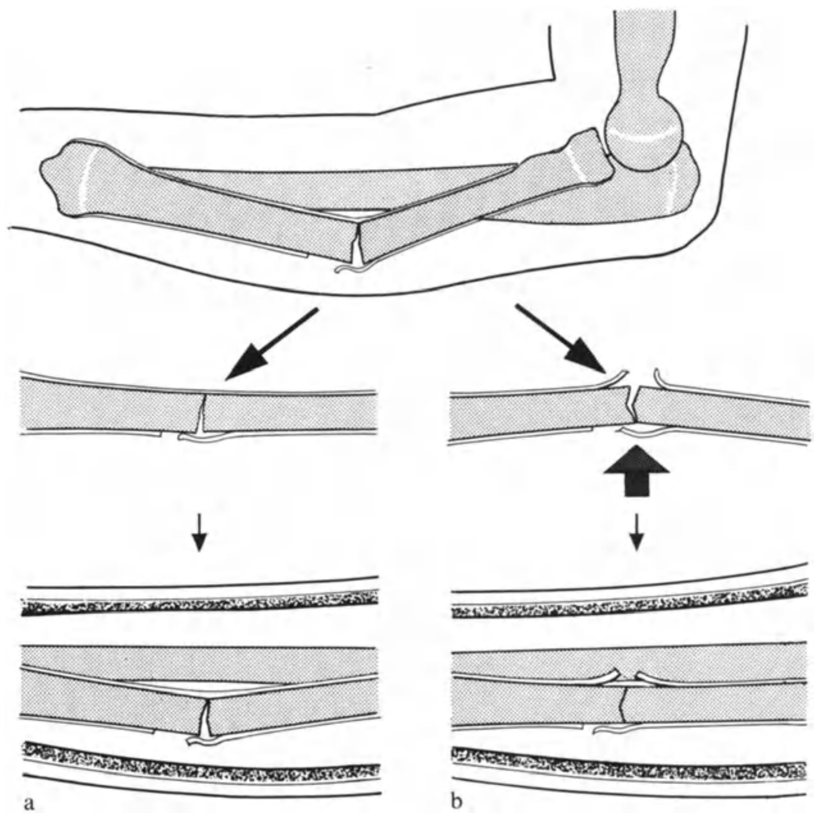
1. Fractures in the distal third of the diaphysis.
2. Fractures in the middle third of the diaphysis.
3. Fractures in the proximal third of the diaphysis.

At each level, two types of fracture may occur, i.e.,

Greenstick fractures.
Dislocated fractures.

Pathological Anatomy of Greenstick Fractures. The cortex on the convex side of the angulation is completely broken and the periosteum is torn apart. On the opposite side, the periosteal cuff is intact and the underlying cortex is only bent. Because of their

Fig. 3a, b. *Greenstick fracture*.
a) Angulation of the fracture recurs if the periosteum is intact on the concave side.
b) Angulation does not recur if the intact periosteum and cortex on the concave side are disrupted by bending the fracture in the opposite direction



elasticity, these intact structures exert a one-sided contraction force on the bone which maintains or even increases the angulation. If the fracture is reduced by simple straightening the fragments, the intact periosteum is stretched and the underlying cortex expands. Thus, the excentric tension force continues to act and may bend the fracture back to its original angle despite fixation with a cast (Fig. 2). A greenstick fracture should therefore always be completed (*Blount, Salter, Chigot*), so that at least the tension effect of the cortex is neutralized (Fig. 3).

Pathological Anatomy of Dislocated Fractures. The trauma causes an uninterrupted fracture of the cortex with complete tearing of the periosteal cuff. Thus, the fracture is unstable, and rotation deformity is frequently present in addition to the angulation and shortening. The most important part of the treatment is the correction of rotation deformity, since the latter will not be corrected by subsequent growth and leads to severe limitation of function.

2.1 Fractures in the Distal Third of the Diaphysis

These fractures should be differentiated from the purely metaphyseal fractures. The force resulting from a fall onto the hand with the wrist in dorsiflexion is partly axial and partly directed backwards. Depending on the magnitude of the resulting force, a greenstick fracture or a completely dislocated fracture occurs; usually both forearm bones are involved.

2.1.1 Greenstick Fractures

2.1.1.1 Pathological Anatomy

The resultant of the axial and backward-directed forces causes a complete fracture of the volar cortex with rupture of the corresponding periosteum. The dorsal periosteum remains intact, and the underlying cortex is only bent (Fig. 4). Frequently, volar angulation of the fragments occurs and is maintained by the tension exerted by the intact dorsal structures. Dorsal angulation is much less common and results from a fall onto the hand with the wrist flexed.

2.1.1.2 Treatment

Initial angulation of a few degrees does not require reduction, since spontaneous correction occurs in the course of growth. Angulation of more than 10° has to be reduced under general anesthesia: the fracture is completely broken over the knee of the surgeon or over a wooden block (Figs. 5 and 9). It is then checked under the image intensifier.

Immobilization: Circular full-arm cast with fixation of the wrist in slight volar flexion. The cast is initially split. Following a radiographic check 3–5 days later, the cast is closed.

Fig. 4. *Typical greenstick fracture*. The dorsal periosteum is intact and the cortex is only bent. The volar periosteum is torn through and the fracture of the volar cortex gapes widely

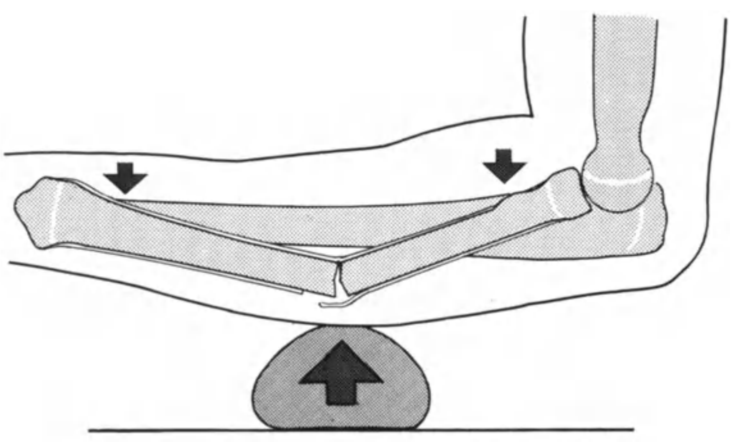


Fig. 5. *Disruption of a greenstick fracture*. The fracture is counter-bent over a padded block or the knee of the surgeon so as to disrupt the intact periosteum

Duration of fixation: 4 weeks.

If there is dorsal angulation of the fragments (flexion mechanism), the wrist is immobilized in slight dorsiflexion.

2.1.2 Dislocated Fractures

2.1.2.1 Pathological Anatomy

A heavy fall onto the hand with the wrist hyperextended produces a dorsally directed force which completely fractures the cortex and tears the periosteum. Very frequently both bones are broken, and there is typical dorsal dislocation of the fragments (Figs. 6 and 10). The radial fragment may pierce the pronator quadratus muscle; thus, the latter is interposed between the fragments and may make reduction difficult. If the radius alone is fractured, the fracture mechanism will have involved supination (*Salter*). This type of fracture is therefore stabilized in pronation. The flexion mechanism is less common and causes volar dislocation of the fragments.

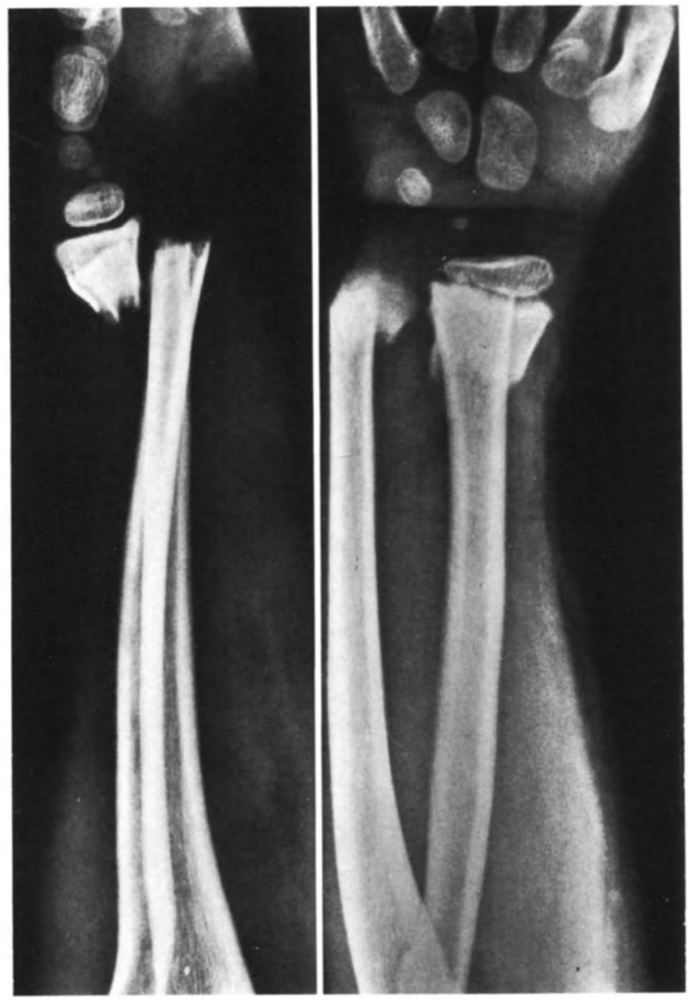
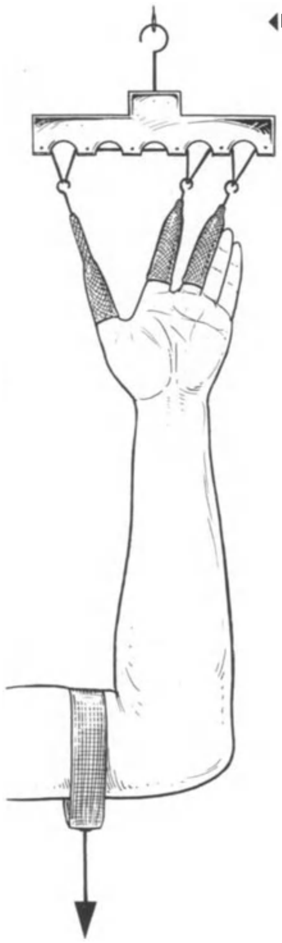


Fig. 6. *Severely dislocated distal fracture of the forearm*. Sch. B., ♂, aged 6 years, No. 148767. Typical dislocation in a dorsal direction with shortening. The pronator quadratus muscle may be trapped between the fragments

2.1.2.2 Treatment

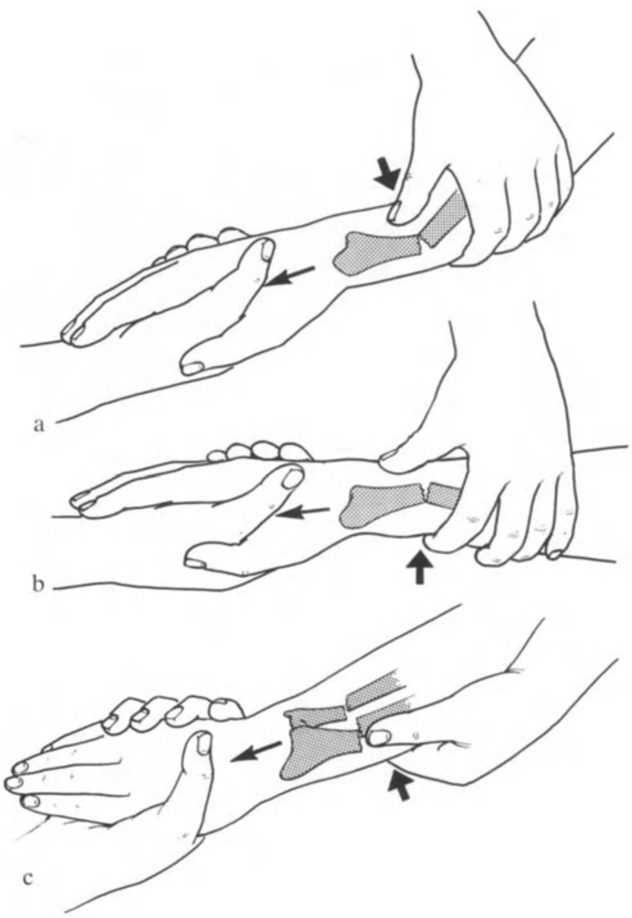
Nonoperative Treatment: Reduction is always carried out under general anesthesia.

Fractures of both bones: Because of the shortening caused by muscle contraction, closed reduction of a severely dislocated fracture may be very difficult. Traction on the arm prior to reduction is therefore recommended. Finger traction caps or gauze strips are



◀ Fig. 7. *Reduction by traction.* The hand and arm are suspended from finger traction caps which are applied to the thumb and to the index and middle fingers. Countertraction is applied by attaching a weight to a padded cuff round the upper arm. The elbow is flexed at a right angle

Fig. 8a–c. *Reduction of a distal fracture which is dislocated in a dorsal direction.* a) The hand is pulled distally and dorsally and the angulation of the fracture is increased; at the same time, the distal fragment is pushed over the edge of the proximal fragment in a distal and volar direction by pressing with the thumb. b) The angulation is corrected and, if necessary, the intact periosteum is disrupted c) Ulnar or radial deviation can also be corrected in the same manner by pressure with the thumb and simultaneous traction ▶



attached to the thumb, index finger, and middle finger and suspended vertically; the elbow is flexed at a right angle and 4–8 kg countertraction is applied to the upper arm (Fig. 7). As soon as the shortening has been more or less corrected, the countertraction is removed and manual reduction is carried out as follows: The surgeon grasps the hand and pulls it dorsally and distally. At the same time, the fragments are hyperextended and, by exerting pressure with the thumb, the cortices on the dorsal side are brought into line with each other. By this maneuver, the distal fragment is extracted from the pronator quadratus muscle, thus reducing the possibility of soft tissue interposition. The angulation is then corrected, thus ending the reduction maneuver (Figs. 8 and 10). The position of the fracture is checked under the image intensifier.

Isolated fracture of the radius: Vertical traction is not indicated, since it has no influence on the shortening of the fragments. The intact ulna is used as a lever, and relaxation of the pronator quadratus muscle is produced by pronation of the forearm. Reduction of the fracture is then usually easy to perform. A final check is carried out with the image intensifier.

Immobilization: Circular, initially split, full-arm cast with the elbow flexed at a right angle. The forearm is positioned as follows:

Both bones fractured: between neutral rotation position and slight pronation.

Isolated fracture of the radius: pronation, in order to neutralize the deforming force exerted by the pronator quadratus muscle.

The cast is applied with the wrist in dorsiflexion or volar flexion, depending on the dislocation of the fragments. A radiographic check is carried out 3–5 days later and the cast is closed.

Duration of fixation: 6–8 weeks, depending on the age of the child. If the fracture is in the vicinity of the metaphysis, the duration of fixation may be shorter.

Note: It is important that the parents be informed about possible disturbances of circulation, sensation, and finger movement. If there is marked swelling, a short hospital stay is indicated in order to allow better surveillance of the fracture.

Operative Treatment: Open reduction and stabilization may be indicated in the following situations:

Wide open fractures: Surgical exploration and treatment of the necessarily involves exposure of the fracture and the surrounding tissues, and tissue repair is significantly improved by mechanical stability (*Weber*).

a

Fig. 9a,b. *Greenstick fracture of the distal forearm with severe angulation.* L.L., ♀, aged 11 years, No. 65843.
a) The dorsal cortex is not broken, but is only bent. The periosteum is torn only on the ventral side.
b) The dorsal cortex and the overlying periosteum have been completely disrupted by manual counterangulation during reduction. The fracture was then immobilized in the neutral rotation position in a circular cast. 6 weeks after the accident, bone healing is well advanced with correct axial alignment. Union of the dorsal cortex is not yet complete

Irreducible fractures: Even severely dislocated fractures can almost always be reduced by the maneuvers described above. These methods may fail if soft tissues, particularly the pronator quadratus muscle, are interposed.

Fractures in adolescents: Since little growth remains, correct axial alignment following reduction is essential.

The amount of implant material used to stabilize the fracture should be kept to a minimum. In small children, a resorbable periosteal suture suffices. Internal fixation may even be dispensed with if the fragments are stable following reduction.

Postoperative treatment: a dorsal full-arm plaster splint is applied immediately following the operation. The skin sutures are removed on the 12th day, and a lightly padded circular full-arm cast is applied and retained for 4–6 weeks, depending on the age of the child.

Duration of fixation: 6–8 weeks from the time of the operation. If the internal fixation is stable, a cast can be dispensed with and the operation can be followed immediately by functional use of the arm.

b

Fig. 10a–c. *Severely dislocated fracture of the distal forearm.* G.E., ♀, aged 6 years, No. 107039.
a) Severe dorsal dislocation of the distal fragments.
b) The fracture has been reduced in the manner described in Fig. 8.
c) 5 years after the accident. Complete recovery has taken place

Fig. 11a–c. *Diaphyseal fractures of the forearm.* W.D., ♂, aged 5 years, No. 101372.
a) Typical angulation with bending of the cortex and intact periosteum.
b) The cortex and periosteum are disrupted by counterangulation and the fracture is then immobilized in a full-arm cast.
c) 7 years after the accident. Complete recovery has taken place

Fig. 10 a b c

Fig. 11 a b c

2.2 Fractures in the Middle Third of the Diaphysis

Depending on the magnitude of the trauma and the age of the child, the fracture may be of the greenstick type or may be completely dislocated.

Very frequently both bones of the forearm are broken. Isolated diaphyseal fractures of the ulna or radius are much less common. An apparently solitary fracture of the ulna should raise suspicion that a *Monteggia* fracture might be present; the latter can only be excluded by roentgenograms of the whole of the forearm.

2.2.1 Greenstick Fractures

2.2.1.1 Pathological Anatomy

A fall onto the outstretched arm or a direct blow cause complete fracture of one-half of the cortical circumference with rupture of the overlying periosteum. The opposite cortex is only bent and the periosteum remains intact. Depending on the position of the hand during the accident, the angulation of the fragments may be volar or dorsal (Figs. 11 and 1). These fractures are stable if the fragments remain in contact with each other and if rotation is prevented by the largely intact surrounding structures.

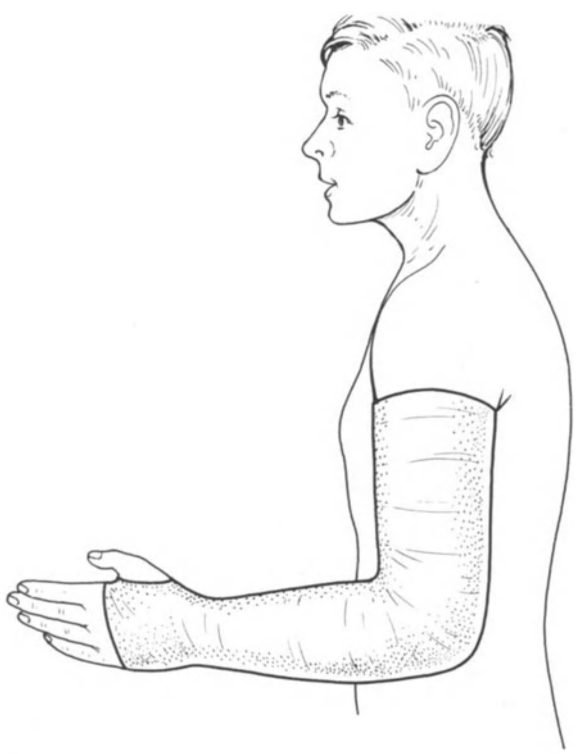


Fig. 12. *Circular full-arm cast.* The elbow is flexed at a right angle and the forearm is in the neutral rotation position. The wrist is fixed at the functional angle

2.2.1.2 Treatment

Nonoperative Treatment: A general anesthetic is given, and the fracture is completed by breaking it over the knee of the surgeon or over a wooden block; success is frequently heralded by an audible crack. The fracture is then checked under the image intensifier (Fig. 11).

Immobilization: Circular, initially split, full-arm cast with the forearm and wrist in the neutral position (Fig. 12). A radiological check is carried out after 3–5 days, and the cast is closed.

Duration of fixation: 5–6 weeks, depending on the age of the child

Note: Angular deformity of the middle third does not usually correct itself satisfactorily, and anatomically precise reduction should therefore be aimed for.

2.2.2 Dislocated Fractures

2.2.2.1 Pathological Anatomy

As a result of direct or indirect trauma, a complete fracture of the cortex occurs and the periosteal cuff is totally ruptured; these injuries may be accompanied by a partial tear of the interosseous membrane. Thus, the fracture is unstable, and the dislocation of the fragments may be considerable and include angulation, shortening, and rotation deformity (Figs. 12, 15–19).

2.2.2.2 Treatment

The spontaneous correction of large degrees of angular deformity is seldom satisfactory, while that of rotation deformity never occurs. The aim of treatment is therefore anatomically precise reduction of the fragments. Furthermore, the gap between the radius and ulna should be restored to its normal width, since rotation movement of the forearm will otherwise be permanently restricted.

Nonoperative Treatment: The reduction of a severely dislocated fracture of the middle third of the shaft can be very difficult and is always carried out under general anesthesia. Since there is frequently considerable shortening, preliminary traction is recommended: the thumb, index finger, and middle finger are suspended with finger traction caps or gauze strips, and countertraction (4–8 kg) is applied to the upper arm (Fig. 7). As soon as the shortening has been corrected, one of the fractures is reduced and this bone is then used as a lever for the reduction of the second fracture. At this level, reduction and stabiliza-

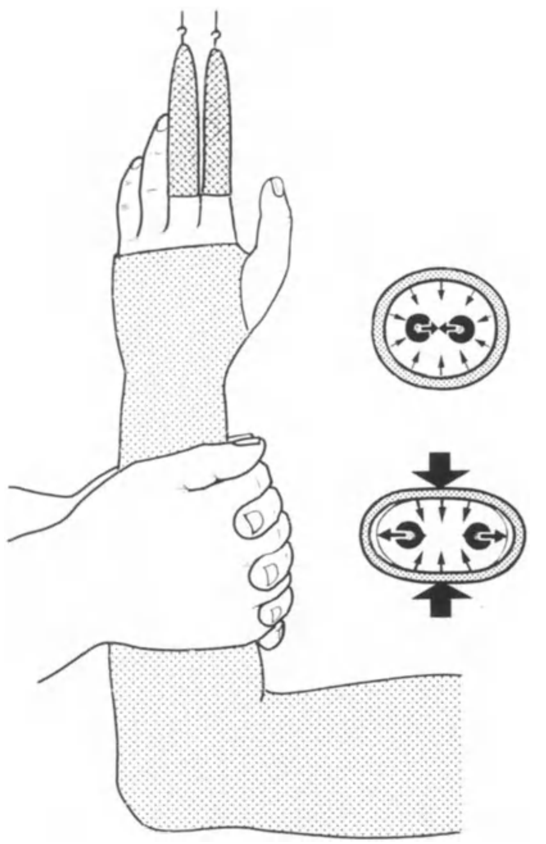


Fig. 13. *"Squeeze grip."* During hardening of the plaster, the cast is pressed together with both hands so as to give it an oval cross section. This increases the distance between the radius and ulna

tion is best carried out with the forearm in the neutral rotation position. The fracture is then checked under the image intensifier.

The criteria for satisfactory reduction are the following:

At least two fragments are in end-to-end contact with each other, thus preventing recurrence of the shortening. Lateral dislocation of the other fracture by the width of the shaft of the bone is of no consequence here (*Ehalt*) (Fig. 18).

Angular deformity is corrected.

Rotation deformity is completely eliminated. To check this, the arm should be compared with its uninjured counterpart on the opposite side.

Immobilization: Circular, initially split, full-arm cast with the forearm in the neutral rotation position and the wrist in the functional position (Fig. 12). During hardening of the cast, the radius and ulna are forced apart by exerting dorsal and volar pressure on the forearm ("squeeze grip", *Charnley*) (Fig. 13). The resulting cast has an oval cross section, and the radius and ulna therefore tend to move in the direction of least pressure, i.e., they move apart. Thus, the distance between the two bones is restored to normal. If the cross section of the cast is circular, the radius and ulna move towards each other (*Charnley*), causing angulation of the fragments (Fig. 14). A radiographic check is carried out after 3–5 days and the cast is then closed. Any malposition must be corrected by further reduction. However, one should try to avoid repetitive manipulation of the fracture, since this increases the chance of a pseudarthrosis occurring.

Duration of fixation: 6–8 weeks, depending on the age of the child

Note: *Volkmann's ischemic contracture* also occurs in association with forearm fractures. The flexor muscles, which are embedded between the radius, ulna, interosseous membrane, and forearm fascia, are those which are in greatest danger of ischemic necrosis. Thus, if there is considerable swelling, one is advised to keep the child in the hospital for a few days so as to allow adequate surveillance. In every case, the cast must be completely split and the arm kept raised.

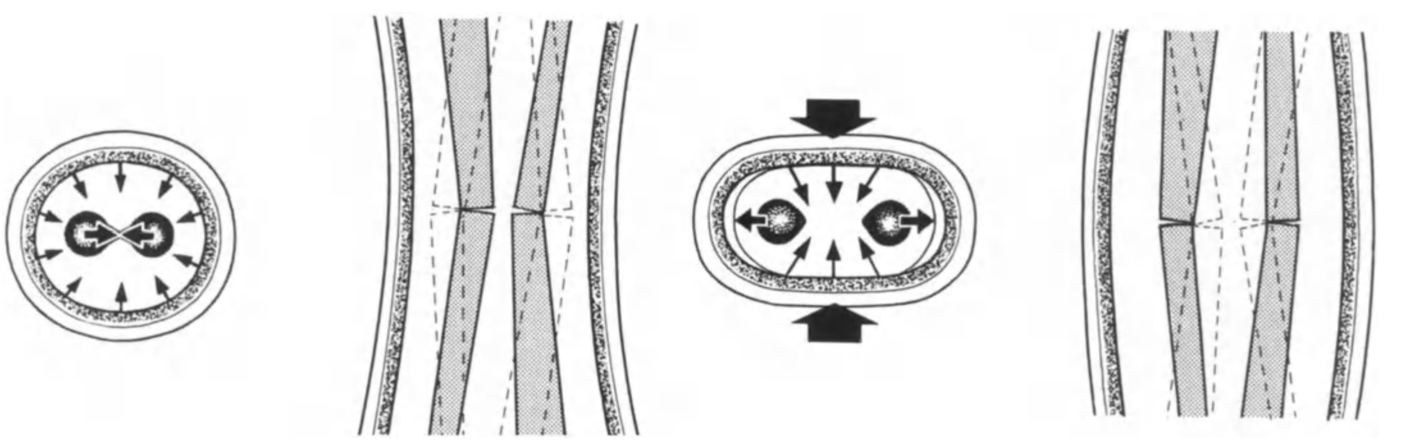
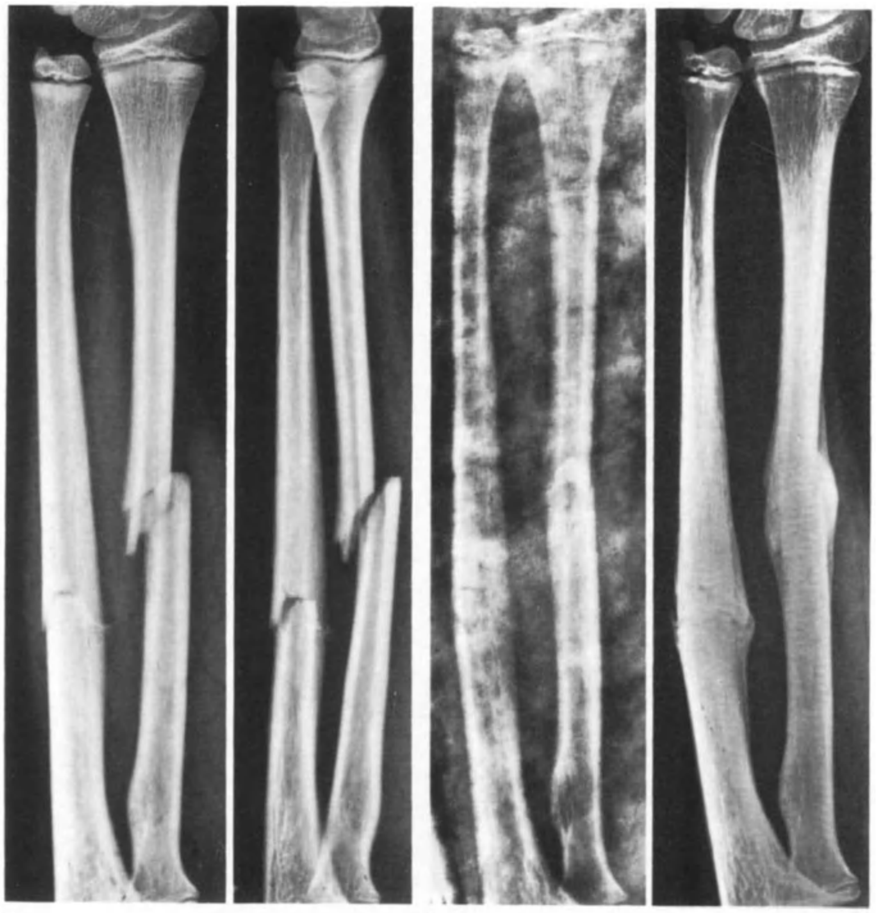


Fig. 14. *Cross section of a forearm cast.* A forearm cast with a circular cross section allows the radius and ulna to bend in towards each other at the the level of the fractures. A cast with an oval cross section forces the radius and ulna apart and thus restores the anatomically normal cross section to the forearm

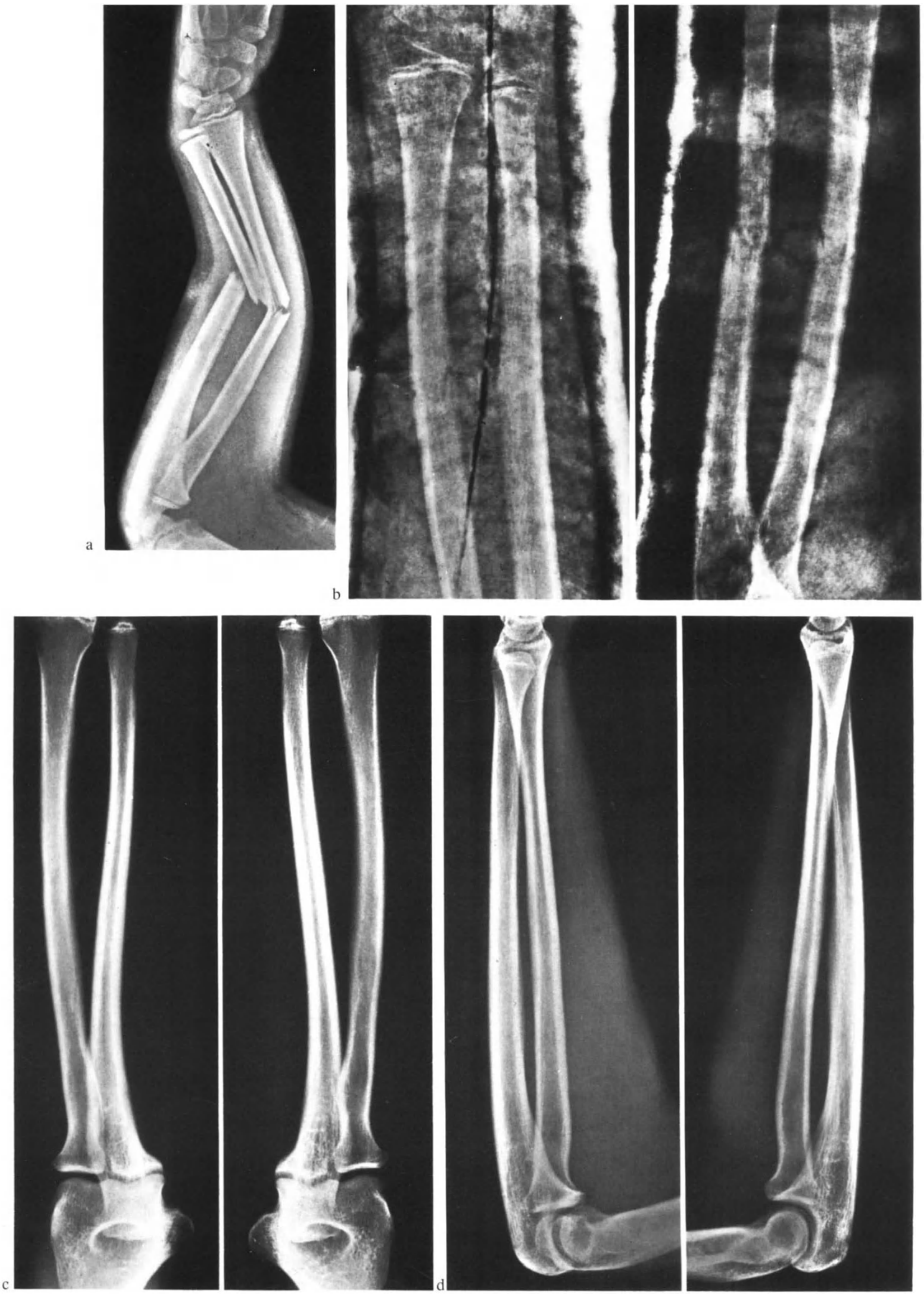


a b

Fig. 15a–c. *Slightly dislocated diaphyseal fractures of the forearm.* S.H., ♂, aged 7 years, No. 88945.
a) Both forearm bones are completely fractured, but the degree of dislocation is slight.
b) The fracture was reduced by applying the "squeeze-grip" to the plaster cast, and union has taken place with correct axial alignment after 8 weeks.
c) $5^1/_2$ years after the accident. Complete recovery has taken place

c

Fig. 16a–d. *Dislocated fracture of the ulna with a greenstick fracture of the radius.* B.D., ♂, aged 10 years, No. 134188.
a) The fracture of the ulna is dislocated and the radius is bent.
b) The largely intact radius is used as a fulcrum for reduction of the ulnar fracture. The "squeeze-grip" is applied to the middle of the forearm.
c, d) 7 years after the accident. Symmetrical forearms


a
b
c
d

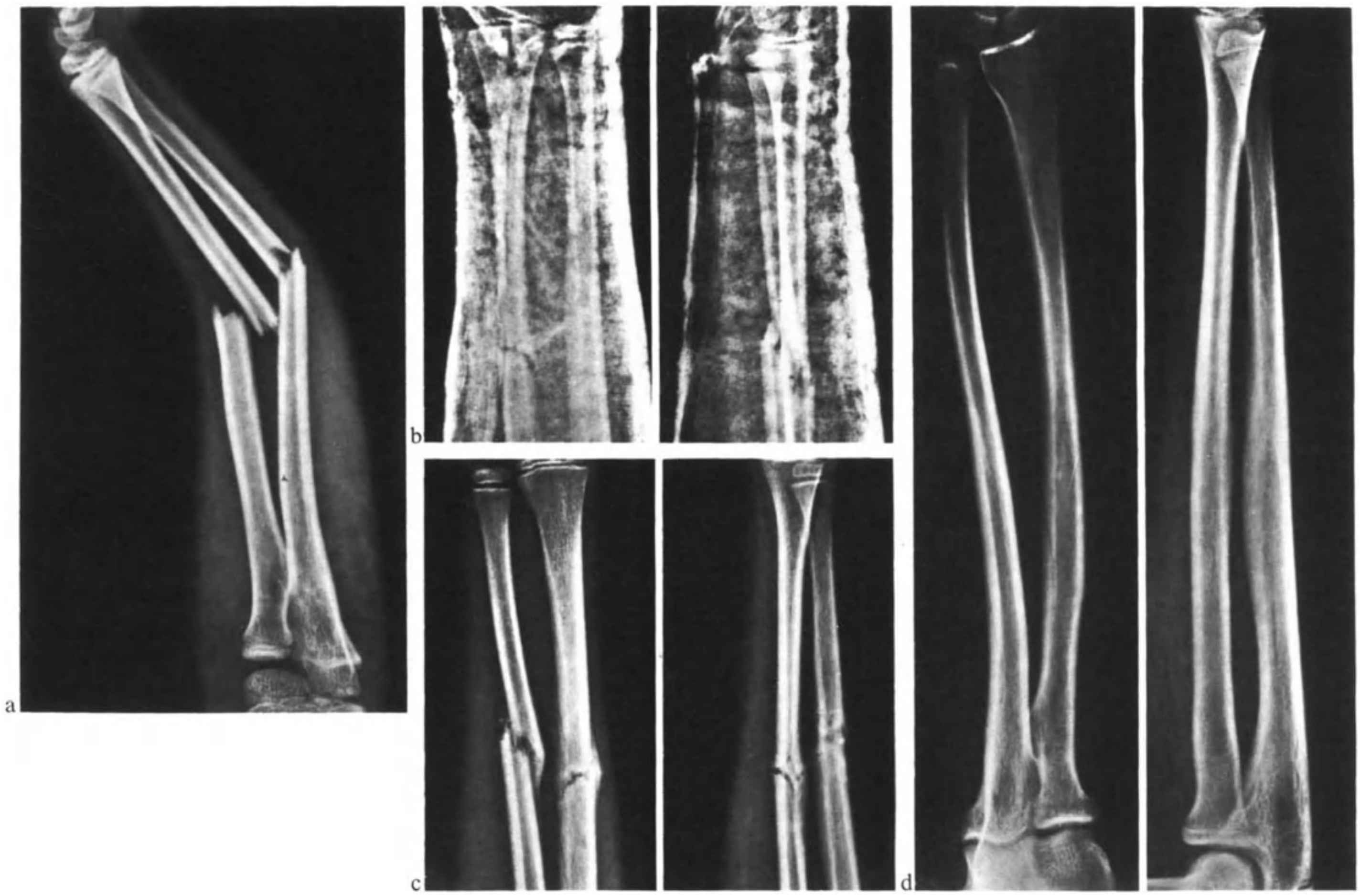


Fig. 17a–d. *Dislocated fracture of the radius with greenstick fracture of the ulna.* M.H., ♂, aged 10 years, No. 119631.
a) The radius fracture is dislocated, but the ulna is only bent.
b) The largely intact ulna is used as a fulcrum for reduction of the radius fracture.
c) 5 weeks after the accident. Bone union with correct axial alignment.
d) 9 years after the accident. Complete recovery has taken place

Fig. 18a–d. *Dislocated fractures of both bones of the forearm.* R.E., ♀, aged $4^1/_2$ years, No. 65460.
a) The radius and ulna are dislocated and the fractures are unstable.
b) Shortening of the radius has been eliminated by end-to-end reduction of the radial fracture and there is correct axial alignment of both bones of the forearm.
c) 7 weeks after the accident. Axially acceptable union.
d) 9 years after the accident. Complete union with no sequelae


a
b
c
d

a b c

Fig. 19a–c. *Irreducible diaphyseal fractures in an adolescent.* H.H., ♀, aged $15^1/_2$ years, No. 129588.
a) Roentgenogram taken immediately after the accident.
b) Treatment: open reduction and stabilization of the radius with a three-cornered *Oberholzer* nail. The ulna was fixed with a compression plate.
c) 1 year after osteosynthesis. The fragments are correctly aligned and the fracture has united

Operative Treatment: Open reduction and stabilization may be indicated in the following situations:

Wide open fractures: Surgical exploration and treatment of the wound necessarily involves exposure of the fracture and the surrounding tissues, and, furthermore, tissue repair is significantly improved by mechanical stability.

Fractures which occur shortly before cessation of growth: since the remaining growth is insufficient to correct deformity, anatomically precise reconstruction is necessary (Fig. 19).

Fractures which have already started to unite at an incorrect angle.

Irreducible, unstable fractures: soft tissue is usually interposed between the fragment ends.

Multiple refractures within a short period of time, and pseudarthroses.

Depending on the age of the child, the fracture may be fixed with a semitubular, 1/3-tubular, or mandibular plate. In a small child, a resorbable periosteal suture may be best.

Postoperative treatment: If the internal fixation is relatively restricted and the fragments are not quite stable, a full-arm plaster splint is applied for 12 days. The skin sutures are then removed and the limb is immobilized in a lightly padded circular full-arm cast for 6 weeks.

Duration of fixation: 8 weeks after operation.

If the internal fixation offers full stability, functional postoperative treatment is possible and the cast can be dispensed with. The implant material is removed after 3 months, since it might otherwise cause accelerated longitudinal growth.

2.3 Fractures in the Proximal Third of the Diaphysis

These fractures do not occur very frequently and make up only 7% of forearm fractures (*Blount*). They result

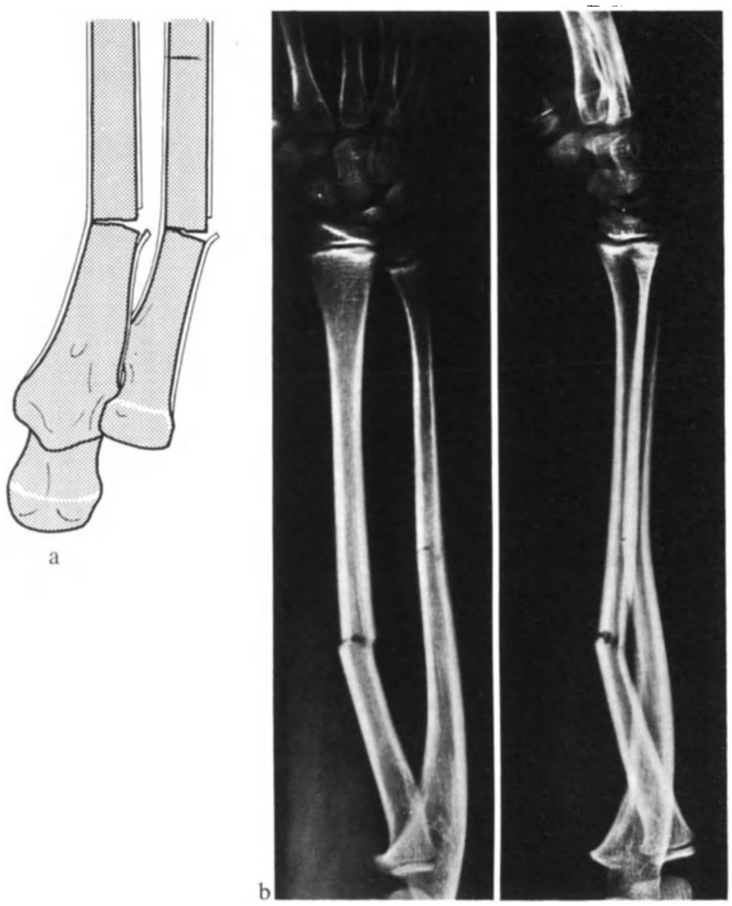


Fig. 20a, b. *Proximal greenstick fracture*. H.H., ♂, aged 12 years, No. 156612.
a) Angulation with unilateral tearing of the periosteum.
b) Subperiosteal fracture of the ulna with greenstick fracture of the proximal radius

from direct or indirect violence, and may be of the greenstick or dislocated type. Frequently both bones are broken; isolated fractures of the radius or ulna are much rarer. An apparently solitary fracture of the ulna should raise suspicion that a *Monteggia* fracture might be present; the latter can only be excluded by roentgenograms of the whole of the forearm, including the elbow joint.

2.3.1 Greenstick Fractures

2.3.1.1 Pathological Anatomy

A greenstick fracture usually results from abnormal bending of the bone. This kind of force is hardly ever applied to the proximal third of the bone, and greenstick fractures of both bones are correspondingly rare. A single fracture frequently results from direct trauma and, if the ulna is involved, suspicion of a *Monteggia* fracture should be raised.

The cortex is incompletely broken, and the periosteal cuff on the concave side of the angulation is intact (Fig. 20). These largely intact parts of the bone and periosteum exert tension on one side of the fracture and tend to cause angulation of the latter; treatment aims at neutralizing this tension.

2.3.1.2 Treatment

Nonoperative Treatment: The fracture is broken in the opposite direction to the original angulation under general anesthesia. The capacity for spontaneous correction of deformity is severely limited at this level, and anatomically precise reduction should therefore be aimed for. A final check is made with the image intensifier.

Immobilization: Split circular, full-arm cast. The forearm is placed in slight supination. The fracture is checked with a roentgenogram after 3–5 days and the cast is then closed.

Duration of fixation: 6 weeks.

2.3.2 Dislocated Fractures

2.3.2.1 Pathological Anatomy

The cortex and the periosteum are broken through completely. An unstable fracture results, with angulation, shortening, and malrotation of the fragments (Fig. 21). The pull of the supinator and biceps muscles causes supination of the proximal fragment of the radius. On the other hand, the distal fragment tends to be pronated by the pronator quadratus muscle. This has to be taken account of during reduction and immobilization of the fracture.

2.3.2.2 Treatment

Nonoperative Treatment: Reduction is always carried out under general anesthesia.

Fractures of the radius and ulna: There is always shortening, and vertical traction on the forearm prior

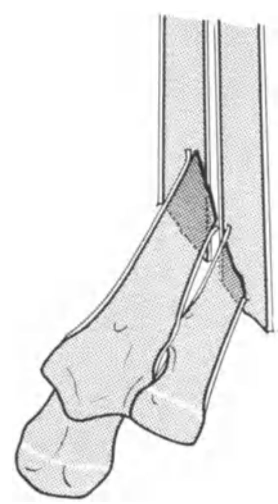


Fig. 21. *Dislocated unstable fracture of the proximal diaphysis.* The periosteum is torn through completely

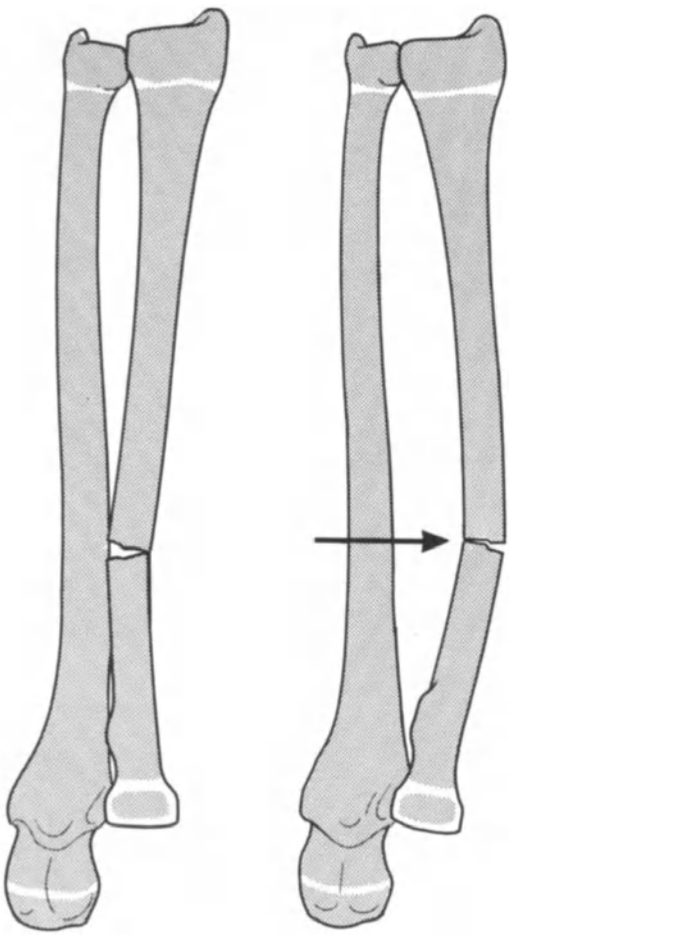


Fig. 22. *Reduction with the ulna intact.* Supination of the forearm and varisation of the radius by pressure with the thumb

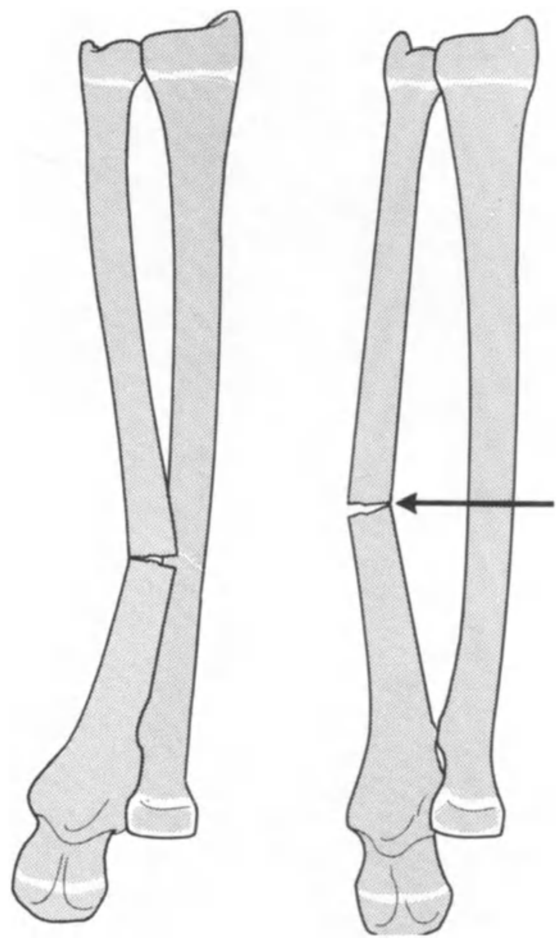


Fig. 23. *Reduction with the radius intact.* Valgisation at the level of the fracture by pressure with the thumb

to reduction is therefore recommended: The arm is suspended by attaching gauze strips or finger traction caps to the thumb, index finger, and middle finger, and a load of 4–8 kg is applied to the upper arm (Fig. 7). As soon as the shortening has been eliminated, reduction of the ulna and then the radius is attempted with the forearm supinated.

Isolated fractures of the radius: The length of the forearm is maintained by the intact ulna, so that significant shortening of the radius cannot occur and vertical traction is unnecessary. Reduction is carried out by varisation at the level of the fracture and supination. The intact ulna serves as a lever during this maneuver (Fig. 22).

Isolated fractures of the ulna: Here a *Monteggia* fracture has to be excluded. The roentgenograms should show the whole forearm, including the elbow joint. Reduction is carried out by valgisation at the level of the fracture, the intact radius serving as a lever. The fragments can then be aligned with each other by pressure with the thumb (Fig. 23).

Immobilization: Split circular, full-arm cast, with the forearm supinated and the hand in the position of function. During hardening of the plaster, the cast is given an oval cross section by pressing on the volar and dorsal surface with the flat of the hand. In this manner, the normal distance between the radius and ulna is restored. This "squeeze grip" (*Charnley*) is fully effective only if the bones are parallel to each other, i.e., in supination.

The child should be kept in the hospital for a short while if there is marked swelling. A radiographic check is carried out after 3–5 days and the cast is then closed.

Duration of fixation: 6–8 weeks, depending on the age of the child.

Note: Spontaneous correction of angular deformity in the proximal third of the bone is limited, and anatomically precise reduction should therefore be aimed at.

Operative Treatment: Open reduction and stabilization may be justified under the following circumstances:

Wide open fractures: Here, internal fixation is carried out for the benefit of the soft tissues. Careful exploration and treatment of the wound usually involves exposure of the fracture, and the stability offered by internal fixation improves soft tissue healing.

Fractures which occur shortly before cessation of growth: since almost no further growth will occur, anatomically precise reduction should be aimed at. This is seldom possible using nonoperative methods.

Fractures which have already started to unite in an incorrect position.

Irreducible fractures: The interposition of soft tissues prevents reduction (*Simon* and *Heydenreich*).

Multiple refractures within a short period of time.

Depending on the age of the child, the fracture may be fixed with a semitubular, 1/3-tubular, or mandibular plate. In adolescents, the fracture may be splinted with an *Oberholzer* nail (Fig. 19). Medullary nailing has been repeatedly reported in the literature (*Simon* and *Heydenreich, Kurz-Lange*), and we have also found it to be satisfactory, although only for stabilization of the radius. Greater rotational stability is necessary for the ulna; medullary wiring is insufficient and a compression plate should therefore be used.

Postoperative treatment: If the fracture is stably fixed, a cast can be dispensed with, and active, functional movement is promoted. In other cases, immediate postoperative immobilization with a plaster full-arm splint for 12 days is recommended. The skin sutures are then removed and a lightly padded full-arm circular cast is applied for 4–6 weeks. The metal is removed after 3–4 months.

Duration of fixation: 6–8 weeks from the date of the operation.

2.4 *Monteggia* Fractures

This is a fracture of the shaft of the ulna with simultaneous dislocation of the head of the radius. On a roentgenogram, the axis of the radius does not pass through the capitulum of the humerus (Fig. 24). Although this injury is rare in children, it requires full discussion in this chapter, since failure to recognize a fracture of this type or to treat it correctly has serious consequences (Fig. 29).

Classification: In the literature, three types of *Monteggia* fractures are described; they are classified according to the direction of dislocation of the head of the radius (*Tachdjian*) as follows:

Type I: Dislocation of the head of the radius and angulation of the ulnar fragments in a ventral direction (85%).

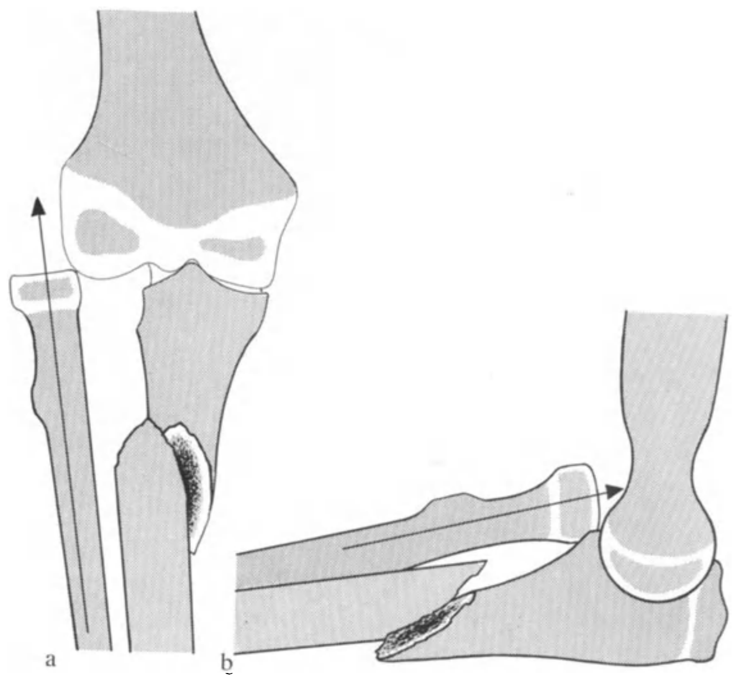


Fig. 24a, b. *Radiological diagnosis of a Monteggia fracture.* The dislocation of the head of the radius, which is one of the components of the *Monteggia* fracture, is shown by the dislocation of the radius itself. The longitudinal axis of the radius no longer passes through the capitulum of the humerus

Type II: Dislocation of the head of the radius and angulation of the ulnar fragments in a dorsal direction (10%).

Type III: Dislocation of the head of the radius and angulation of the ulnar fragments laterally (5%).

The level of the fracture varies considerably: according to *Tachdjian,* 4/6 are at the junction of the proximal and middle thirds, 1/6 in the middle third, and 1/6 in the distal third and in the region of the olecranon. The *theories* concerning the *fracture mechanism* vary from author to author. *Speed* and *Boyd* consider *direct trauma* to be responsible for this complex injury. The bones of the forearm are bound tightly together, both by ligaments and by the interosseous membrane. Fracture and shortening of the ulna immediately causes traction to be exerted on the radius, resulting in dislocation of its head. However, one could also imagine that angulation of the ulna might force the head of the radius out of its containing ligaments. According to *Tompkins,* the *Monteggia* fracture is caused by *hyperextension.* A fall onto the outstretched hand with the elbow hyperextended is accompanied by dislocation of the head of the radius by the pull of the biceps muscle. The whole of the body weight is then borne by the ulna, which is no longer able

Fig. 25. *Monteggia fracture with a greenstick fracture of the ulna.* B.S., ♀, aged $3^1/_2$ years. No. 172611. Dislocation of the head of the radius with greenstick fracture of the ulna

to resist the tension and compression forces and thus fractures.

The trauma causes tearing of the annular ligament or dislocation of the head of the radius out of the ligament. In the latter case, the ligament remains intact and the dislocated head of the radius lies in front of it. Depending on the degree of violence and on the age of the child, the ulnar fracture may be of the greenstick type or dislocated.

2.4.1 Greenstick Fractures

2.4.1.1 Pathological Anatomy

The angulation of the ulna and the direction of dislocation of the head of the radius are determined by the direction of the force acting on the limb as follows:

Direct dorsal trauma: Angulation of the ulna and dislocation of the head of the radius in a ventral direction.

Direct dorsomedial trauma: Angulation of the ulna and dislocation of the head of the radius in a ventrolateral direction.

The positions of the two bones relative to each other at the time of the accident may be a further determinant of the type of injury.

In each case, the ventral part of the cortex is fractured and the overlying periosteum is torn. The dorsal periosteum is intact and the underlying cortex is only bent (Fig. 25). Thus, since the bone is only partially fractured, the fragments are subjected to one-sided tension. This tends to maintain the angulation of the fracture, which may therefore recur, even in a circular cast.

2.4.1.2 Treatment

Nonoperative Treatment: Reduction always requires general anesthesia. The fracture is completed by breaking it in a direction opposite to that of the original angulation; as a rule, the head of the radius is automatically reduced by this maneuver. The fracture is then checked under the image intensifier (Fig. 26).

Immobilization: Circular, initially split full-arm cast with the forearm in the neutral rotation position. If the ulna tends to bend in towards the radius, the "squeeze grip" should be applied to the cast while it hardens. This grip is fully effective only if the forearm is in maximum supination. Three to five days later a radiographic check is carried out and the cast is closed.

Duration of fixation: 6–8 weeks.

If precise reduction of the head of the radius is prevented by folding-in of the annular ligament, open reduction is necessary. The ulna need not be fixed in such cases, since the fracture is stabilized sufficiently by the partially intact periosteal cuff.

2.4.2 Dislocated Fractures

2.4.2.1 Pathological Anatomy

As a result of the accident, complete fracture of the cortex occurs with tearing of the periosteal cuff. The fracture is therefore unstable, and there may be considerable dislocation of the fragments with angulation, shortening, and malrotation (Fig. 24).

2.4.2.2 Treatment

Nonoperative Treatment: Nonoperative treatment should be attempted if the fracture is dislocated. If it is sufficiently stable following reduction, it can be immobilized in a cast. Reduction is always carried out under general anesthesia: The shortening of the limb is first eliminated by traction, and the fragments can then be reduced by valgisation at the level of the fracture; this usually results automatically in anatomically correct reduction of the head of the radius. The fracture is then checked with the image intensifier (Fig. 27).

a

b

c

Fig. 26a–c. *Monteggia fracture with greenstick fracture of the ulna.* M.H., ♀, aged 7 years, No. 133472.
a) Greenstick fracture of the ulna with volar dislocation of the head of the radius. Treatment: closed reduction followed by a full-arm cast.
b) 7 weeks after the accident. The fracture of the ulna has healed and the anatomically correct relationship between the head of the radius and the capitulum of the humerus has been restored.
c) 7 years after the accident. A normal elbow joint

Immobilization: Circular full-arm cast, which is immediately split. If the ulna tends to bend in towards the radius, the "squeeze grip" is applied to the cast while it hardens, so as to give it an oval cross section. By tensioning the interosseous membrane, the normal distance between the radius and ulna can be restored. After 3–5 days, the stability of the fracture is checked with roentgenograms of the whole forearm, including the elbow, and the cast is then closed. Open reduction and stabilization is recommended if the position of the fragments or that of the head of the radius is not quite ideal. Any malunion or subluxation causes biomechanical disturbance and results in limitation of function.

Duration of fixation: 6–8 weeks, depending on the age of the child.

Operative treatment: The indications for the operative treatment of *Monteggia* fractures tend to be less restricted than those of other types of fracture. They are the following:

Open fractures: Internal fixation improves the healing of the soft tissues.

Irreducible or unstable fractures: Reduction is prevented either by the folded-in annular ligament or by interposed soft tissues (Fig. 28).

Late or renewed dislocation.

Fractures which occur shortly before cessation of growth. Since these fractures have little potential for spontaneous correction of malunion, the same rules apply as in the treatment of fractures in adults.

Operative procedure: The *Boyd* approach is used. The first step is the open reduction and fixation of the ulnar fracture. Depending on the age of the child, a semitubular plate, a $^1/_3$-tubular plate or a mandibular plate may be used (Fig. 28). The head of the radius usually returns to its correct position in the course of the latter procedure. If the annular ligament is torn, it is sutured.

Postoperative treatment: A well-padded, dorsal, full-arm splint is applied at the end of the operation. Twelve days later, the skin sutures are removed and a lightly padded circular full-arm cast is applied for 4–6 weeks.

Duration of fixation: 6–8 weeks from the date of the operation.

Fig. 27a–d. *Monteggia fracture with a dislocated fracture of the ulna.* J.S., ♀, aged 3 years, No. 104819.
a) The fresh fracture.
b) Treatment: Successful reduction under general anesthesia, followed by cast fixation.
c) 5 weeks after the accident. The fracture has united with the radius in the correct position.
d) $4^1/_2$ years after the accident. Recovery is complete, with symmetrical ranges of movement

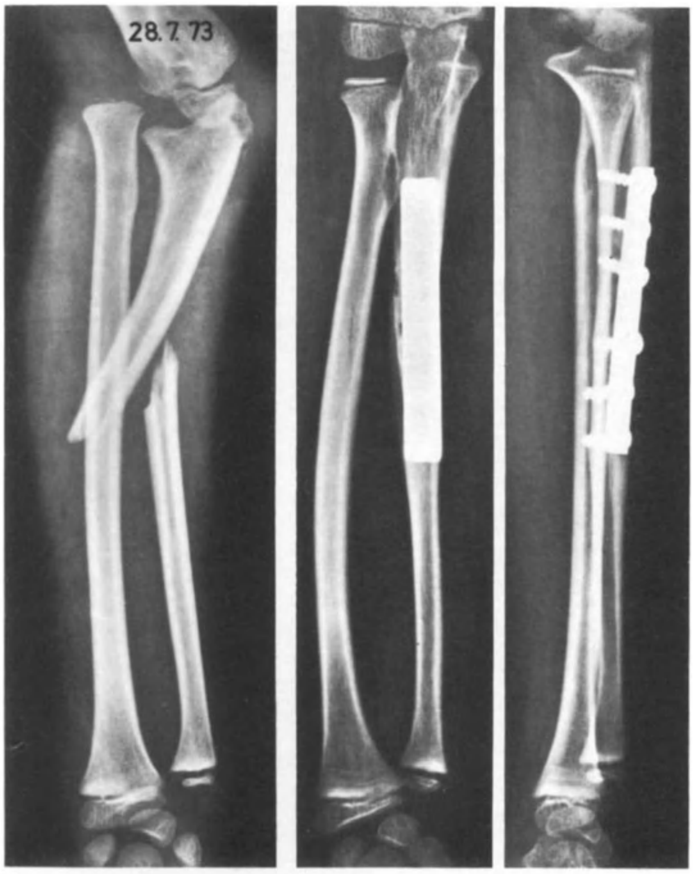


Fig. 28a, b. *Internal fixation of an unstable Monteggia fracture*. R.M., ♂, aged 7 years, No. 169850.
a) Dislocation of the head of the radius and severe dislocation of the ulnar fracture. Treatment: closed reduction was unsuccessful. During the subsequent operative reduction and internal fixation of the ulnar fracture, spontaneous reduction of the head of the radius occurred.
b) 1 year after the accident. The ulnar fracture has healed with correct axial alignment and the head of the radius is in the correct position. The range of motion is normal

3 Prognosis

3.1 Fracture Healing and Fracture Type

The healing of diaphyseal forearm fractures in children is generally uneventful, but every now and then one sees cases in which *refracture* occurs. According to *Blount*, they occur within 6 months of the original injury and often result from excessively brief or otherwise incorrect immobilization in a cast. In our series of cases, the fractures which recurred were mainly located in the middle and proximal thirds of the diaphysis.

Pseudarthroses are rare and are particularly frequently associated with repeated reductions and readjustments of a fracture or with internal fixation. They always require operative treatment with stable plate fixation.

Monteggia fractures exhibit the same characteristics. In addition, however, these fractures may undergo gradual angulation; if the dislocation of the head of the radius is not correctly reduced, the latter is no longer buttressed by the capitulum of the humerus and the ulna therefore tends to bend in a radial direction. The result is valgus deformity of the elbow which gradually increases if the head of the radius remains completely dislocated. Corrective osteotomy of the ulna combined with reduction of the head of the radius may reduce or abolish the subjective complaints and significantly improve the cosmetic appearance (Fig. 29).

3.2 Initial Deformity

The shafts of the radius and ulna are bound firmly to each other by the taut interosseous membrane, which keeps them together without preventing rotation movement. On the other hand, the proximal and distal articulations with their stabilizing ligaments, such as the annular ligament, maintain precise control over the movements. This complex system allows pronation and supination of the forearm, and damage to a bony or ligamentary component of the system results in limitation of function. The latter is particularly true of *malrotation,* which is not corrected by subsequent growth. It causes limitation of pronation or supination and may necessitate corrective osteotomy. Care should therefore be taken during reduction to ensure precise rotational alignment of the bones. Marked degrees of *angular deformity* also cause limitation of function, since the radius can no longer rotate freely about the ulna. The younger the child and the more distal the fracture, the greater is the capacity of the bone for spontaneous correction of angular deformity in the course of subsequent growth. The literature contains little precise data on the degrees of angulation which may be tolerated. *Chigot* refers to "angulation discrète", and *Ehalt* allows angulation of up to 10°.

Translational displacement by the width of the shaft is of no consequence, and the deformity is rapidly compensated for by the remodelling which occurs during growth.

In summary, we recommend the following guidelines concerning the maximum permissible degrees of malreduction:

Rotation:	Always precise reduction
Angulation:	Up to 10° permissible. Precise reduction required in adolescents
Translational displacement:	By one shaft width

Fig. 29a–d. *A Monteggia fracture which was not reduced. Corrective osteotomy*. W.M., ♂, aged 7 years, No. 167948. a) 8 months after the accident. Dislocation of the head of the radius with malunion of the proximal ulnar fracture and varus deformity of the elbow joint.
b) Corrective surgery. Osteotomy of the ulna, open reduction of the head of the radius, and percutaneous fixation with *Kirschner* wires. A circular cast was then applied for 8 weeks.
c, d) 5 years after corrective surgery. Slight reduction in the range of movement. No symptoms

4 Results

Our results are derived from observations on 115 patients with a total of 117 forearm fractures which were treated between 1961 and 1969. One hundred and fifteen were treated nonoperatively and two operatively.

4.1 Results of Nonoperative Treatment

The results shown here are derived from clinical and radiological follow-up examinations of 69 fractures which were carried out at an average of 9 years following the respective accidents (maximum = $16^1/_4$ years, minimum = 5 years).

The localizations of the fractures are shown in Table 1. Simultaneous fractures of both forearm bones

Table 1. Localization of the fracture

Proximal third	3
Middle third	45
Distal third	21
Total	69

Table 2

Isolated fracture of the ulna	6
Isolated fracture of the radius	3
Fractures of both bones	60
Total	69

Table 3. Fracture types

Greenstick	37
Dislocated	14
Combined	18
Total	69

constituted by far the commonest injury (Table 2). Greenstick fractures were more frequent than dislocated or combined fractures (Table 3). The nonoperative treatment almost always corresponded to the guidelines described, and further reduction was carried out in only four cases. In two cases, refractures occurred as a result of immobilization of insufficient duration; they all healed uneventfully with further cast fixation. In 37 cases, the anatomy and function of the limb were found to be normal at follow-up, while fracture sequelae were found in 32 cases.

4.1.1 Subjective Results

Five patients complained of occasional pain at the site of the fracture, with slight limitation of function both at work and in sports. Clinically or radiographically identifiable causes could not be found.

4.1.2 Range of Movement

Pronation and supination were limited in 21 cases (Table 4). In only five cases could this be attributed to residual angular deformity of the radius or ulna (5°–20°). No radiologically identifiable cause for the restriction of movement could be found in the remaining 16 patients. Pronation was mainly affected, but few patients were seriously bothered by this limitation of movement. One patient with two successive fractures of the forearm later became a boxer despite a 40° limitation of pronation.

Table 4. Restrictions of the ranges of movement

Pronation	5°–10°	10
	15°–20°	7
	25°–30°	2
	35°–40°	1
	45°–50°	1
Supination	5°–10°	1
	15°–20°	1
	25°–30°	–
	35°–40°	–
	45°–50°	1

4.1.3 Radiological Results

Angular deformities of 5°–20°, particularly of the radius, were found in 12 cases. Surprisingly, these deformities caused embarassment of function in only five patients. *Differences in length* could be found in only two cases (+0.5 cm and −0.5 cm, respectively).

4.2 Results of Operative Treatment

In the first case, a $15^1/_2$-year old girl had suffered dislocated fractures of both bones of the forearm which could not be reduced. The fractures were stabilized with a plate and a nail, with excellent results (Fig. 19).

In the second case, that of a 14-year old boy, an attempt at nonoperative treatment was followed by dislocation of the ulna. Internal plate fixation resulted in infection, which could be controlled by premature removal of the implant and perfusion-suction drainage. The patient is now free of symptoms and the ranges of movement are the same on both sides.

5 Summary

Diaphyseal fractures of the forearm are very frequent in children, and mainly result from a fall onto the outstretched arm. Treatment is nonoperative in the majority of cases and should be appropriate to the type and level of the fracture. Malreduction of up to 10° is permissible, as is sideways displacement of the

shaft by its own width; rotation deformity, on the other hand, must always be completely corrected. Large degrees of residual angular deformity may limit movement, particularly pronation. *Operative* treatment is only permissible in exceptional cases, being mainly applicable to *Monteggia* fractures.

6 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Boyd, H. B.: Treatment of fractures of the ulna with dislocation of the radius. J. Amer. med. Ass. **115**, 1699 (1940).

Charnley, J.: Die konservative Therapie der Extremitätenfrakturen. Berlin-Heidelberg-New York: Springer 1968.

Chigot, P. L., Esteve, P.: Traumatologie infantile. Paris: Expansion Scientifique 1958.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Kurz-Lange: Operative Behandlung von Vorarmschaftbrüchen bei Kindern. Pädiat. Praxis **10**, 1971.

Renné, J., Weller, S.: Verrenkungen und Frakturen der oberen Gliedmaßen. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer 1974.

Salter, R. B.: Textbook of disorders and injuries of the musculoskeletal system. Baltimore: Williams and Wilkins 1970.

Simon, L., Heydenreich, W.: Markdrahtungsosteosynthese bei kindlichen Unterarmschaftfrakturen. Aktuelle Traumatologie **2**, 1975.

Speed, J. S., Boyd, H. B.: Treatment of fractures of the ulna with dislocation of the radius. J. Amer. med. Ass. **115**: 1699, 1940.

Tachdjian, M. O.: Pediatric Orthopedics, Philadelphia-London-Toronto: Saunders 1972.

Tompkins, D. G.: The Monteggia fractures. J. Bone Jt Surg. **53 A**, 1109 (1971).

Weber, B. G.: Indikationen zur operativen Frakturenbehandlung bei Kindern. Chriurg **10**, 441-444 (1967).

Fractures of the Distal Forearm

K.G. Stühmer

CONTENTS

1 Introduction

Fractures of the distal forearm occur at every age, but their frequency increases significantly between the 7th and 14th years of life (*Renné* and *Weller*). This is the commonest type of forearm fracture, making up 75% of the total, compared to 18% in the middle third of the forearm and 7% in the proximal third (*Blount*).

The most frequent *cause* of a distal fracture of the forearm is a fall onto the hand with the wrist hyperextended. The resulting impact is directed axially and dorsally, which explains the commonly encountered dorsal dislocation of the distal fragment (Fig. 1). A fall onto the hand with the wrist in marked volar flexion is rarer and causes volar dislocation of the distal fragment (Fig. 2). An extremely rare trauma mechanism is a purely axial impact with the wrist

Fig. 1. *The more common fracture type with dorsal tilt of the distal fragment.* L.E., ♂, aged 15 years, No. 146965. The distal fragment is dislocated in a dorsal direction

Fig. 2. *A rare type of fracture with volar dislocation of the distal fragment*. K.H., ♀, aged 8 years, No. 121637

Fig. 3. *A rare type of fracture following axial impact*. K.F., ♂, aged 14 years, No. 132619. The fracture passes through the radial epiphysis, the epiphyseal plate, and the distal metaphysis (*Salter* and *Harris* type IV fracture). The styloid process of the ulna has been fractured by radial abduction during the accident

Fig. 4

Fig. 5

Fig. 6

in radial abduction or ulnar adduction; this leads to fracture of the epiphyseal plate with transection of the growth zone by the fracture line (Fig. 3).

2 Fracture Types and Treatment

The best classification of distal fractures of the forearm is a morphological one which takes into account the degree of injury to the epiphyseal plate, since the latter is a particularly important determinant of treatment and prognosis. Thus, the fractures are classified as follows:

Distal metaphyseal fractures of the forearm.
Simple separation of the epiphysis (*Salter* I).
Separation of the epiphysis together with a metaphyseal fragment (*Aitken* I, *Salter* II).
Fracture of the epiphysis (*Aitken* II, *Salter* III; *Aitken* III, *Salter* IV).

2.1 Metaphyseal Fractures of the Distal Forearm

These fractures are situated proximal to the epiphyseal plate, i.e., at the border with the diaphysis of the radius or ulna, and can be divided into three groups.

2.1.1 Buckling Fractures

2.1.1.1 Pathological Anatomy

A roentgenogram of this type of fracture in its least severe form may show nothing more than an increase in the density of the dorsal cortex without a change in the plane of the wrist joint (Fig. 4). In other cases, the dorsal cortex is visibly buckled and the plane of the wrist shows a slight dorsal tilt (Fig. 5). Greater force causes injury to the opposite cortex in addition to the buckling of the dorsal part of the bone; at the same time, the dorsal displacement of the plane of the wrist joint is increased (Fig. 6). In all these cases, the periosteum remains intact.

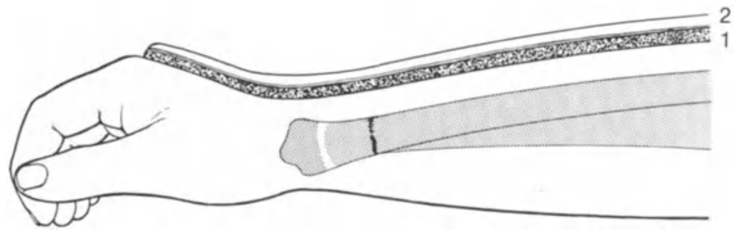


Fig. 7. *Dorsal plaster splint applied to a subperiosteal fracture.* (*1*) Felt strip. (*2*) Plaster splint

2.1.1.2 Treatment

The fracture does not tend to dislocate and is surrounded and splinted by the periosteum, which is very thick in the child, so that immobilization with a cast is unnecessary. Nevertheless, the application of a dorsal plaster splint is recommended for its psychological effects on the parents and playmates of the child.

Immobilization: With the wrist in slight extension, the forearm is padded with a felt strip which reaches up to the heads of the metacarpal bones. The previously prepared plaster splint, which is of the same length as the felt strip, is then applied to the dorsal aspect of the forearm and fixed with crêpe paper and an elastic bandage (Fig. 7).

Duration of fixation: 1–3 weeks, depending on the age of the child.

2.1.2 Greenstick Fractures

2.1.2.1 Pathological Anatomy

Since childrens' bones are very elastic, the cortex breaks on only one side and the overlying periosteum is torn (Fig. 8). The intact cortex and its periosteum exert one-sided tension on the fracture following reduction, which may cause redislocation despite cast fixation. Thus, treatment must include fracture of the intact cortex and tearing of the overlying periosteum prior to reduction.

2.1.2.2 Treatment

Fractures with limited angulation: These do not require reduction, and the angulation will correct itself in the course of growth.

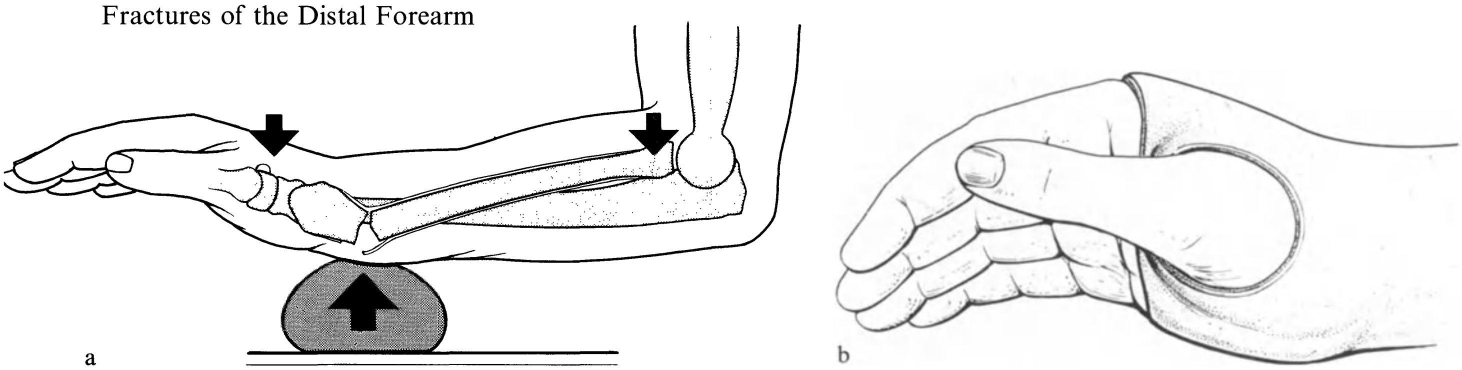
Immobilization: Circular forearm cast, which is immediately split if there is marked swelling and is then closed after 3–5 days.

Fig. 4. *Buckling fracture.* K.M., ♀, aged 5 years, No. 129818. Increase in density of the dorsal cortex with no change in the plane of the joint

Fig. 5. *Buckling fracture with slight angulation.* K.R., ♂, aged 5 years, No. 163759. Marked buckling of the dorsal cortex. Slight dorsal tilt of the plane of the joint

Fig. 6. *Buckling fracture with marked angulation.* H.B., ♂, aged 8 years, No. 150653. Buckling and folding of the dorsal cortex with slight angulation of the ventral cortex. The distal joint surface has a definite dorsal tilt

Fig. 8a–d. *Greenstick fracture of the distal forearm.*
a) (*1*) The fresh fracture. (*2*) The fracture has simply been reduced and immobilized in a forearm cast. (*3*) Despite immobilization, the dorsal tilt has recurred, with reappearance of the original angulation. The intact dorsal cortex and periosteum act as tension bands.
b) R.M., ♂, aged 10 years, No. 135282. Dorsal tilt of the distal fragment.
c) Anatomically correct reduction and immobilization with a cast.
d) 4 weeks after the accident. The deformity has recurred, since the dorsal periosteum has been left intact



a b

Fig. 9a, b. *Reduction and fixation of a distal fracture of the forearm.*
a) The intact periosteum is disrupted by counterangulation of the fracture.
b) The distal palmar fold is clear of the cast. The plaster bridge which separates the thumb from the palm of the hand should be strong enough to prevent the plaster from fracturing

Duration of fixation: 3–4 weeks.

Fractures with considerable angulation: Large degrees of angulation should always be corrected. This is best carried out under a general anesthetic. The fracture is broken over the knee of the surgeon or over a wooden block and is then checked under the image intensifier.

Immobilization: Circular forearm cast, which must be immediately split. After 3–5 days (the exact interval depending on the degree of swelling following the accident), a radiological check is carried out and the cast is closed.

Duration of fixation: 4 weeks.

Note: The plaster strut which crosses the palm of the hand should leave the distal palmar fold free, and should be sufficiently strong, such that early renewal or reinforcement of the cast is unnecessary (Fig. 9).

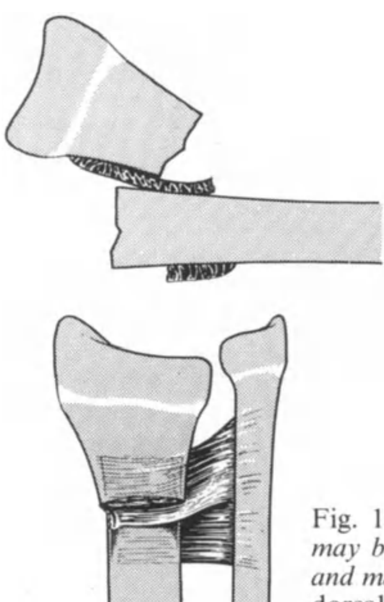


Fig. 10. *The pronator teres muscle may become trapped in the fracture and make reduction difficult.* Severe dorsal dislocation causes partial dislocation of the muscle on to the dorsal side of the proximal fragment

2.1.3 Dislocated Fractures

2.1.3.1 Pathological Anatomy

The bone is completely broken and the periosteum is torn through. If the fracture is located at or near the junction of the metaphysis and diaphysis, the pronator quadratus muscle may be interposed and prevent reduction (Fig. 10).

2.1.3.2 Treatment

Nonoperative Treatment: Dislocated distal metaphyseal fractures of the forearm always require reduction under general anesthesia. The arm is suspended from traction caps or gauze strips applied to the fingers,

Fig. 11. *Reduction of a dislocated fracture of the distal forearm by traction.* Finger traction caps are attached to the thumb and two fingers, and countertraction is applied to a padded cuff placed around the arm just above the elbow

with the elbow flexed at a right angle, and 4–8 kg traction is applied to the upper arm; the exact weight depends on the age of the child and the degree of dislocation (Fig. 11). As soon as the shortening has been eliminated, the traction is removed. Manual reduction is then carried out, using the following procedure: Pull is exerted on the distal fragment, which is simultaneously angled dorsally so as to increase the degree of dislocation. The two cortices can then be interlocked by dorsal pressure with the thumbs and the fracture is reduced (Fig. 12).

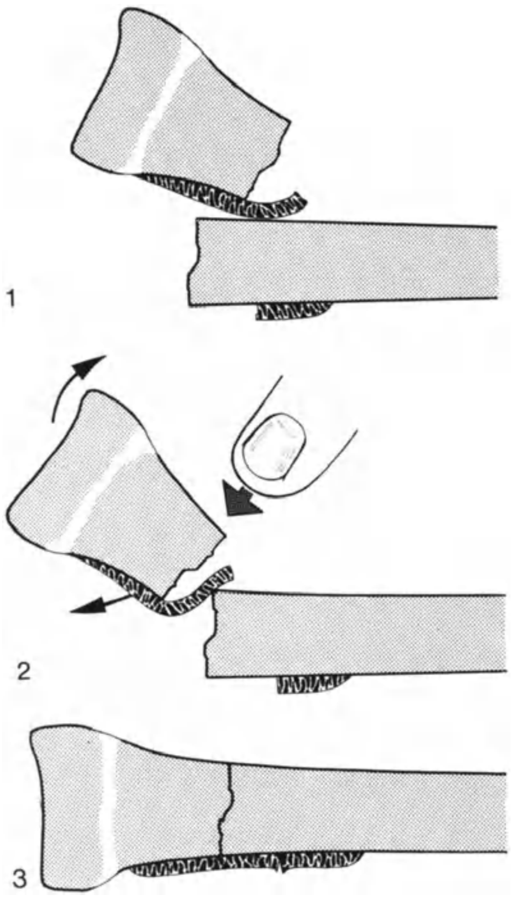


Fig. 12. *Reduction of a fracture in which the pronator quadratus muscle is trapped.* (*1*) Dislocation of the fracture and interposition of the muscle. (*2*) Reduction maneuver; maximum dorsal tilt of the distal fragment and downward pressure with the thumb on its proximal end, thus causing the muscle to slip back into place. (*3*) Volar flexion and reduction of the fracture

Note: If both bones are fractured, reduction is easier with the arm in neutral rotation. If only the radius is fractured, full pronation is best (*Salter*).

Immobilization: The fracture is checked under the image intensifier and is then fixed in a full-arm cast which is immediately split. A further radiographic check is carried out after 5 days and the cast is closed. In order to prevent complications, the parents should be advised about possible disturbances of circulation, sensation, and finger movement.

Duration of fixation: 4–5 weeks, depending on the age of the child.

Operative Treatment: Operative treatment is indicated in the following circumstances:

Wide open fractures: Internal fixation benefits soft tissue healing (*Weber*).

Irreducible fractures. The majority are situated at the junction of the metaphysis and diaphysis. Surgical exposure reveals interposition of the pronator quadratus muscle; reduction is no problem once the muscle has been extracted from the fracture gap. The fracture is fixed with *Kirschner* wires which are inserted through the styloid process, driven into the cortex, and buried under the skin (Fig. 13).

Postoperative treatment: Full-arm plaster splint for 12 days, followed by removal of the skin sutures and application of a lightly padded circular full-arm cast with the forearm in slight pronation.

Duration of fixation: 6 weeks from the time of the operation. The *Kirschner* wires are then removed and the child is allowed to use the arm freely.

2.2 Simple Separation of the Epiphysis (*Salter* I)

2.2.1 Pathological Anatomy

The fracture line is situated in the layer of degenerating cartilage cells, and the growth zone of the epiphyseal plate is not affected. Disturbance of growth will not occur as long as the blood supply to the epiphyseal plate is not interrupted. The periosteum is torn and may be folded into the fracture gap; if so, it will hinder reduction (Fig. 14).

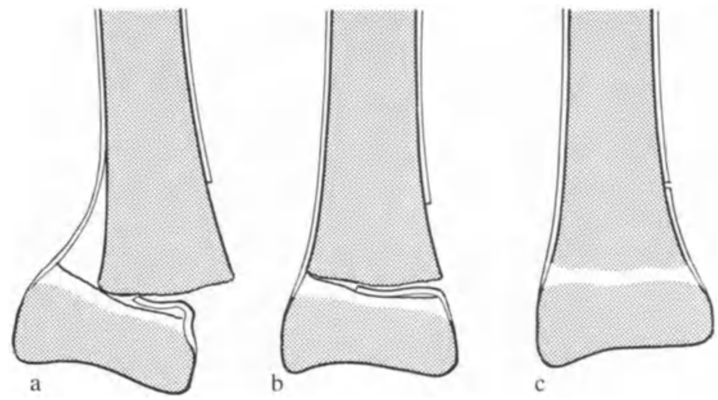


Fig. 14a–c. *Prevention of reduction by trapping of a periosteal flap in the fracture.* If this occurs shortly before cessation of growth, the residual deformity caused by the trapped periostal flap does not undergo spontaneous correction. Open reduction is indicated.
a) Situation following the accident.
b) Incomplete reduction.
c) Precise reduction following operative extraction of the periosteal flap

2.2.2 Treatment

Nonoperative Treatment: Reduction is always carried out under general anesthesia.

Separation with slight dislocation: The fracture can usually be reduced by dorsal pressure with the thumb. Vertical traction is unnecessary.

Separation with considerable dislocation: Reduction may be very difficult in such cases, and preliminary vertical traction is recommended. The arm is suspended from finger traction caps or gauze strips, with the elbow flexed at a right angle, and 4–8 kg traction is applied to the upper arm; the exact weight depends on the age of the child and on the degree of dislocation (Fig. 11). Subsequent reduction usually presents no problems.

Immobilization: Circular forearm cast with the wrist slightly flexed; the cast is immediately split. Five days later, a radiological check is carried out and the cast is closed. If the epiphysis is dislocated in a volar direction, the fracture is reduced in the opposite sense and fixed with a cast with the wrist extended.

Duration of fixation: 4 weeks.

Operative Treatment: If closed reduction in an older child is unsuccessful, then open reduction should be carried out, since considerable deformity otherwise results. At this age, growth has almost ceased in the

←

Fig. 13a–d. *Open reduction of an otherwise irreducible distal fracture of the forearm.* I.B., ♀, aged 10 years, No. 130892.
a) Severe volar dislocation and shortening of the distal fragment.
b) Unsatisfactory reduction under general anesthesia.
c) Operation: open reduction with extraction of a large periosteal flap from the fracture. *Kirschner* wire fixation.
d) 1 year after the accident. Correct axial alignment and normal growth

a b

Fig. 15a, b. *Open reduction following separation of the distal radial epiphysis.* S.T., ♀, aged 13 years, No. 185553. a) There is severe dislocation of the fragments, and closed reduction failed because of interposition of a periosteal flap. b) Open reduction and transfixation with *Kirschner* wires

radial epiphyseal plate, and the capacity of the latter for correction of axial deformity is therefore severely limited. Reduction is prevented by the periosteal tag which is attached to the distal fragment and which is folded into the fracture gap (Fig. 14); as soon as it is removed, reduction is easy. If the reduced fracture is stable enough, a periosteal suture suffices for fixation. If it is unstable, the fragments are fixed with *Kirschner* wires which are inserted through the styloid process and anchored in the cortex (Fig. 15).

Postoperative treatment: A full-arm plaster splint is applied for 12 days, after which the skin sutures are removed and a lightly padded circular full-arm cast is applied.

Duration of fixation: 6 weeks from the time of the operation. The *Kirschner* wires are then removed and the child can use the limb freely.

2.3 Separation of the Epiphysis with a Metaphyseal Fragment (*Aitken* I, *Salter* II)

2.3.1 Pathological Anatomy

As in the case of a simple separation, the fracture passes through the layer of degenerating cartilage cells, but in addition, a bone fragment breaks away from the metaphysis. This fragment is sometimes very small

Fig. 16. *Separation of the epiphysis with a metaphyseal fragment.* S.U., ♂, aged 12 years, No. 149613. The small metaphyseal fragment is only visible on the lateral film (*arrow*). The appearance on the a-p film is that of simple separation of the radial epiphysis


a


b


c

Fig. 17a–c. *Fracture of the distal radial epiphysis.* K.F. ♂, aged 14 years, No. 132619.
a) The fresh fracture.
b) Treatment: closed imprecise reduction followed by immobilization with a cast.
c) 3 years after the accident. There are no symptoms, and function is normal. There is dorsal tilt and slight shortening of the radius due to premature closure of the epiphysis. In spite of pseudarthrosis of the styloid process, growth of the ulna was normal

and only seen in one radiographic plane (Fig. 16). Disturbance of growth need not be feared if the blood supply to the epiphyseal plate is intact.

2.3.2 Treatment

Nonoperative Treatment: Reduction is always carried out under general anesthesia. Fractures with only slight dislocation: These fractures can usually be reduced by traction on fingers I–III with simultaneous dorsal pressure with the thumb.

Fractures with considerable dislocation: Reduction is hardly ever possible without prior traction. The arm is suspended from traction caps or gauze strips applied to the fingers, with the elbow flexed at a right angle, and 4–8 kg traction is applied to the upper arm; the exact weight depends on the age of the child and the degree of dislocation. Frequently, the fracture is found to be largely reduced following a period of vertical traction and additional dorsal pressure suffices to complete the reduction.

Immobilization: Circular forearm cast, which is immediately split, with the wrist flexed. After 5 days, a radiographic check is carried out and the cast is closed. In the rare cases of volar dislocation, reduction is carried out in the opposite direction and the cast is applied with the wrist extended.

Duration of fixation: 4 weeks.

Note: Following reduction, the parents should always be advised about possible disturbances of circulation, sensation, and finger movement.

Operative Treatment: In some cases, anatomically precise reduction is impossible and, as in the case of

a

b

c

d

Fig. 18a–d. *Severe epiphyseal fracture of the distal ulna with fracture of the distal radius.* H.S., ♀, aged 13 years, No. 202422.
a) Dislocation of the head of the ulna from the radial notch. *Aitken* Type III fracture of the styloid process of the ulna. Metaphyseal fracture of the distal radius.
b) Satisfactory alignment following closed reduction of the radial fracture. The head of the ulna is still dislocated.
c) Roentgenograms following open reduction and *Kirschner* wire fixation of the head of the ulna, suture of the radioulnar ligaments, plate fixation of the fracture of the distal radius, and transverse bridging of the gap between the radius and ulna to prevent rotation.
d) 4 months later. At present, growth of the distal ulna is normal. The fracture has healed with correct axial alignment of the fragments

simple separation of the epiphysis, it will be the folded-in periosteum which is causing the obstruction (Fig. 15). In the young child, angular deformity of up to 15°–30° is of no consequence and is corrected by subsequent growth. However, the older the child, the more precise must be the reduction, and irreducible *Aitken* Type I fractures therefore require surgical exposure and reduction. The latter is simple once the interposed tissue has been extracted from the fracture. The subsequent surgical procedure is the same as that for separation of the epiphysis.

Postoperative treatment: Full-arm plaster splint for 12 days, followed by removal of the skin sutures and application of a lightly padded, circular full-arm cast.

Duration of fixation: 6 weeks from the time of the operation. The *Kirschner* wires are then removed and active use of the limb is permitted.

2.4 Epiphyseal Fractures (*Aitken* II, *Salter* III; *Aitken* III, *Salter* IV)

2.4.1 Pathological Anatomy

Both of these rare types of fractures are intraarticular and, at the same time, transect the germinative layer of the epiphyseal plate (Fig. 17). It follows from both these aspects that the fracture requires anatomically precise reduction and stable fixation. If the reduced fracture is not completely "watertight," a callus bridge can form between the epiphysis and the metaphysis, causing partial closure of the epiphysis and, as a result, disturbance of growth (Fig. 17). Our series of cases contains only two fresh fractures of the epiphysis (Fig. 18), but a few cases were referred to us for further treatment.

2.4.2 Treatment

The required anatomically precise reconstruction can only be carried out by open reduction and stabilization. Since we have treated only two fresh fractures, the following therapeutic guidelines are only tentative. They correspond to those applicable to fractures of other epiphyseal plates, which occur much more frequently, e.g., those of the ankle joint.

The reduction of the fracture must be absolutely "watertight." The fragments are fixed with *Kirschner* wires, or, if the epiphysis is sufficiently large, with screws placed parallel to the epiphyseal plate (Fig. 19).

Postoperative treatment: The only aim of the operation is the prevention of a poor result. The fixation described is insufficiently stable to allow active movement, and additional immobilization with a cast is therefore necessary. Immediately following the operation, the wrist is placed in a padded full-arm plaster splint. The skin sutures are removed after 12 days and a lightly padded circular full-arm cast is applied.

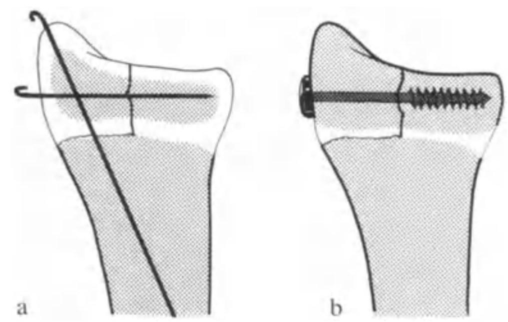


Fig. 19a, b. *Operative treatment of a fracture of the distal radial epiphysis.*
a) In small children, a transverse *Kirschner* wire is used.
b) In older children, a lag screw is inserted parallel to the distal epiphyseal plate of the radius

Duration of fixation: 6 weeks from the time of the operation. After 6 weeks, the *Kirschner* wires are removed and, after 2–3 months, the screws.

3 Prognosis

3.1 Fracture Healing and Fracture Type

The initial healing of distal fractures of the forearm presents no problems, and there were no pseudarthroses in our series of cases. Disturbances of growth do not usually occur following fracture of the metaphysis or separation of the epiphysis with or without a metaphyseal fragment. They only occur following the latter type of fracture if the blood supply to the epiphyseal plate has been compromised as a result of the accident.

Disturbances of growth almost always occur following *Aitken* Type II and III fractures. Despite perfect, closed reduction of the fracture, skew growth very frequently occurs (*Blount*). It results from the damage to the germinative cartilage layer which occurs at the time of the accident, and also from the formation of a callus bridge between the epiphysis and the metaphysis, which causes localized closure of the epiphyseal plate (*Süssenbach* and *Weber*). This leads to deformation of the plane of the wrist joint, and to diminished longitudinal growth of the radius with a disproportionately long ulna. Thus, ugly radial deviation of the hand occurs (*Madelung* deformity) (Fig. 20). The

a

b

Fig. 20a, b. *Premature epiphyseal closure following fracture separation of the distal radial epiphysis.* S.T., ♀, aged 13 years, No. 185553.
a) Severely dislocated fracture in a young girl shortly before cessation of skeletal growth. The results of closed reduction were unsatisfactory, and open reduction was therefore carried out. This was followed by normal fracture healing.
b) 12 years and 7 months after the accident (roentgenogram of the intact side shown for comparison). Excessive length of the ulna caused by premature closure of the radial epiphysis. The growth of the ulna continued undisturbed, thus affecting the function of the distal radioulnar joint

younger the child, the more serious are the consequences of injury to the epiphyseal plate. Progressive deformity is not likely to occur if the bone is fractured shortly before the cessation of growth. As with all fractures in children, those of the distal forearm may also be followed by increased longitudinal growth.

3.2 Initial Deformity

The distal ends of the radius and ulna form the curved surface of the wrist joint and are united at the radioulnar joint. It is this combination of joints which gives the wrist joint its freedom of movement in several planes. Incorrectly reduced fractures of the distal forearm therefore always result in limitation of function which, in extreme cases, requires operative correction. Since angular deformity, with the exception of rotation deformity, is largely corrected by growth, it is important to know what degrees of malreduction may be tolerated.

According to *Blount, Renné,* and *Weller,* the following degrees of malreduction may be tolerated following fracture of the metaphysis, simple separation of the epiphysis, and separation of the epiphysis with a metaphyseal fragment:

Children up to 6–7 years of age: 30° deformity,
Children between 6–12 years of age: 10°–15° deformity,
Children over 12 years of age: 0° deformity.

Large, but tolerable degrees of angulation cause visible deformity of the arm which persists for several months, i.e., until remodelling is complete. It is therefore advisable to inform the parents that the aesthetically displeasing appearance of the arm is only temporary.

a b

c d

Fig. 21a–d. *Excessive longitudinal growth following fracture of the distal radius.* A.E., ♀, aged 9 years, No. 107047.
a) Distal fracture of the radius with intact ulna. Treatment: Closed reduction followed by cast fixation.
b) 3 years after the accident. Markedly excessive growth of the distal radius with limitation of pronation and supination (compare with the intact side).
c) Lengthening osteotomy of the ulna was followed by insertion of a bone graft.
d) The congruence of the distal radioulnar joint is only partially improved

True fractures of the epiphysis (*Aitken* Types II and III) always require precise "watertight" reduction and stable fixation.

4 Results

4.1 Number of Fractures Treated

A total of 160 distal fractures of the forearm were treated at the Cantonal Hospital in St. Gall between 1961 and 1969. Table 1 shows the distribution of the fracture types.

Table 1. Fracture types (160 distal forearm fractures, 1961–1969)

Metaphyseal fractures	117
Separations of the epiphysis (incl. *Aitken* I)	41
Fractures of the epiphysis (*Aitken* II and III)	2

The ratio of isolated fractures of the radius to fractures of both forearm bones was 2:1. Of the 160 fractures of the forearm, eight required operative treatment for various reasons (Table 2).

Table 2. Reasons for operative treatment of 8 distal fractures of the forearm

Aitken Type II fracture of the epiphysis	1
Irreducible separations of the epiphysis	3
Irreducible metaphyseal fractures (interposition of pronator quadratus muscle)	3
Wide open metaphyseal fracture	1

4.2 Results of Nonoperative Treatment – 152 Cases

In our series of cases, we found no difference between epiphyseal separations and metaphyseal fractures in respect to *differences in length* caused by an increased or decreased rate of growth. The cases with decreased growth were in the majority, and the greatest clinically and radiologically determined shortening of the radius was 10 mm (compared to the intact side). In the latter case, the blood supply to the epiphyseal plate may have been compromised as a result of the accident. A 9-year old girl experienced increased longitudinal growth of the radius following an isolated metaphyseal fracture (Fig. 21); this resulted in severe pain in the wrist, and comparative roentgenograms taken 3 years after the accident showed incongruence of the distal radio-ulnar joint with shortening of the ulna. The ulna was therefore osteotomized to lengthen it by 6 mm. Following removal of the metal, the patient was symptom-free and there was no limitation of function.

As might be expected, serious disturbances of growth follow fracture of the epiphyseal plate. A 9-year old boy suffered an *Aitken* Type II fracture of the distal radius with dislocation of the radio-ulnar joint. The fracture was treated in another hospital and may have been of the *Galeazzi* type: Two years later, increasing pain arose with restriction of the range of movement, particularly that of pronation and supination. As a result, resection of the distal ulna had to be carried out 7 years after the accident. At follow-up, flexion, extension, and adduction of the wrist were each limited by 15°.

In no case was significant *angular deformity* or *limitation of function* observed.

Only three patients complained of slight *symptoms* following prolonged exertion 2–5 years after the accident, above all when writing.

4.3 Results of Operative Treatment – 8 Cases (Table 2)

Seven of the total of eight fractures which were operated on healed without *differences in length, limitation of motion,* or *angular deformity*. One wide open metaphyseal fracture of the forearm with a large soft tissue defect subsequently became infected; at the time of follow-up, supination was limited by 35% and flexion of the wrist by 20°.

All patients whose fractures had been operated on were *symptom-free*.

5 Summary

Fractures of the distal forearm are frequent in children and result from a fall onto the outstretched arm with the wrist hyperextended. The most satisfactory classification is a morphological one which takes into account the degree of injury to the epiphyseal plate, i.e., metaphyseal fracture, simple separation of the epiphysis, epiphyseal separation with the inclusion of a metaphyseal fragment (*Aitken* Type I), and true fractures of the epiphysis (*Aitken* Types II and III) (the latter two types are very rare). Treatment is generally nonoperative, but situations occasionally arise in which open reduction and fixation are indicated, i.e.,

Irreducible metaphyseal fractures: reduction is prevented by interposition of the pronator quadratus muscle.

Irreducible separations of the epiphysis, and separations with the inclusion of a metaphyseal fragment: reduction is prevented by trapping of a flap of periosteum.

True fractures of the epiphysis (*Aitken* Types II and III): failure to ensure "watertight" reduction and stable fixation usually leads to serious disturbance of growth.

Wide open fractures: internal fixation is carried out here for the benefit of the soft tissue healing.

The results of the nonoperative and operative treatment of 160 distal fractures of the forearm are analysed in terms of *differences in bone lengths, ranges of movement, angular deformities, and subjective complaints.*

6 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Renné, J., Weller, S.: Verrenkungen und Frakturen der oberen Gliedmaßen. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer 1974.

Salter, R. B.: Textbook for disorders and injuries of the musculoskeletal system. Baltimore: Williams and Wilkins 1970.

Salter, R. B., Harris, R.: Injuries involving the epiphyseal Plate. J. Bone Jt Surg. **45 A**, 587 (1963).

Süssenbach, F., Weber, B. G.: Epiphysenfugenverletzungen am distalen Unterschenkel. Bern: Huber 1970.

Weber, B. G.: Indikationen zur operativen Frakturbehandlung bei Kindern. Chirurg **10**, 441-444 (1967).

Fractures of the Hand

G. SEGMÜLLER, F. SCHÖNENBERGER

CONTENTS

1 Introduction

Metacarpal and phalangeal fractures in children are frequently seen in clinical practice, even if they are somewhat less common than other types, such as distal fractures of the radius. There are no precise *figures* available concerning their frequency, since the majority of these fractures are successfully treated by general practitioners. The open fractures or problem cases are those which are referred to the hospital. They make up 50% of our series of cases.

Types of accident. In children, trapping of the hand or finger is by far the most frequent cause of injury. Thus, even at this age, the fractures are frequently accompanied by serious soft tissue injuries. In older children, crush injuries combined with lacerations are more frequent, but the proportion of sporting injuries (fracture dislocations) is increasing; traffic accidents are less common. Fractures of the phalanges predominate in young children, and fractures of the metacarpals in the older age groups. In our case series, the metacarpals were affected with equal frequency; the injuries were not concentrated in the bones which make up the edge of the hand, as is the case in adults. Fractures of the hand present *special problems* because of the close proximity of a large number of joints. Articular fractures were present in 21% of cases, and, together with fractures in the vicinity of joints, made up more than 50% of the cases in our series. Here, too, the epiphyseal plates are very numerous and vulnerable, and injuries to them are correspondingly frequent. The resulting disturbances of growth are rare in terms of absolute numbers, but the hand surgeon is frequently faced with such cases for assessment. Limitation of function is restricted almost exclusively to cases with radial or ulnar deviation, while other types of growth disturbance, e.g., slowing of growth, simply cause aesthetically displeasing deformity. Rotatory malunion of 8° in one digit suffices to prevent effective gripping with the hand (Table 1).

Table 1. Abnormal longitudinal growth following finger fracture (% of that of the intact side). In half the cases there is no discernible change in longitudinal growth. However, reduced growth is twice as frequent as increased growth

	Cases	Phalanges	Metacarpals
Symmetrical growth	19		
Increased growth	7	3%–18%	2%
Decreased growth	14	3%–30%	2%–13%
Total cases	40		

As in adults, *soft tissue injuries* in the growing hand frequently contribute more to the subsequent limitation of function than the fracture itself. Disturbances of function result from flexion or extension stiffness of the finger joints; these may be caused by open fractures in the vicinity of joints or by adhesion of tendons to surrounding structures.

Finally, full recovery may be prevented by contractures caused by periarticular proliferation, even if fracture healing was satisfactory.

2 Classification of the Fractures According to Prognosis and Treatment

2.1 General Remarks

The treatment of fractures in the growing hand is, in general, relatively simple. However, these injuries may usefully be subdivided into those with a good prognosis and those with a potentially poor prognosis, so as to concentrate attention on the latter group. The fractures with a potentially poor prognosis are mainly those involving the growth cartilage and fractures with residual bone gaps. The first group—the injuries with a good prognosis—includes:

1. Epiphyseal separations and *Aitken* Type I fractures (Fig. 1).
2. Distal fractures of the distal phalanges.
3. Diaphyseal fractures of the phalanges and of the metacarpal bones.
4. Fractures of the bases of the metacarpals (with the exception of the first metacarpal).
5. Subcapital fractures of the metacarpals.
6. Fractures of the carpal bones.

2.2 Group I: Fractures with a Good Prognosis

2.2.1 Epiphyseal Separations and *Aitken* Type I Fractures (Metaphyseal Fractures)

Fracture type: Of the four epiphyseal plates of each digital ray, that at the base of the proximal phalanx is by far the most frequently affected. Epiphyseal separation caused by an axially-directed impact combined with abduction occurs with almost the same frequency as *Aitken* Type I fracture, e.g., metaphyseal fracture dislocation. As in adults, the small finger is that which is most frequently affected.

Treatment: Epiphyseal separations and *Aitken* Type I fractures are reduced by traction with the metacarpophalangeal joint flexed at 90°. This flexion offers two advantages: (a) the collateral ligaments of the M–P joint tighten when the joint is flexed; thus, the short fragment is stabilized and the distal mobile fragment

a b

Fig. 1a, b. *Epiphyseal separation with a metaphyseal fragment.* S.J., ♂, aged 13 years, No. 170176.
a) Roentgenogram taken immediately after the accident. Separation of the epiphysis with a metaphyseal wedge. 30° angulation.
b) Reduction is unnecessary. Union is already complete after 4 weeks and straightening of the bone has commenced

can then be manipulated: (b) With the joint flexed, the reduced fracture can be *simultaneously* checked for rotation deformity; this is the only important aspect of the treatment of this type of fracture. Sideways displacement due to inadequate reduction is of no consequence since it is corrected spontaneously by subsequent growth. The fracture can be immobilized with the finger in flexion (but not in maximum flexion) by the use of a plaster splint which includes the wrist joint and the forearm; this fixation is maintained for 2 weeks only. Special attention should be paid to impaction of the ulnar side of the metaphysis with ulnar deviation amounting to 10° or more. A certain degree of spontaneous correction is likely to occur in the course of growth, but requires months or years for completion; in the meantime, the abduction deformity will cause considerable disability and it is therefore worth correcting the angulation immediately. The 4th finger serves as a fulcrum for the purposes of reduction; it is flexed and the 5th finger is forced over it in a radial direction. Here the digits on the radial side of the hand are not included in the plaster splint (Fig. 2).

Immobilization in plaster can be dispensed with if the fragments are interlocked following reduction and the fracture is stable. The broken finger can be strapped to an intact neighbor so as to allow a certain degree of active movement.

Prognosis: Excellent

a b c d

Fig. 2a–d. *Separation with a metaphyseal fragment.* S.M., ♀, aged 12 years, No. 95122.
a) Severe dislocation.
b) Severe residual dislocation. Immobilization with a cast.
c, d) State of healing 5 years later. The angulation has been corrected by subsequent growth and the function is symmetrical (compare the right and the left sides)

2.2.2 Distal Fractures of the Distal Phalanx (Processus Unguicularis)

Fracture type: Crush injury with or without temporary or permanent damage to the nail; usually open comminuted fractures.

Treatment: The comminuted fracture of the unguicular process is simply splinted with the aid of the partially or completely avulsed nail. This type of splinting is contraindicated for fractures involving the base of the distal phalanx because of the tendency for volar tilt of the distal fragment to occur at the level of the proximal end of the fingernail. The fingernail is fixed with two skin sutures, especially in cases of comminuted fracture. This allows the nailbed to regain its normal function.

Prognosis: We have occasionally seen pseudarthroses of individual bone splinters. These are usually painless and have no effect on function.

2.2.3 Shaft Fractures of the Phalanges and Metacarpal Bones

Fracture type: Transverse fractures of the metacarpal and phalangeal diaphyses are more frequently seen than oblique or spiral fractures. Dorsal, palmar, radial, or ulnar angulation of more than 10° must be reduced carefully, while angulation of less than 10° may undergo spontaneous correction in the course of subsequent growth. Rotation deformity must always be eliminated since it cannot be expected to

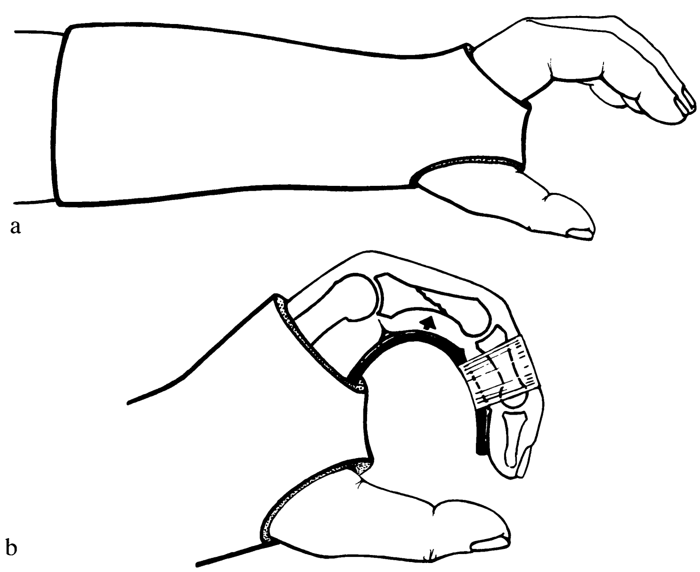


Fig. 3a, b. *Attachment of the metal splints to a circular forearm cast.*
a) Circular forearm cast; the bridge across the palm of the hand is kept narrow in order to allow unrestricted movement in the MP-joint.
b) The splint is shaped to fit the forearm surface and is fixed to the cast with plaster of Paris. The finger is loosely bound to the splint with nonirritating adhesive tape

a b c d

Fig. 4a–d. *Subcapital fracture of the metaphysis of the fifth metacarpal.* V.S.A., ♂, aged 14 years, No. 105930.
a) Correct rotation following closed reduction.
b) 4 weeks later. Increased tilt in a palmar direction. The fracture has united.
c, d) 4 years later. The intact side is shown for comparison. Shortening of 5 mm. Almost complete spontaneous correction of the angulation. Functionally and aesthetically perfect result

correct itself (*Salter* and *Harris*). Fractures of the proximal phalanx form a dorsally directed obtuse angle owing to the prevailing pull of the intrinsic muscles and the central extensor tendon; those of the metacarpals are angled in the opposite direction by the pull of the flexor tendons on their palmar aspects.

Treatment: Dorsal and palmar splinting for 14 days following closed reduction; the hand is kept raised for 24 h to combat swelling (*Leonhard* and *Dubravcik*). Diaphyseal fractures of P1 and P2 which tend to redislocate owing to muscle pull are carefully immobilized with metal splints which are attached to a circular forearm cast; the finger is splinted with the metacarpophalangeal joint flexed and the proximal and distal interphalangeal joints almost completely extended. This position should be maintained for no longer than 12–14 days (Fig. 3).

Prognosis: very good, as long as care is taken to eliminate rotation of the fragments.

2.2.4 Fractures of the Bases of the Metacarpals II–V (With the Exception of Metacarpal I)

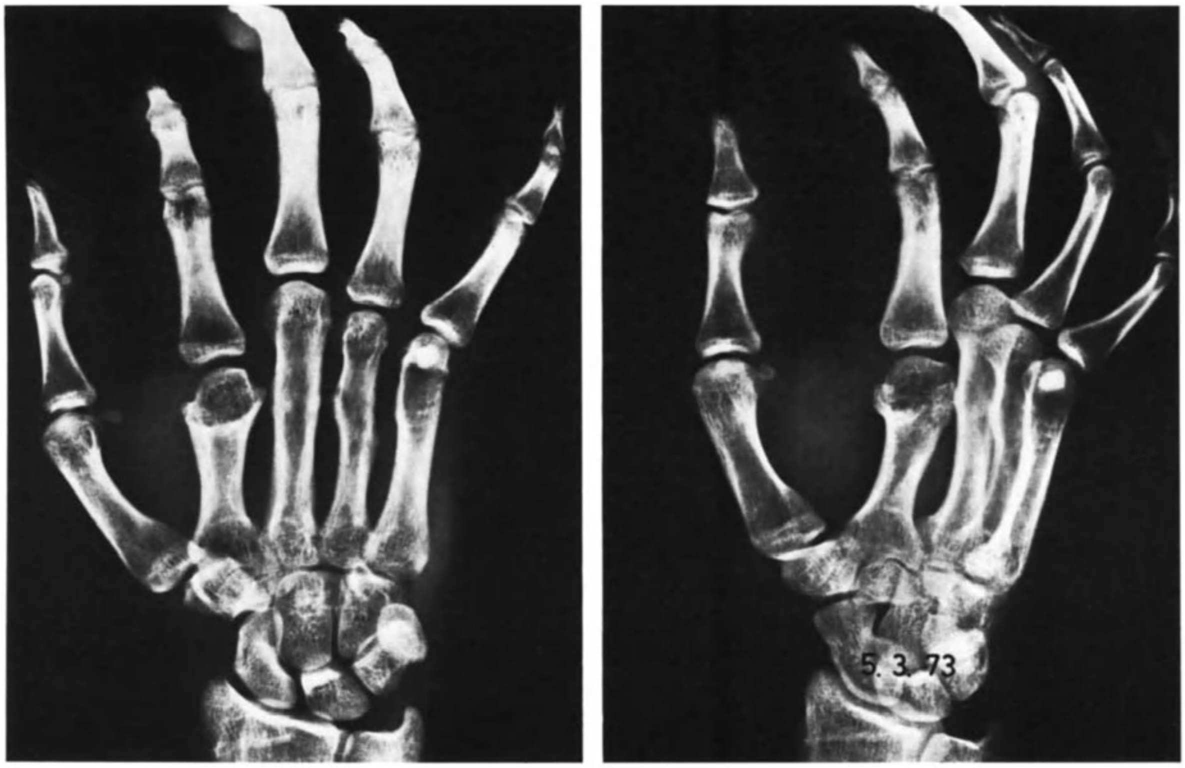
Fracture type: These are frequently stable impacted fractures with little shortening and no significant angular deformity. The epiphyseal growth plate of the first metacarpal, in contrast to those of metacarpals II–V, is located at the base of the bone rather than at its head; thus, fractures of the base of the first metacarpal (i.e., epiphyseal fractures) belong to Group II.

Treatment: Stable fractures do not require reduction, but are immobilized for 10 days on a palmar plaster splint to prevent pain. Fractures with marked ad latus dislocation, particularly those of the 4th and 5th metacarpals, require closed reduction in order that the transverse arch of the hand recover its normal shape. Irreducible fractures of the base of a metacarpal with shortening and lateral dislocation by the width of the bone require open reduction and transfixation with crossed *Kirschner* wires; here again, the aim is restoration of the normal shape to the transverse arch of the metacarpals.

Prognosis: As in 3.3.

2.2.5 Subcapital Fractures of the Metacarpals

Fracture type: Impacted fracture with tilting of the fragment in a palmar direction and towards the midline. This tilting about two axes is the cause of the rotation deformity which frequently results and which is only noticed later on closing the fist. The shortening which results from impaction is, on the other hand,



a b

Fig. 5a, b. *Typical skeletal changes following metaphyseal and epiphyseal fractures of the metacarpal bones.* F.E., ♂, aged 19 years, A.K. The original injury occurred at the age of 8 years (roentgenograms of the fresh fractures no longer available). These roentgenograms were taken 11 years after the accident and show the following residual signs: 1. Metacarpals III, IV, and V: transection of the metaphysis just proximal to the epiphyseal plate; almost normal longitudinal growth; no deformity. 2. Transection of the bone across the growth cartilage of the distal epiphyseal plate. Immediate epiphyseal fusion resulted and longitudinal growth ceased at the age of 8 years. Circumferential growth remained normal

usually of no consequence and is completely corrected by accelerated growth. It is interesting that true epiphyseal fractures (*Aitken* Types II and III) are the exception at this site, even though the epiphyseal plates of metacarpals II–V are situated subcapitally. On the other hand, epiphyseal separations and metaphyseal fracture dislocations (*Aitken* Type I) are seen, but their treatment presents no problems (Fig. 4).

Treatment: Realignment of the fragments by exerting axially-directed longitudinal pressure on the finger which is flexed at a right angle is only necessary if the angulation exceeds 40° or if the fracture is completely unstable. The bone is immobilized for only 10 days in a similar position, using a volar plaster splint which passes over the clenched fist (*Compere*, *Banks*, and *Compere*). Pressure necrosis is prevented by light padding. Stable fractures with less than 40° angulation are immobilized for only 8 days in a plaster splint in order to prevent pain; the metacarpophalangeal joints are placed in flexion and the interphalangeal joints in almost full extension.

Prognosis: Good, with the exception of the true epiphyseal fractures (*Aitken* Types II and III) which, theoretically, may occur at this site.

2.2.6 Fractures of the Carpal Bones

Fracture type: With the exception of fractures of the carpal scaphoid, which may be seen 1–2 years before cessation of growth, carpal fractures are almost exclusively associated with severe complex injuries to the proximal part of the hand.

Treatment: Fresh scaphoid fractures do not require operative treatment, and the same applies to those in which healing is delayed. They are immobilized in a scaphoid cast. Three fractures of this type with delayed union occurred in our series. In each case, the fracture initially went unnoticed. Union is brought about by immobilization for several months in a scaphoid cast, despite clearly visible cyst formation in the vicinity of the fracture gap. The treatment of open fractures of other carpal bones forms part of the soft tissue reconstruction which is required following complex injury to the hand; the fracture itself is of background importance in the overall management.

Prognosis: Scaphoid – excellent.

Fractures which form part of a complex injury to the proximal part of the hand are frequently followed by abnormal development of individual carpal bones which may become severely deformed. However, the multicentric wrist joint is able to adapt functionally and structurally to a surprising degree. The tendency to early posttraumatic osteoarthrosis is slight.

2.3 Group II: Fractures with a Potentially Poor Prognosis

2.3.1 Epiphyseal Fractures (*Aitken* Types II and III) and Separations with Partial Damage to the Growth Cartilage Zone (Fig. 5)

Fracture type: These fractures may result from shear forces acting on any one of the 19 epiphyseal plates of the five rays of the hand. The most frequent site is again the base of the proximal phalanx. The majority of injuries to the epiphyseal plate itself are open wounds, e.g., caused by an axe or crushing.

Treatment: In every case, there is danger of premature, partial, or total fusion of the epiphysis with correspondingly abnormal growth. To prevent this, anatomically precise open reduction and "watertight" reconstruction of the epiphyseal plate with complete elimination of the fracture gap by internal fixation is essential. Closed reduction, however well it is carried out, is not a satisfactory alternative to the latter procedure. Following open reduction, the fracture may sometimes be stabilized with two thin *Kirschner* wires (0.3–0.4 mm); larger fragments are fixed with lag screws (screw diameter: 2 mm).

Prognosis: The prognosis is excellent if anatomically precise reduction has been followed by "watertight" closure of the fracture gap at the level of the epiphyseal plate. If the fracture is comminuted, whatever the degree, premature partial closure of the epiphysis is to be expected. This bone bridge which crosses the epiphyseal plate may be disrupted by the pressure of subsequent growth. If it is small, surgery may be indicated to free the epiphysis. If fusion has occurred over a large area, one or more corrective osteotomies will offer the only means of correcting the deformity. If possible, these are carried out shortly before cessation of growth.

2.3.2 Fractures of the Base of the Thumb

Fracture type: These fractures result from impaction and abduction of the thumb in a manner analogous to that which causes *Bennett* fracture in the adult. The broad base of the first metacarpal is firmly seated on the saddle-shaped trapezium, and its ulnar corner is therefore shorn off by the impact. Predictably, the sagittal fracture line transects the epiphysis, the epiphyseal plate, and the metaphysis, thus constituting an *Aitken* Type III fracture. The germinative cartilage zone is split. The dislocation is maintained by the pull of the abductor pollicis longus muscle.

Treatment: Reduction which more or less eliminates the fracture gap suffices to ensure adequate healing of a *Bennett* fracture in the adult, but the treatment of a fracture which transects an epiphyseal plate requires greater precision. Premature fusion of the epiphysis on the ulnar side causes complete incongruence of the joint, since the growth of the "Bennett fragment" on the ulnar side is slowed. This rare type of fracture therefore requires anatomically correct open reduction and internal fixation.

Prognosis: Despite inadequate reduction and progressive deformity of the joint, hardly any symptoms arise during the growth phase and the function of the joint is seldom affected. However, the joint incongruence is a prerequisite for early osteoarthrosis. On the other hand, the prognosis is excellent following adequate treatment by "watertight" internal fixation of the fracture.

2.3.3 Distal Fractures of the Proximal and Middle Phalanges

Fracture type: Unicondylar and T-shaped fractures of the heads of the proximal phalanges are those which are most frequently seen; they are caused by impaction and tilting in a dorsal direction (*Segmüller* and *Schönenberger*). The fracture transects the bone just proximal to its head, and the latter may be displaced dorsally by the width of the shaft of the bone or tilted dorsally at an angle of 80°. In children under the age of 7 years, the head of the phalanx is incompletely developed, and a thin chip of bone with a cartilaginous cap is shorn off (Fig. 6). This chip may also be displaced sideways by the width of the shaft of the bone. These fractures frequently cause abnormal growth despite precise reduction; the head of the bone loses its sphericity, probably as a result of partial necrosis (*Wakefield*).

Treatment: Subcapital fractures may be unstable following reduction. It is difficult to keep the fragments in place with a plaster cast, especially if the patient is a young child. If the cast is unsuccessful, a *Kirschner* wire placed in the soft tissues next to the bone is an excellent alternative. One may also use two extremely thin *Kirschner* wires which are carefully inserted on the ulnar and radial sides of the bone (Fig. 7). When using fine *Kirschner* wires, vascular injuries are avoided by inserting them laterally,

a b

Fig. 6a, b. *Distal fracture of the proximal phalanx of the thumb.* P.B. ♂, aged 6 years, No. 125837.
a) Intracapsular fracture of the condyle of the joint caused by trapping of the thumb. The distal fragment is dislocated by almost the width of the shaft. Closed reduction with an unsatisfactory result.
b) Comparison with the intact side 2 years later. Acceleration of growth (3 mm); loss of condylar sphericity and abnormal growth; radialangulation of 10°; dorsal tilt (15° hyperextension); rotation deformity; limited range of movement

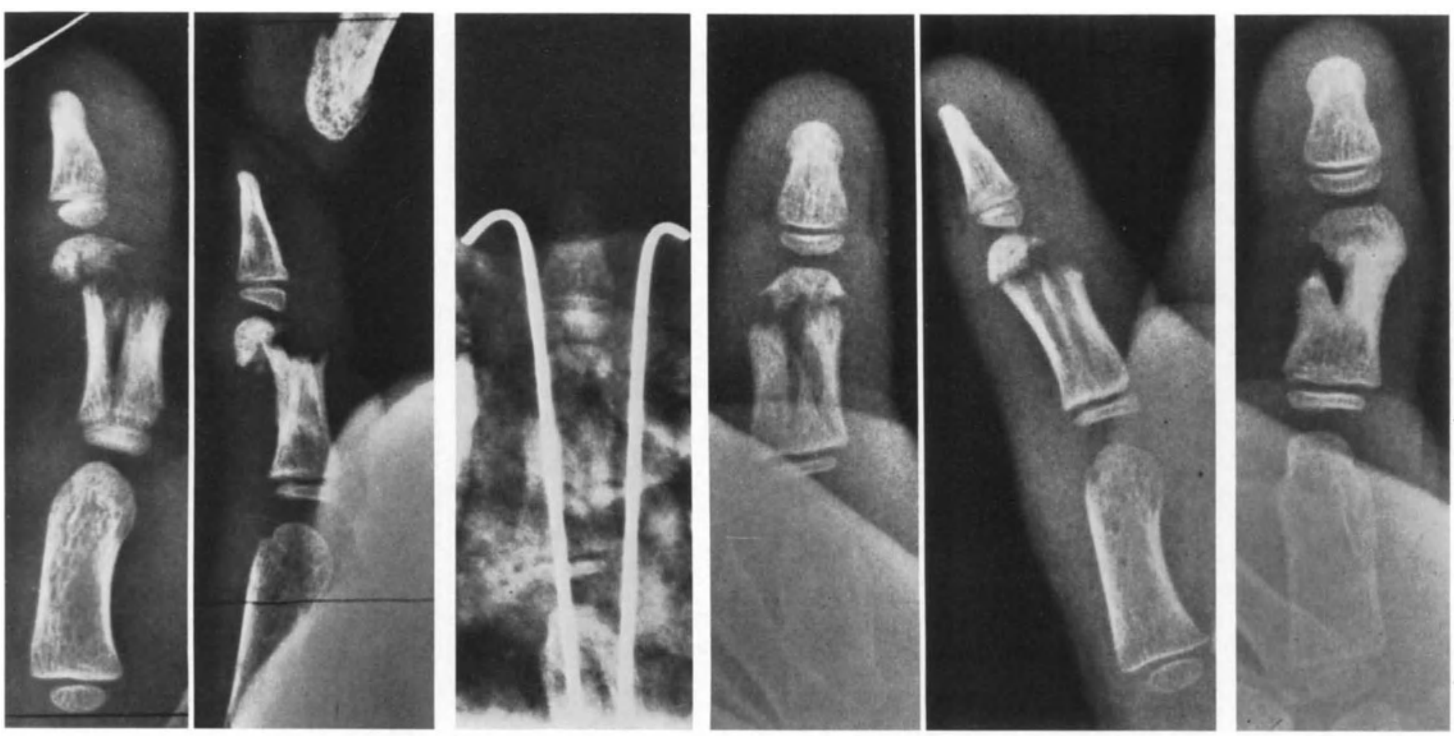
i.e., not in the vicinity of the neurovascular bundle and not on the volar side. They are implanted transcutaneously and the ends are bent over. The arm and forearm are then placed in a plaster splint, which is mainly for the protection of the *Kirschner* wires. The *Kirschner* wires and the cast can be removed after 2 weeks.

Prognosis: Perfect closed reduction and immobilization are prerequisites of a good prognosis. If they are not fulfilled, complications, such as malunion, articular deformity, avascular necrosis, and pseudarthrosis are likely to occur (Fig. 7).

2.3.4 Fractures with Bone Defects

Fractures types: Wide open fractures frequently contain bone gaps. Their treatment is complicated by the fact that one is very reluctant to perform immediate arthrodesis in a child, since an excessive difference in the lengths of the fractured and intact limbs needs to be avoided.

Treatment: In the management of a fracture with a bone gap in the vicinity of a joint, priority is given to the treatment of the soft tissue injury so that the effects of subsequent bone growth may be established.



a b c d

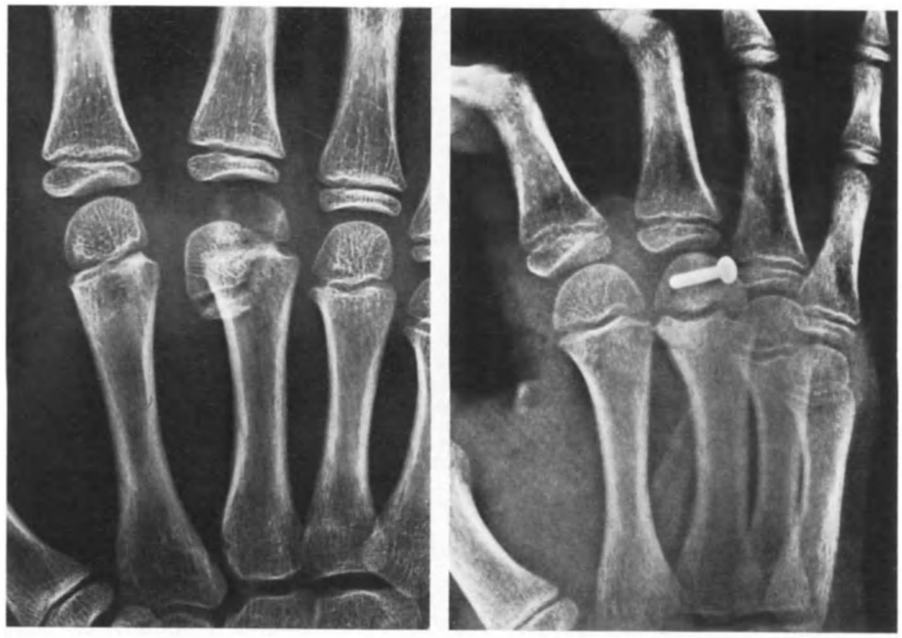


Fig. 8a, b. *Operative treatment of a rare epiphyseal fracture of the third metacarpal.* S.F., ♂, aged 12 years, No. 202913.
a) *Aitken* Type III epiphyseal fracture of the third metacarpal.
b) 4 months after surgery. Anatomically precise reduction was followed by stabilization with a lag screw through the epiphysis. There is neither avascular necrosis of the head of the bone nor premature ossification of the epiphyseal plate in the vicinity of the fracture

Arthrodesis should be delayed for as long as possible but, even in a child, may be made inevitable by increasing deformity.

For the treatment of diaphyseal fractures with missing bone, we recommend immediate bone grafting, even if the fracture is wide open. The corticocancellous graft is taken from the iliac crest. A longitudinal *Kirschner* wire usually suffices for stabilization of the fractures. This procedure is mainly recommended for cases in which the epiphyseal plate has remained undamaged.

Prognosis: The prognosis is determined by the concomitant soft tissue injuries and by the involvement of joints and epiphyseal plates.

3 Summary

The immobilization of a finger fracture in a child should cease as soon as painless exercises are possible, i.e., 2 weeks from the time of fracture in the majority of cases. Splinting should never be prolonged until bone union is complete. This principle also applies to fractures in the adult, but is even more important in children. Since the joints are not under load, redislocation of the fracture is unlikely to occur, even if the callus does not yet show radiological signs of calcification.

The rules which govern the operative treatment of finger fractures are the same as those which apply to childrens' fractures in general.

Precise reduction of a true epiphyseal fracture is insufficient on its own; it must be followed by stable internal fixation. Intracapsular articular fractures and open comminuted fractures can sometimes be successfully stabilized by a *Kirschner* wire placed alongside the bone in the soft tissues. A well-planned *Kirschner* wire fixation is still frequently justified, since screw or plate fixation is only occasionally possible (Fig. 8). Disturbances of growth are as serious in the hand as elsewhere. The child may be able to adapt to slight losses of function during the growth phase, but problems arise later when choosing a trade or profession which requires manual skill.

←

Fig. 7a–d. *Condylar fracture of the proximal phalanx of the thumb with fracture of the diaphysis.* H.C., ♂, aged 6 years, No. 197461.
a) The fresh fracture. The distal condyle is dislocated and unstable and the shaft of the bone is split wide open.
b) Treatment: Closed reduction and splinting with two *Kirschner* wires placed next to the bone.
c) 3 weeks after the accident. Removal of the *Kirschner* wires.
d) 1 year after the accident. The condylar fragment is viable and growth is normal. A gap remained in the diaphysis following healing of the fracture

4 References

Compere, E. L., Banks, S. W., Compere C. L.: Frakturbehandlung, S. 92. Stuttgart: Thieme 1966.

Leonhard, M. H., Dubravcik, P.: Management of fractured fingers in the child. Clin. Orthop. **73**, 160 (1970).

Salter, R. B., Harris, W. R.: Epiphyseal-Plate Injuries. J. Bone Jt Surg. **45 A**, 587 (1963).

Segmüller, G., Schönenberger, F.: Zur Problematik der Frakturbehandlung am wachsenden Handskelett. Handchirurgie **3**, 109–115 (1971).

Wakefield, A. R.: Hand injuries in the child. J. Bone Jt Surg. **46 A,** 1226 (1964).

Fractures and Dislocations of the Vertebral Column

F. Magerl, Ch. Brunner, K. Zöch, P. Berruex

CONTENTS

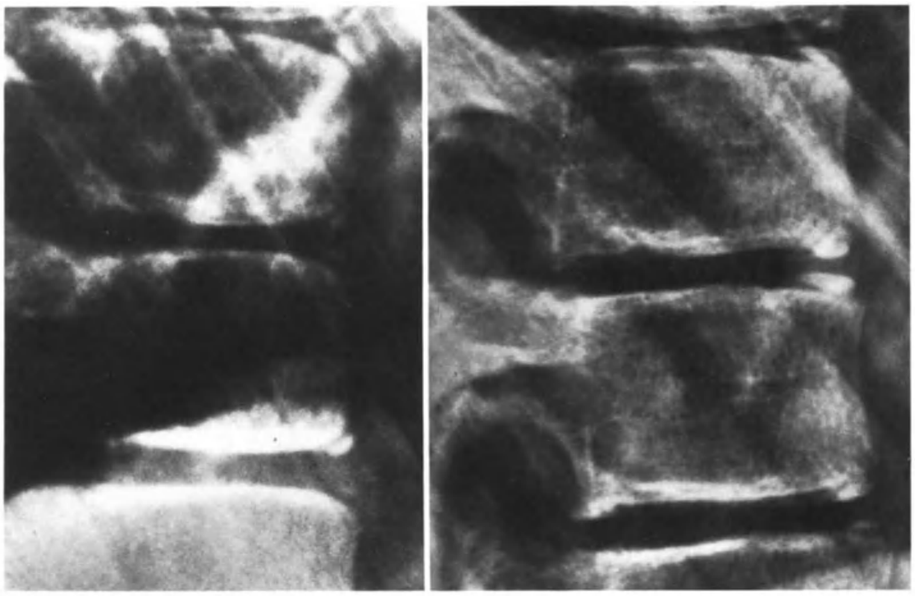
1 Introduction

As in the adult, spinal fractures in the child may occur in any segment of the vertebral column. However, they are much less common; of 583 patients with fractures of the vertebral column, only 28 were children. The rarity of spinal fractures in children is not due to a reduced accident risk, but is mainly a result of the increased elasticity of the vertebral column and also of the smaller mass of a child's body. In the child, abrupt deceleration entails less energy transfer than in the heavier adult. Thus, it is not surprising that only 3 of the 28 children with spinal fractures treated in our clinic between 1961 and 1975 were under 5 years of age. Eight were between 5 and 10 years of age, and 17 were older than 10 years.

Another special feature of the growing vertebral column is the presence of epiphyseal plates and apophyses, which may be the sites of traumatic epiphyseal separation. Thus, in common with fractures in other parts of the growing skeleton, those in the spine may be simple or may involve an epiphyseal plate and thus cause abnormal growth.

2 Development of the Vertebral Column

Ossification of the vertebral bodies begins in the lower thoracic spine and subsequently extends upwards and downwards along the column. That of the vertebral arches begins in the lower cervical vertebrae and gradually extends caudally. The centers of ossification of the vertebral bodies enlarge by appositional growth in all directions until birth and reach the dorsal and ventral surfaces, upon which perichondral bone is deposited (*Töndury*). The cranial and caudal cartilage plates are remnants of the original cartilage of the vertebral body. The upper and lower plates continue to function as *centers of growth* of the vertebral bodies until the child ceases to grow. During the 5th year of life, centers of ossification appear in the thickened margins of the upper and lower cartilaginous plates and gradually fuse so as to form an annular epiphysis by the 12th year of life. This annular epiphysis remains separated from the vertebral body by a thin seam of cartilage until the two finally fuse. The cartilage

a


b


c


Fig. 1a–c. *Edge of the vertebral body.*
a) Edge of a normal vertebral body with the annular epiphysis in the thickened margin of the end plate. a_1: 12-year old girl. a_2: 14-year old girl.
b) Edge defect. Failure of normal fusion of the annular epiphysis with the body of the vertebra (*Scheuermann*'s disease).
c) Fracture of the anterior margin. The annular epiphysis had already fused with the body of the vertebra at the time of the fracture. The interruption of the continuity of the edge is caused by the trauma

is analogous to the *epiphyseal plate* of a long bone. Fusion of the annular epiphysis with the vertebral body commences during the 14th or 15th year and is complete by the 24th year (*Töndury*). Until this fusion is complete, *traumatic separation of the epiphyseal ring* can occur, an injury which should be carefully distinguished from *fracture of the epiphyseal ring* itself (Fig. 1).

The anatomy and development of the two uppermost cervical vertebrae have special features. The *odontoid process* is, in a developmental sense, the body of the atlas. It is already present at birth in the form of a center of ossification which is separated from the body of the second cervical vertebra by an *epiphyseal plate* (Fig. 2). According to the work of *Cattell*

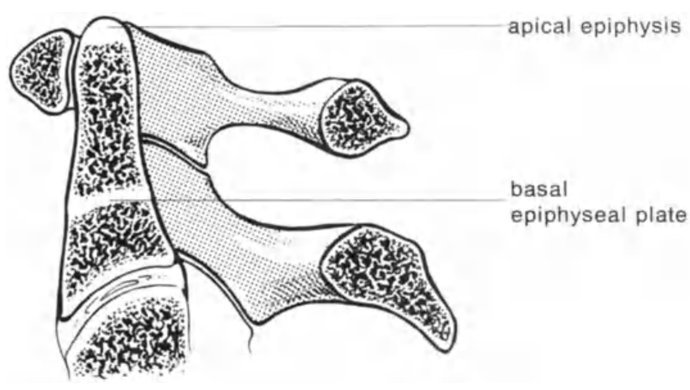


Fig. 2. *The odontoid process prior to ossification of the epiphyseal plate.* The apical epiphysis (proatlas) and the basal epiphyseal plate are clearly recognizable

and *Fitzer*, the epiphyseal plate remains open in 50% of cases up to the 4th or 5th year of life; in some of the remaining 50% of cases, it persists up to the 11th year and, if the adjacent bone is sclerotic, may give the appearance of an old fracture. Very rarely, it continues to be present as a permanent radiolucent line with regular contours which may be misinterpreted as a nondislocated fracture of the odontoid process. During the second year of life, a further center of ossification appears above that of the odontoid process. This apical epiphysis, which represents the proatlas, fuses with the rest of the odontoid process at the 12th year. In practice, the lower epiphyseal plate is the only important potential site of traumatic epiphyseal separation. The *sacral segments* do not fuse to form a single bone until the fourth decade of life. Until then, the five sacral vertebrae are separated by four atypical intervertebral discs whose inner zones are composed of hyaline cartilage. The first sacral intervertebral disc is that which most nearly resembles the lumbosacral disc. The physiological fusion of the sacral vertebrae begins around the 15th or 16th year of life; the two middle sacral intervertebral discs are the first to ossify, followed by the fourth and, finally, the first disc (*Töndury*). Thus, fracture of the sacrum in a growing child may occur by avulsion of an intervertebral disc.

3 Pathological Anatomy of Vertebral Fractures in Children

The spinal cord and the surrounding vertebral column are protected against impacts and tensile stresses by numerous structures which may be rigid or flexible and active or passive (*Braus*). In contrast to the long bones, which serve as static and dynamic components of the locomotor system, the vertebral column has the additional function of *enclosing the spinal cord and the cauda equina*. Thus, the latter structures lie in a neutral zone which is least affected by compression of the vertebral bodies or disruption of the vertebral arches. This is the reason why very few vertebral fractures involve damage to the spinal cord or cauda equina. Cord transection occurred in only 60 (10.3%) of a group of 583 patients of all ages whose vertebral fractures were treated in our clinic.

Because of its protected position and its greater elasticity, which is due to the increased thickness of the intervertebral discs and the greater proportion of cartilage, the vertebral column of a child has to be subjected to considerable violence before a fracture or dislocation occurs. Vertebral fractures are rarely caused by a direct impact on the spine. The majority result from indirect trauma; a particularly common example is the longitudinal compression generated by a fall onto the head or buttocks from a great height. Road traffic accidents, diving headfirst into shallow water, and falls from great heights are the most frequent causes of vertebral fractures in children (*Ehalt, Blount, Chigot* and *Estève, Rettig*). The mechanisms of injury were similar in our series of cases; only two of the children suffered vertebral fractures as a result of falls at ground level.

3.1 Types of Fracture

As with fractures in adults (*Nicoll, Lob, Weber*), those in children are best divided into stable and unstable types.

3.1.1 Stable Fractures

Stable fractures exhibit the following characteristics:

The cancellous bone is crushed and compacted by the compression force. This manifests itself as a band of increased cancellous bone density in the vicinity of the end plate. Sometimes this zone of increased density is contiguous with the end plate and cannot be distinguished from the latter in a roentgenogram. The end plate simply appears to be thickened and is somewhat broader than normal. Bending or buckling of the anterior cortex is visible. Since the cancellous bone is impacted it resists axial loading and tends to prevent an increase of the wedge deformity (Figs. 3 and 7).

The ligaments are intact and prevent further dislocation of the fragments.

As a rule, the articular processes of the vertebrae must be undamaged for a fracture to be stable. A simple compression fracture of the vertebral body is not accompanied by fracture of the articular processes and, in the majority of cases, the posterior cortex of the vertebral body is intact. The posterior wall is only fractured if the centrum is severely compressed; once this occurs, the fracture can no longer be said to be completely stable, since the compression strength of the vertebra is no longer sufficient to allow early mobilization; the only remaining structures which resist compression are the articular processes, and the intact ligaments function as a posterior tension band.

Summary: The stable fracture is characterized by compression of the cancellous bone of the vertebral body which mainly occurs on the ventral side. The ligaments, articular structures, and intervertebral discs are intact. The posterior wall of the vertebral body is usually intact. The vertebral body is characteristically wedge-shaped (Figs. 3 and 7). If a vertebral fracture is stable, there is no danger of dislocation and the vertebral deformity is unlikely to worsen.

3.1.2 Wedge Deformity of the Vertebral Body

The most important radiological sign of a fracture, apart from the band of increased bone density, is wedge-shaped deformity of the vertebral body. Wedge-shaped deformity of traumatic origin is accompanied by fracture of the anterior cortex which manifests itself as ventral buckling or step formation. If, following spinal injury, wedging of a vertebral body is seen which is unaccompanied by other radiological signs of vertebral facture, the differential diagnosis should include the following conditions:

a) Congenital wedge-shaped deformity of the vertebral body;
b) *Legg-Calvé*'s disease;
c) *Scheuermann*'s disease; wedge-shaped deformation of the vertebral body, decrease in thickness of the intervertebral discs, increase in the a-p diameter of the vertebral body, separation of the epiphyseal ring, sclerosis around the protruding disc, *Schmorl*'s nodes, etc. (Fig. 1 b);
d) Tumors, such as hemangioma, aneurysmal bone cyst, giant cell tumor, sarcoma;
e) Storage diseases;
f) Histiocytosis X;
g) Dysostosis multiplex (*Hurler*'s syndrome).

3.1.3 Unstable Fractures

Unstable vertebral fractures are characterized by the following features:

1. The body of the vertebra loses its rigidity as a result of the bursting fracture.
2. The capsular and ligamentary fibers are torn, leaving nothing to prevent tilting (kyphosis) or displacement of the fragments.

The type and degree of instability are determined by the site of the structural damage.

a) A bursting fracture which is not accompanied by damage to the ligaments, capsules, articular processes, or vertebral arches may be unstable.
   If the anterior support is missing, progressive kyphosis may result (Fig. 11).
b) A bursting fracture which is accompanied by ligamentary and capsular rupture is less stable.

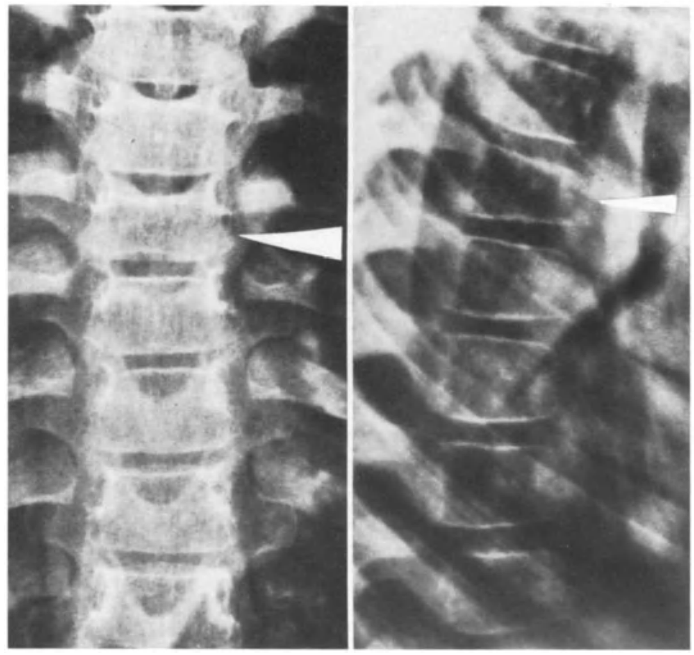


Fig. 3. *Traumatic wedge deformity of the vertebral body*. P.K., ♀, aged 7 years, No. 89675. Fracture following a fall from a swing. Wedge-shaped deformity of the fifth thoracic vertebra. The decrease in height is also visible in the a-p film

   A certain degree of stability is maintained by the articular processes.
c) A bursting fracture with ligamentary and capsular rupture and fracture of the articular processes or, an analogous injury, bursting fracture combined with fracture of the laminae and pedicles (Fig. 8), are completely unstable.
d) *Dislocation:* here, the ligamentary and capsular fibers are ruptured and the intervertebral disc is destroyed, thus rendering the articular complex completely unstable (Fig. 6 b).
e) *Subluxation of the upper cervical vertebral column:* the joints of this part of the spine are particularly flat in children, and subluxation of the upper cervical vertebral column should therefore be regarded as an unstable injury (Fig. 6 a).

3.2 Fracture Sites

3.2.1 Fractures of the Cervical Spine

Of all fractures of the vertebral column in children, those of the cervical spine occur least frequently. The atlanto-axial joint is particularly vulnerable, the most frequent injury in children being fracture dislocation. The trauma mechanism always involves considerable violence, such as that resulting from a dive into shallow water or a high-energy traffic accident.

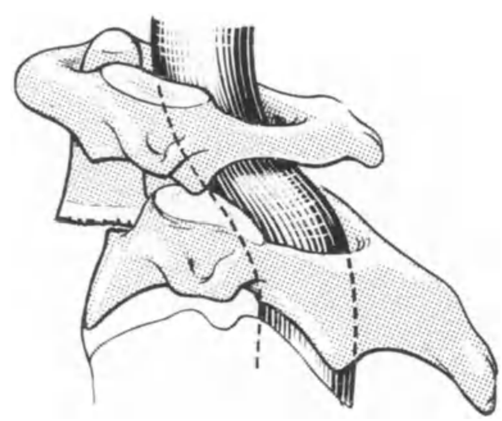


Fig. 4. *Dislocation of the atlantoaxial joint with fracture of the odontoid process.* The odontoid process is carried forward with the atlas, so that the cervical spinal cord is displaced rather than compressed

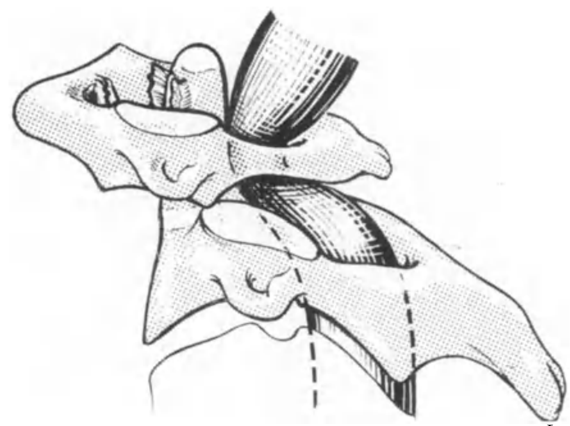


Fig. 5. *Dislocation of the atlantoaxial joint without fracture of the odontoid process.* The atlas is dislocated forwards and its posterior arch compresses the cervical spinal cord against the dens. This type of injury is very frequently lethal

A. Injuries to the Atlanto-axial Joints

a) Dislocation of the atlanto-axial joint: This is a simple dislocation without fracture (transligamentary dislocation). The atlas slides forwards on the axis and the transverse ligament of the atlas is torn through; thus, the spinal cord can be compressed between the intact odontoid process and the posterior arch of the atlas (Fig. 5). This injury is very frequently lethal.

b) Fracture of the odontoid process (transdental fracture dislocation): The dens fractures at the basal epiphyseal plate, which is its narrowest point, and may be dislocated forwards (Fig. 4) or, exceptionally, backwards. Since the atlas is also displaced forwards, the spinal cord is not compressed, but is somewhat displaced (Fig. 12). In children up to 11 years of age, traumatic separation of the basal epiphyseal plate of the dens may occur.

B. Fractures and Dislocations of Other Parts of the Cervical Vertebral Column

Compression fractures with subluxation of the suprajacent joint mainly occur in C2 and C3, and are the result of flexion trauma.

A special category of injury to the cervical spine is that of dislocation or subluxation. According to *Emminger*, these injuries do not involve rupture of the intervertebral disc; instead, the cartilaginous plate separates from the vertebral body, i.e., epiphyseal separation occurs.

Dislocation may be unilateral or bilateral, and complete (luxation) or incomplete (subluxation) (Fig. 6). The main clinical features of luxation or subluxation are torticollis and neck pain. The level of the spine which is most frequently affected is C2/C3. The differential diagnosis of torticollis includes:

Klippel-Feil syndrome;
Torticollis of muscular origin;
Torticollis of ocular origin;
Grisel-Burgeois pseudodislocation, which mainly affects the upper segments of the cervical vertebral column. This is a pseudodislocation of the upper cervical spine secondary to nasopharyngeal inflammation.

Dislocation of the cervical column may be complicated by radicular or medullary symptoms. Radicular symptoms usually regress following reduction of the dislocation, but the prognosis following medullary injury tends to be poor.

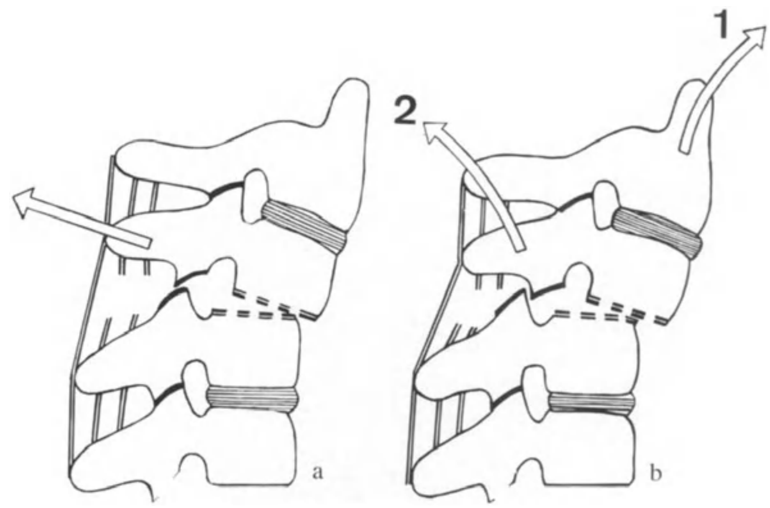


Fig. 6a, b. *Subluxation and dislocation of the cervical spine.* a) Subluxation. The posterior joints are not completely dislocated. The *arrow* shows the reduction maneuver, i.e., the head is tilted backwards.
b) Dislocation. The posterior joints are completely dislocated and locked. The *arrows* show the sequence and direction of the movements required for reduction. *1*: freeing of the posterior joints by longitudinal traction and careful flexion of the neck. *2*: reduction by tilting the head backwards

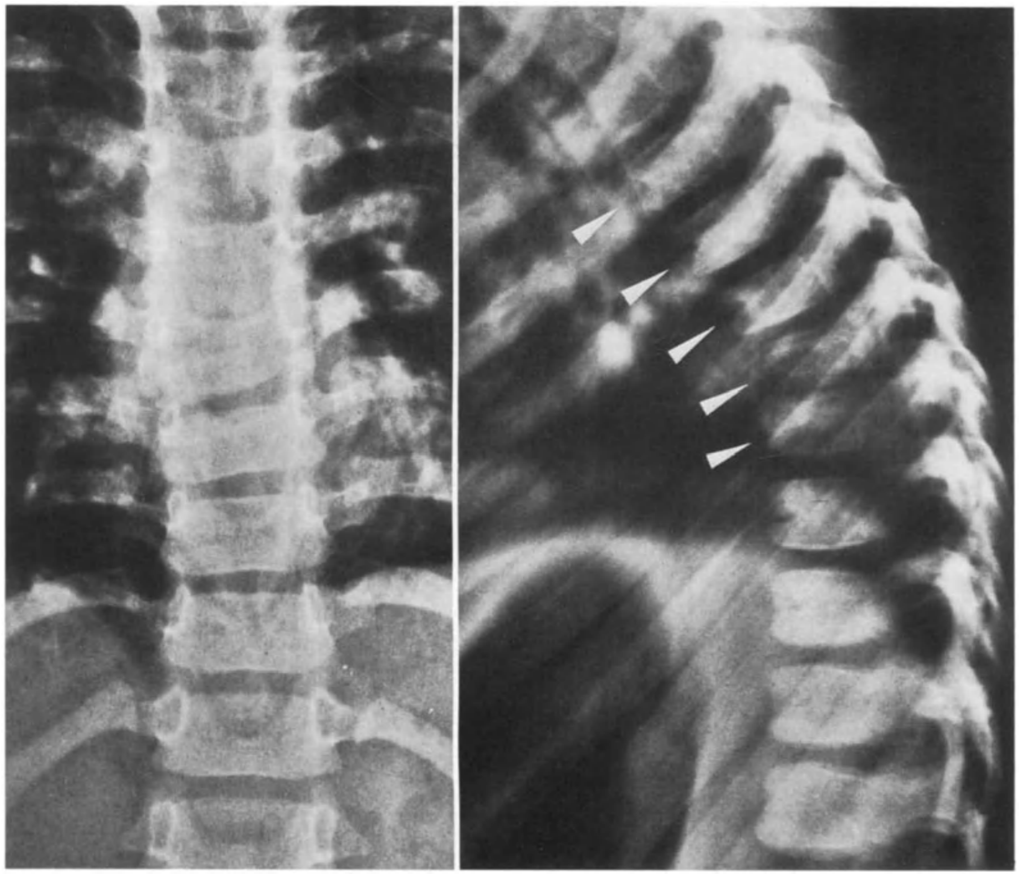


Fig. 7. *Multiple wedge fractures of the thoracic spine*. Sch. R., ♂, aged 3 years, No. 129412. Simultaneous wedge deformity of several vertebrae in the frontal and sagittal planes. Wedge fractures of T5/6/7/8/9

3.2.2 Fractures of the Thoracic Spine

This is the region in which vertebral fractures in children most frequently occur. They are almost always compression fractures with wedge-shaped deformation of one or more vertebral bodies (Figs. 3 and 7). Separation of the upper or lower plate or fracture of the annular epiphysis in the course of dislocation rarely occur (Fig. 13).

Unstable fractures with involvement of the spinal cord occur less frequently in the thoracic spine than in other segments of the vertebral column, since the thoracic vertebrae are stabilized by the ribs. Those which do occur are usually fracture dislocations of lower thoracic vertebrae (Fig. 13).

3.2.3 Fractures of the Lumbar Spine

Here too, the fractures are most frequently of the compression type. However, bursting fractures and even dislocations are not uncommon (Fig. 8, Table 2). Fractures of the transverse processes occur almost exclusively in the lumbar spine; they are caused by abrupt contraction of the psoas major and quadratus lumborum muscles, which are inserted into the transverse processes, or by considerable direct violence, e.g., as an accompaniment of a *Malgaigne* fracture of the pelvis (Fig. 9).

3.2.4 Fractures of the Sacrum

These occur very rarely. Longitudinal fracture through the lateral part of the sacrum may occur as one component of a *Malgaigne* fracture of the pelvis. More serious sequelae result from fracture dislocation of the sacrum in children and adolescents before synostosis has occurred (Fig. 10). Compression of the sacral roots may occur as a result of bending and narrowing of the sacral canal and lead to neurological signs of irritation or nerve damage in the corresponding sacral segments. In such cases, disturbances of urinary and fecal continence are accompanied by perianal and genital anesthesia (saddle anesthesia).

3.3 Special Aspects of the Pathological Anatomy of Spinal Injuries in Children

Traumatic separation of the upper or lower end plate or of the annular epiphysis from the vertebral body, may occur with or without fracture of the edge, and corresponds to traumatic separation of the epiphysis of a long bone with or without a metaphyseal fragment. These injuries are therefore classified as *Aitken* Type I. Furthermore, one must assume that traumatic separation of the articular plate leaves not only the

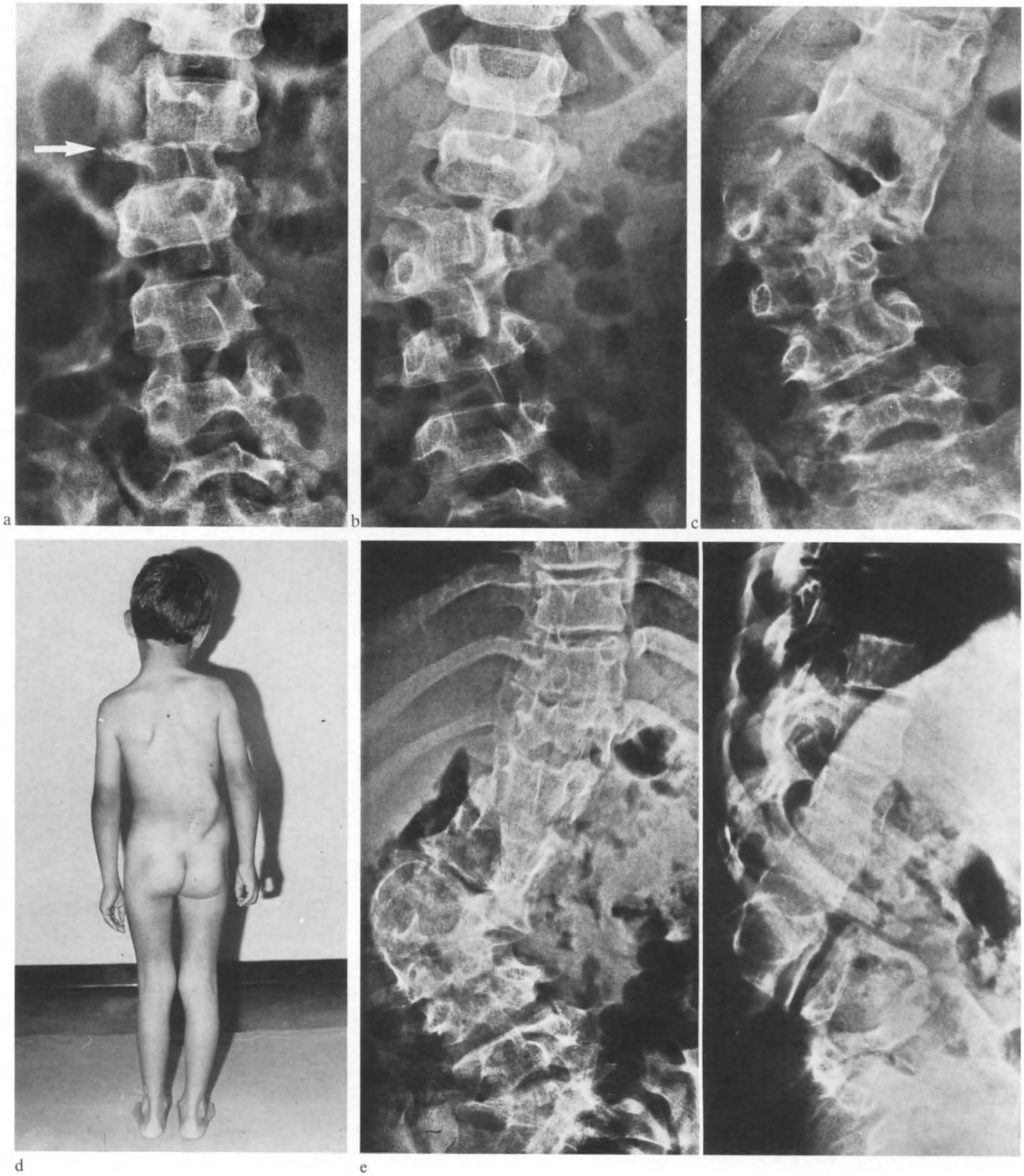
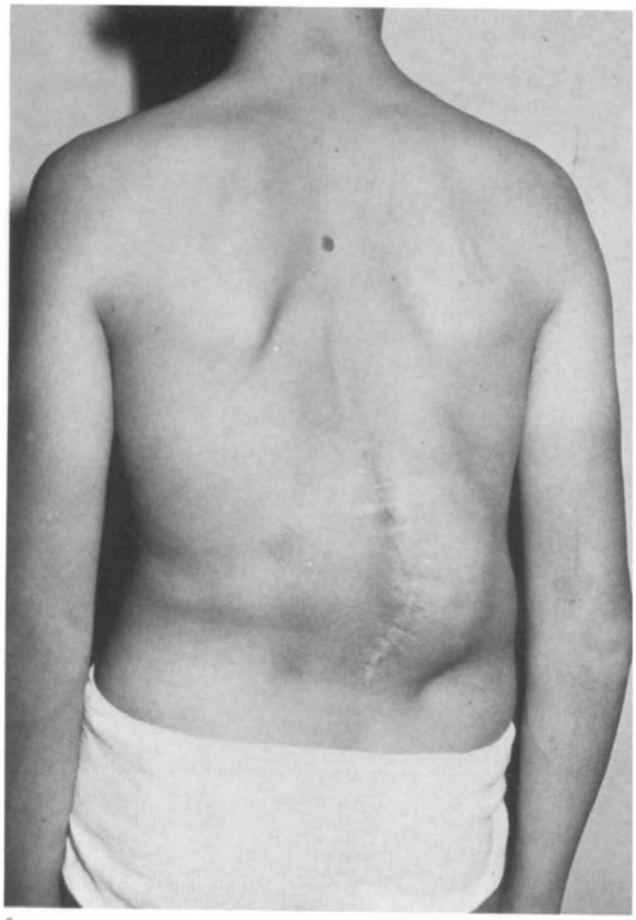
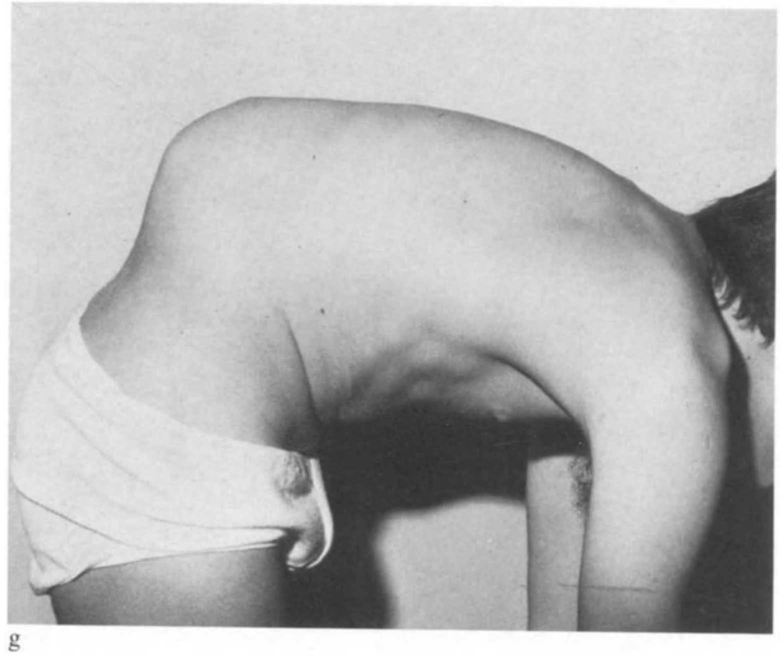


Fig. 8a–e



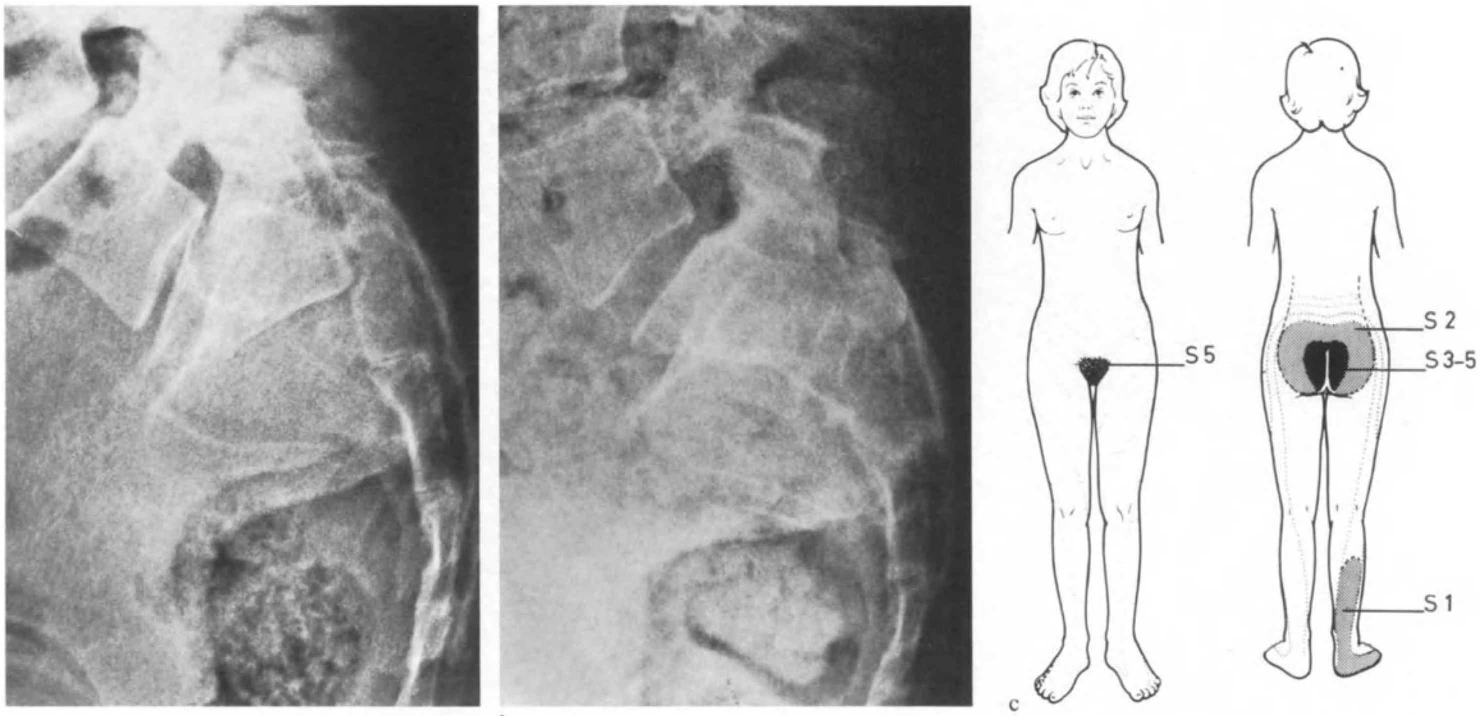
f



g

Fig. 8a–g. *Fracture dislocation of the lumbar spine.* St. H., aged $6^3/_4$ years, No. 117144.
a) Fracture dislocation of L 1–2 with fracture of the vertebral arch and transverse process of L3. Dislocation and angulation.
b) 1 month after the accident. Increase in the degree of dislocation and angulation. Open reduction was now attempted, but without success.
c) 18 months after the attempt at open reduction, there is severe lateral dislocation and angulation of 40°.
d) Photograph taken 18 months after the operation.
e) 10 years after the accident. Extremely severe lumbar kyphoscoliosis with grotesque intrinsic rotation deformity of the vertebral column (scoliosis angle of more than 90°).
f, g) 10 years after the accident. Clearly visible deformity of the vertebral column. The patient now has back symptoms and the prognosis is poor

Fig. 9. *Fracture of the transverse process of L5 with Malgaigne fracture of the pelvis.* B. St., ♀, 14 years, No. 145576. Example of an oblique *Malgaigne* fracture with fracture of the transverse process of L5



a b c

Fig. 10a–c. *Fracture dislocation of the sacrum.* B.R., ♀, aged 15 years, No. 77292.
a) Fracture dislocation of S 1–2. Total loss of sacral root innervation. Closed reduction on the day of the accident.
b) 15 months later. Anatomically satisfactory healing of the fracture dislocation.
c) Neurological deficit 2 years after the accident: hypesthesia in the S-2 dermatomes on both sides and in the distal part of the S 1 dermatome on the right side. Perianogenital anesthesia from S 3–S 5. Partial loss of innervation to the organs of urinary and fecal continence

germinative layer, but also the intervertebral disc intact. In contrast, bursting fractures of the vertebral body necessarily include the annular epiphysis and involge damage to the germinative layer and the intervertebral disc. There is little doubt that these fractures should, in principle, be categorized as *Aitken* Type II or III. This implies a danger of abnormal growth due to premature epiphyseal fusion. Furthermore, collapse of the intervertebral disc occurs, since its tissue can be extruded through the tears in the annulus fibrosus and/or through the fracture gap in the end plate of the vertebral body. In addition, fractures of these types may involve crushing of the epiphyseal plate in the manner described by *Salter* and *Harris.*

These injuries cause deformation of the vertebral bodies which, in turn, leads to deformity of the vertebral column. The latter is made worse by collapse of the intervertebral discs. Destruction of the ventral part causes progressive kyphosis in the corresponding segment, while unilateral destruction leads to scoliosis. Finally, synostosis of adjacent vertebrae may occur.

3.4 Prognosis of Vertebral Fractures in Children

3.4.1 Simple Compression Fractures

Compression fracture results in a greater or lesser degree of wedge deformity in the frontal or sagittal plane. By definition, the end plates and annular epiphyses remain intact. If the remaining growth potential is sufficient, spontaneous restraightening of the vertebral body may occur (*Blount, Gelehrter*). Isolated impression fractures of the end plate with localized damage to the growth cartilage have not been described in children (*Gelehrter*).

3.4.2 Bursting Fractures and Fracture Dislocations

All these types of fractures involve damage to the growth zones of the articular plates and to the intervertebral discs. They therefore cause abnormal growth with subsequent deformity. Wedge deformity of the vertebral body persists, since the growth of the latter is disturbed. The deformities can only be compensated for by changes in the adjacent structures, such as compensatory assymetrical growth in the neighboring vertebrae (Fig. 11) or lordosis of the spine to make up for kyphosis. However, changes in the structures of the neighboring vertebrae seldom cancel out the deformity completely, especially since these fractures usually occur in older children. Fractures of the end plate are typically followed by a reduction in the thickness of the intervertebral disc. Vertebral synostosis following destruction of the intervening intervertebral disc is not uncommon.

Severe deformity always results in postural compensation in the other parts of the spine which, sooner or later, causes symptoms due to overloading of individual segments. Scoliosis results or, following wedge deformation of thoracolumbar vertebrae, hyperlordosis of the lumbar spine and straightening of the thoracic kyphosis occurs. Deformity which occurs in the growing skeleton can seldom be corrected later, since permanent compensatory deformation of the neighboring vertebrae takes place.

For the above reasons, particular care should be taken to prevent deformity following fractures of the spine in children. As regards the chances of deformity arising, fractures of the dens which occur prior to fusion of the epiphysis are an exception. By definition, they are classified as fracture dislocations, but they differ significantly from the latter group since neither an intervertebral disc nor an epiphyseal growth zone is included in the injury. Fractures of the odontoid process are *Aitken* Type I lesions and, as with other injuries in this category, spontaneous correction of posttraumatic deformity can occur. An odontoid process which has malunited with the axis can be straightened up by subsequent growth and thus regain its previous shape.

3.5 Paraplegia in Children

Paraplegia of traumatic origin is rarely seen in children since, apart from any other reason, vertebral fractures in children are less common than in adults. Of 28 children with vertebral fractures treated by us, two developed paraplegia. Paraplegia has more serious consequences in children than in adults. In the course of time, gradually irreversible paralytic scoliosis develops which makes sitting impossible and leads to respiratory embarrassment as a result of the thoracic deformity. Furthermore, growth of the limbs is slowed by the paralysis. The thin bones of a paraplegic child are constantly in danger of being fractured by slight trauma. The neurogenic disturbances of micturition create considerable problems, but are not dealt with in this text. Urinary tract infection and decubitus ulcers present a lifelong threat to the paraplegic. For these reasons, everything should be undertaken to ensure optimum rehabilitation and, during the acute phase, as much as possible should be done to limit or reverse the paraplegia. Paraplegia in children is almost always caused by fracture dislocation. Precise reduction and stable fixation are, in our opinion, the only measures which make effective use of the existing chances of recovery.

Rehabilitation is carried out along the usual guidelines. Particular attention must be paid to the prevention of contractures and deformities.

4 Treatment

The aim of treatment of a vertebral fracture is the restoration of the normal anatomy and function of the vertebral column. The choice between operative or nonoperative treatment is based on the type of fracture and the presence or absence of concomitant injury to the spinal cord or cauda equina.

4.1 Simple Compression Fractures

Simple compression fractures are by definition stable and are therefore treated in the manner recommended by *Magnus*, i.e., bed rest until the pain has regressed sufficiently to allow movement. Early functional treatment (isometric back exercises) results in rapid disappearance of symptoms and the early return of normal function. Management in this simple fashion suffices because the compression strength of the interlocked cancellous bone fragments is adequate and is rapidly increased by the subsequent endosteal callus formation (*Lob*).

4.2 Bursting Fractures

As mentioned in § 3.1.2, this type of fracture is unstable. It is reduced by straightening the vertebra and is then immobilized by bed rest with the patient in a plaster shell until bone union is sufficiently advanced. As a rule, this requires 6–8 weeks. The patient can then be gradually mobilized, and a plaster corset which is shaped so as to correct any deformity is applied for a further 6 weeks.

4.3 Fracture Dislocations Without Nerve Injury

Fracture dislocations always require reduction, since severe deformity otherwise results.

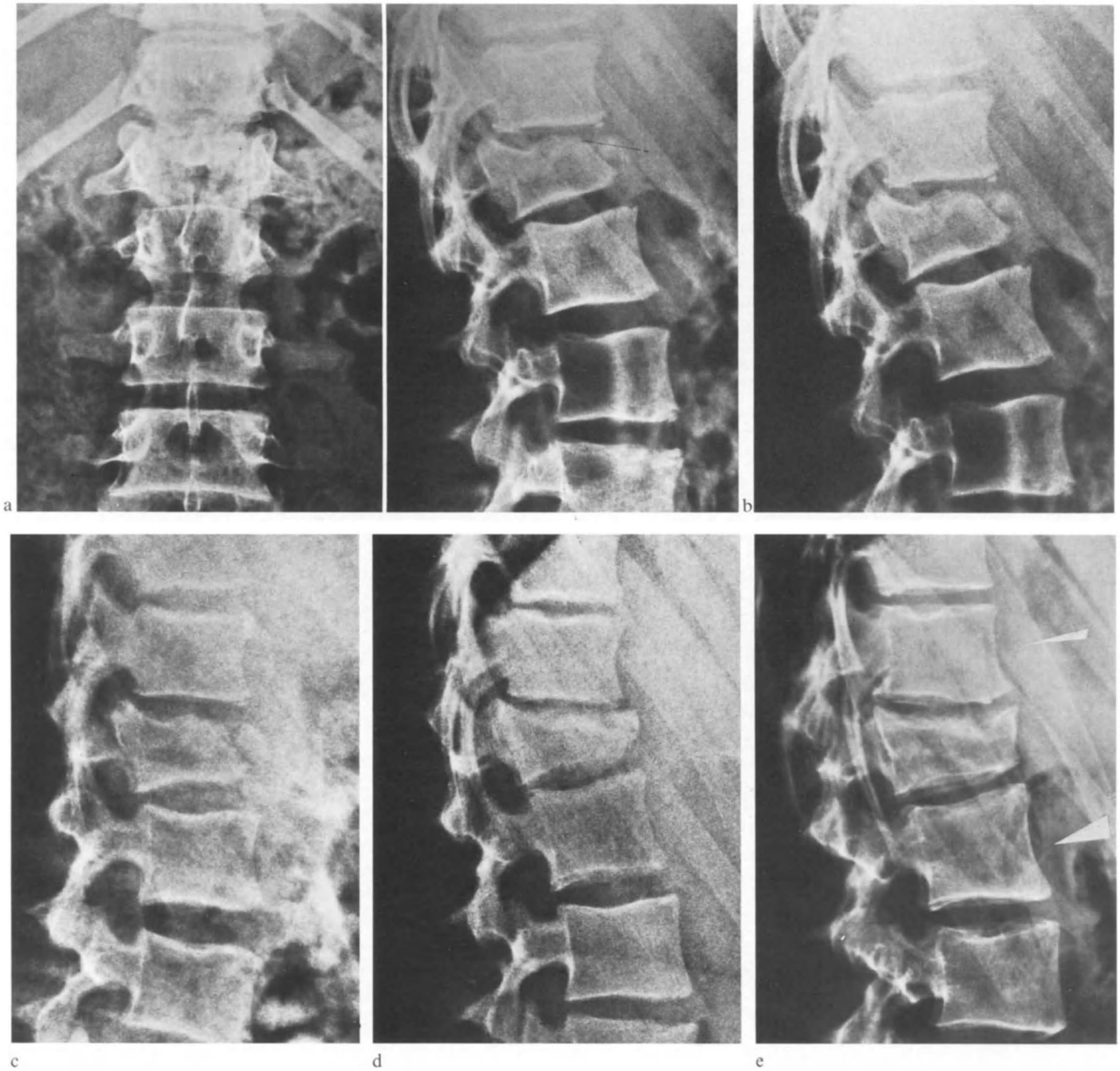


Fig. 11a–e.

a) *Fracture-dislocations of the cervical spine.* In children, these are mainly fractures of the dens. They are reduced by careful longitudinal traction with the spine in lordosis. There are two alternative methods, i.e.,

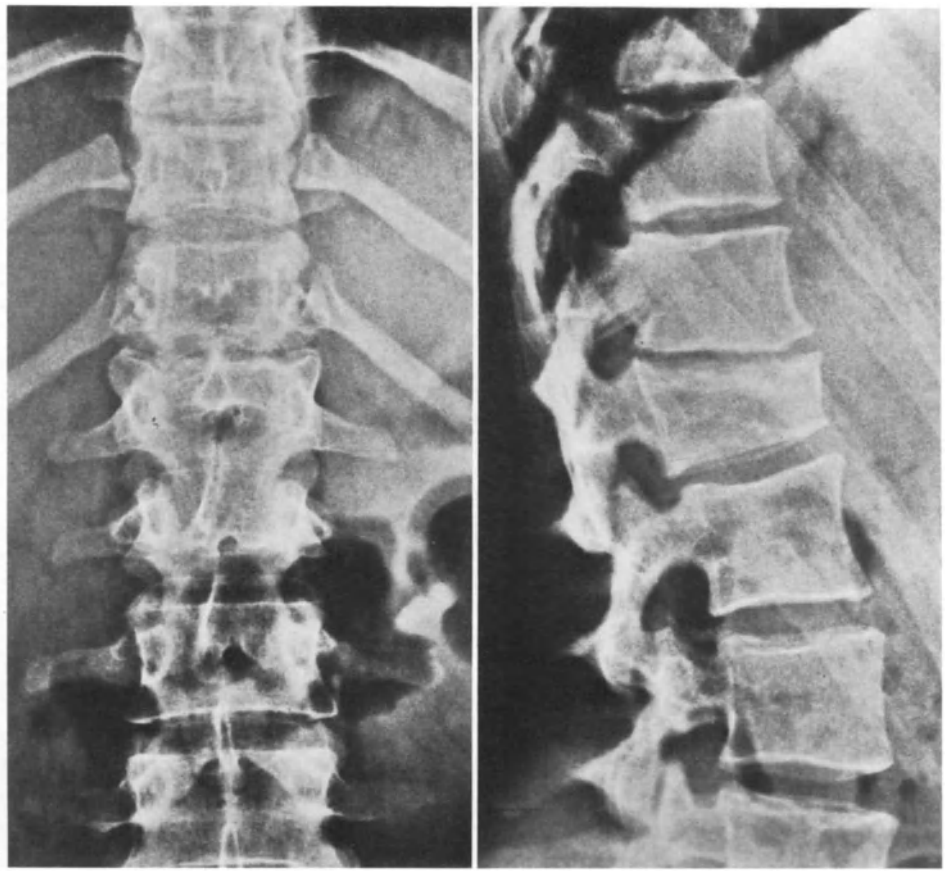
immediate reduction under anesthesia, followed by application of a Minerva cast which holds the cervical spine in extension (immobilization for 6–10 weeks);

induction of lordosis by application of *Glisson* traction for 4 weeks; the child then has to wear a Minerva cast for the remaining period of immobilization (Fig. 12).

b) *Dislocations of the cervical spine.* This type of injury is rare and is reduced by continuous traction by the *Glisson* method followed by application of a Minerva cast for 6–8 weeks.

c) *Subluxation of the cervical spine.* Subluxation of the cervical spine is reduced by continuous traction by the *Glisson* method or by manual reduction under anesthesia. If the degree of subluxation is limited, reduction is followed by immobilization with a *Schanz*

Fig. 11a–f. *Compensatory increase in growth of neighboring vertebrae.* G.U., ♀, 13 years, No. 107583.
a) More or less stable compression fracture of L 1; the anterior margin has broken off.
b) The fresh fracture.
c) 1 month after the accident.
d) 7 months after the accident. Permanent wedge deformity of L 1.
e) 78 months after the accident. The compensatory increase in growth of T 12 and L 2 is clearly visible.
f) 10 years after the accident. Adequate correction of the deformity by increased growth of the upper and two lower vertebral bodies

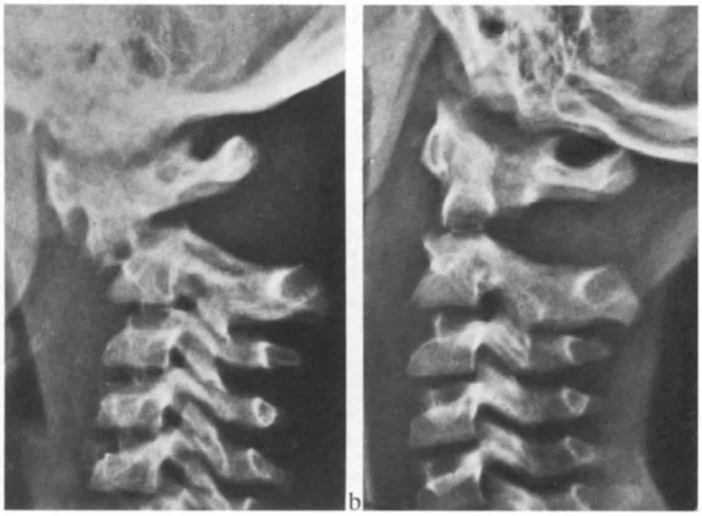
f


collar for 2–6 weeks. Severe degrees of subluxation caused by heavy trauma require immobilization for 6 weeks with a Minerva cast.
d) *Fracture dislocations of the thoracic or lumbar spine.* These require open reduction and temporary stabilization by dorsal tension-band osteosynthesis. The implant can be removed after 6–8 months. We recommend *operative* treatment for these rare fractures because this is the only means of assuring correct reduction and preventing subsequent deformity. The procedure should be carried out as soon as possible, since safe and complete reduction rapidly becomes impossible, even for a skilled surgeon. Any deformity which may be present is quickly fixed by callus and scar tissue, and organized hematoma, callus, and scar tissue in the medullary canal may compress the spinal cord in the course of delayed reduction. Angulation or dislocation of the spine may arise at a later stage and combine with abnormal growth to cause severe scoliosis or kyphosis which can rarely be influenced by orthopedic apparatus (Fig. 8).

4.4 Fracture Dislocations with Injury to the Spinal Cord or Cauda Equina

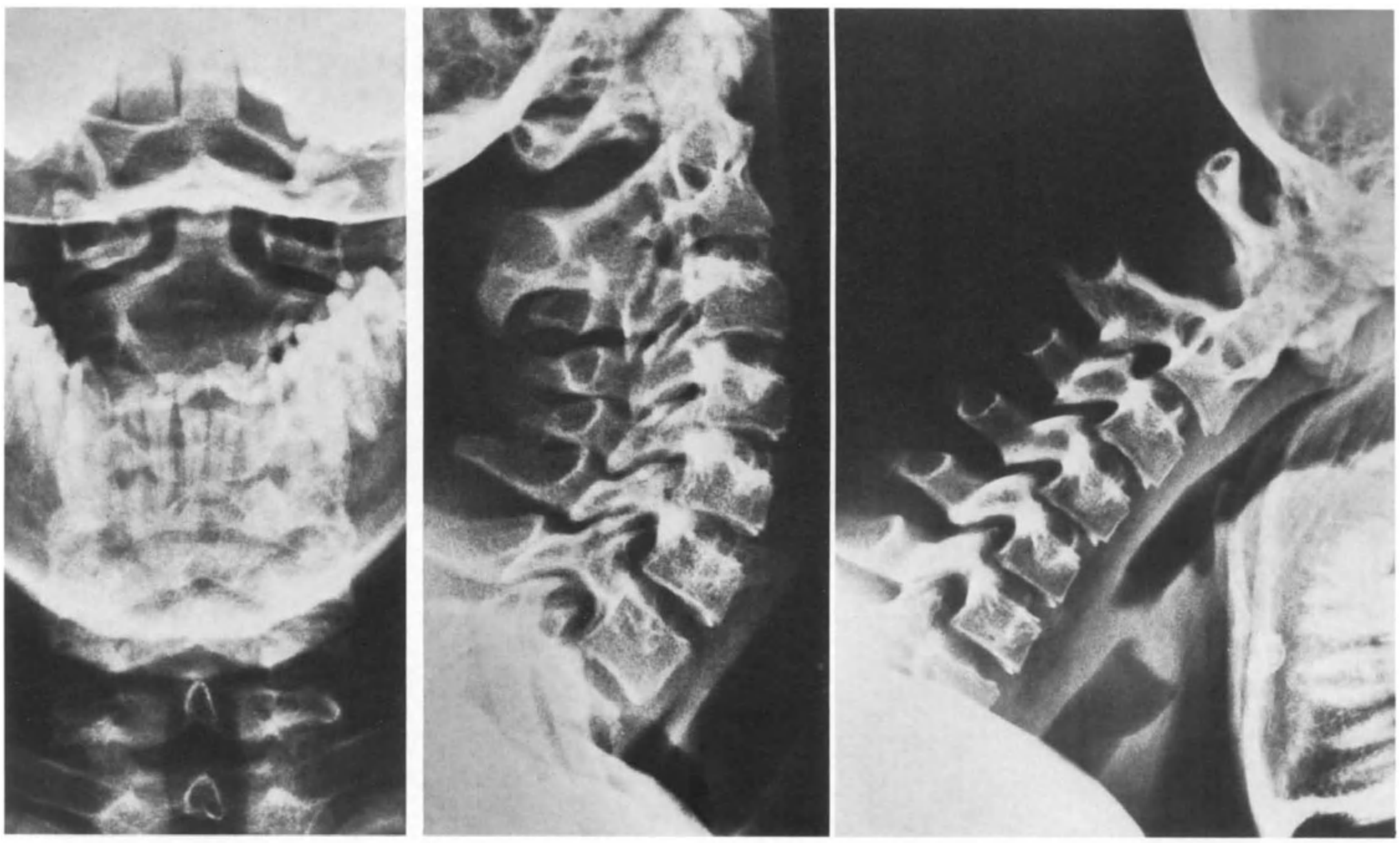
Time is a very important factor in the treatment of these serious injuries in the acute phase. If a fragment is compressing the spinal cord, or if localized ischemia is present, the necessary therapeutic measures must be undertaken as soon as possible. Within a few hours or at the latest, 1–2 days, the damage to the spinal cord becomes irreversible. Because of the necessity for rapid action, the treatment of paraplegia and tetraplegia in the acute phase requires a considerable investment of skilled personnel and high standards of organization. Patients who have suffered injury to the spinal cord should therefore be immediately transported by suitable means to a unit which is staffed and equipped for the emergency treatment of paraplegia.

In our clinic, the acute phase of the treatment of spinal injuries has two aspects: the treatment of the fracture, which is specific to the type of fracture being dealt with, and the treatment of the cord injury. The corresponding measures require careful coordination and can be summarized by the therapeutic triad: reduction – stabilization – decompression (*Weber*). Reduction and stabilization of the fracture is especially important in children, because scoliosis resulting from the fracture can summate with that due to paralysis. The phase of emergency treatment is immediately followed by that of rehabilitation, and the latter measures are carried out with the same dispatch as those immediately following the accident. The treatment of traumatic paraplegia in the acute phase can be summarized as follows:



a b

Fig. 12a–d. *Transodontoid fracture dislocation of C 1–2.* K.M., ♂, aged 5 years, No. 103178.
a) Typical fracture dislocation of C 1–2 with fracture of the odontoid process at the level of the basal epiphyseal plate. No neurological symptoms.
b) Immediate reduction under general anesthesia, followed by *Glisson* traction for 4 weeks and a Minerva cast for a further 2 weeks.
c, d) 11 years after the accident. Clinically and radiologically complete recovery. The anatomy appears normal in the transbuccal film and in the flexion and extension views



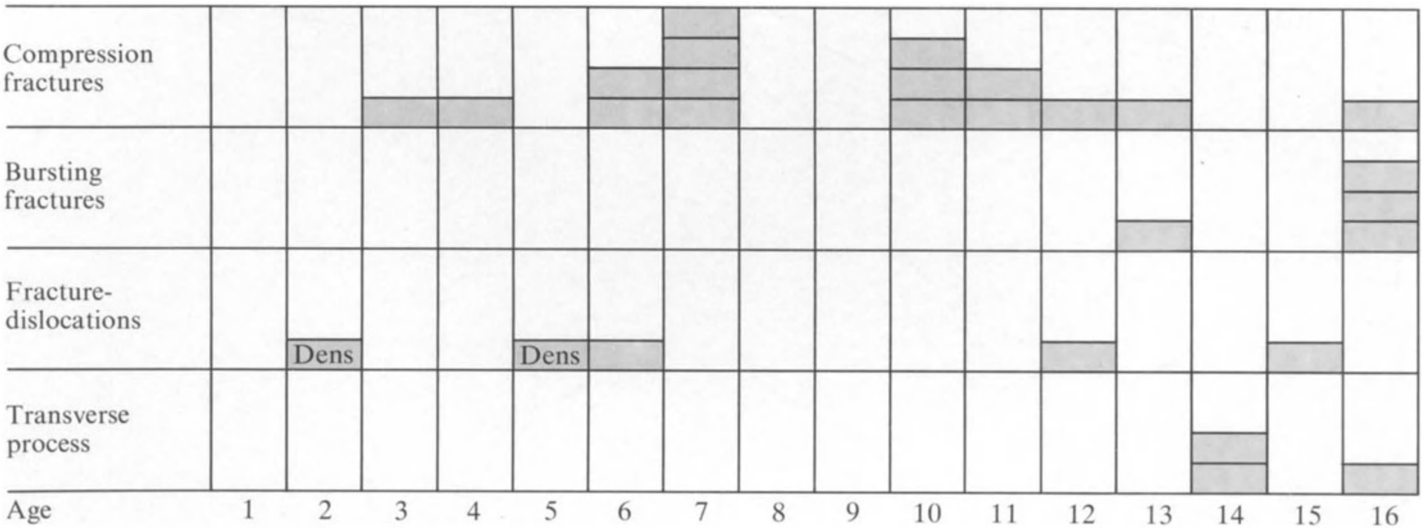
c d

1. There is general agreement that progressive paralysis is always an indication for surgery. In addition, we consider operative treatment to be necessary for unstable fractures, narrowing of the spinal canal by fracture fragments, and obstruction to the flow of liquor (even if no fracture is visible).

2. The fractures are usually reduced via a dorsal approach and stabilized by internal fixation. Firmly anchored tensionband wiring frequently suffices, especially in children. In many cases, reduction of the fracture is accompanied by decompression of the spinal cord. If the cerebrospinal fluid does not flow freely following reduction or if projection of one or more fragments into the spinal canal is seen on the roentgenograms, the canal is exposed by laminectomy and the obstruction is cleared.

3. Large posterior marginal fragments, such as those which sometimes result from bursting fractures in adolescents may compress the spinal cord from a ventral direction. Fractures of this type in the thoracic and lumbar spine require anterolateral decompression with simultaneous anterior spondylosyndesis, while those in the cervical vertebrae have to be treated by spondylectomy and spondylosyndesis. An osteosynthesis or

Table 1. Classification of the 28 cases of vertebral fracture by age and type of fracture (main injury). The incidence of compression fractures is independent of age. Bursting fractures and fractures of the transverse processes only occur in adolescents. Fracture-dislocations mainly occur in adolescents, with the exception of transdental fracture-dislocation



spondylosyndesis should be so stable that it not only prevents dislocation during the subsequent period of immobilization in bed, but also eliminates mechanical irritation of the tissues in the vicinity of the fracture. Mechanical stability is essential for rapid resorption of the fracture edema.

4.5 Fractures of the Transverse Processes

A fracture of the transverse process of L5 is usually accompanied by a *Malgaigne* fracture of the pelvis. It does not require specific treatment (Fig. 9).

Simple fractures of the transverse processes are treated by bed rest until pain has regressed. Active exercises are then encouraged. There are no significant late sequelae.

5 Our Own Series of Cases

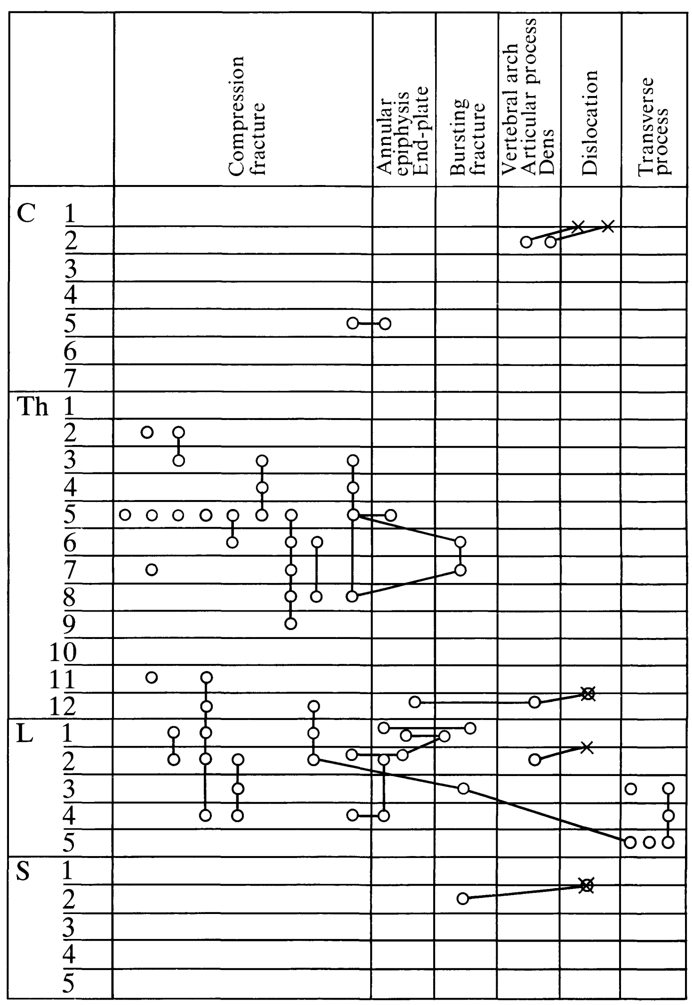
5.1 Vertebral Fractures

We treated a total of 28 children and adolescents with vertebral fractures between 1961 and 1975. Table 1 shows the age distribution and the fracture types.

Accident causes: Seven children were injured in road traffic accidents, ten by falls from great heights, one by diving into water, and ten in the course of sport or play.

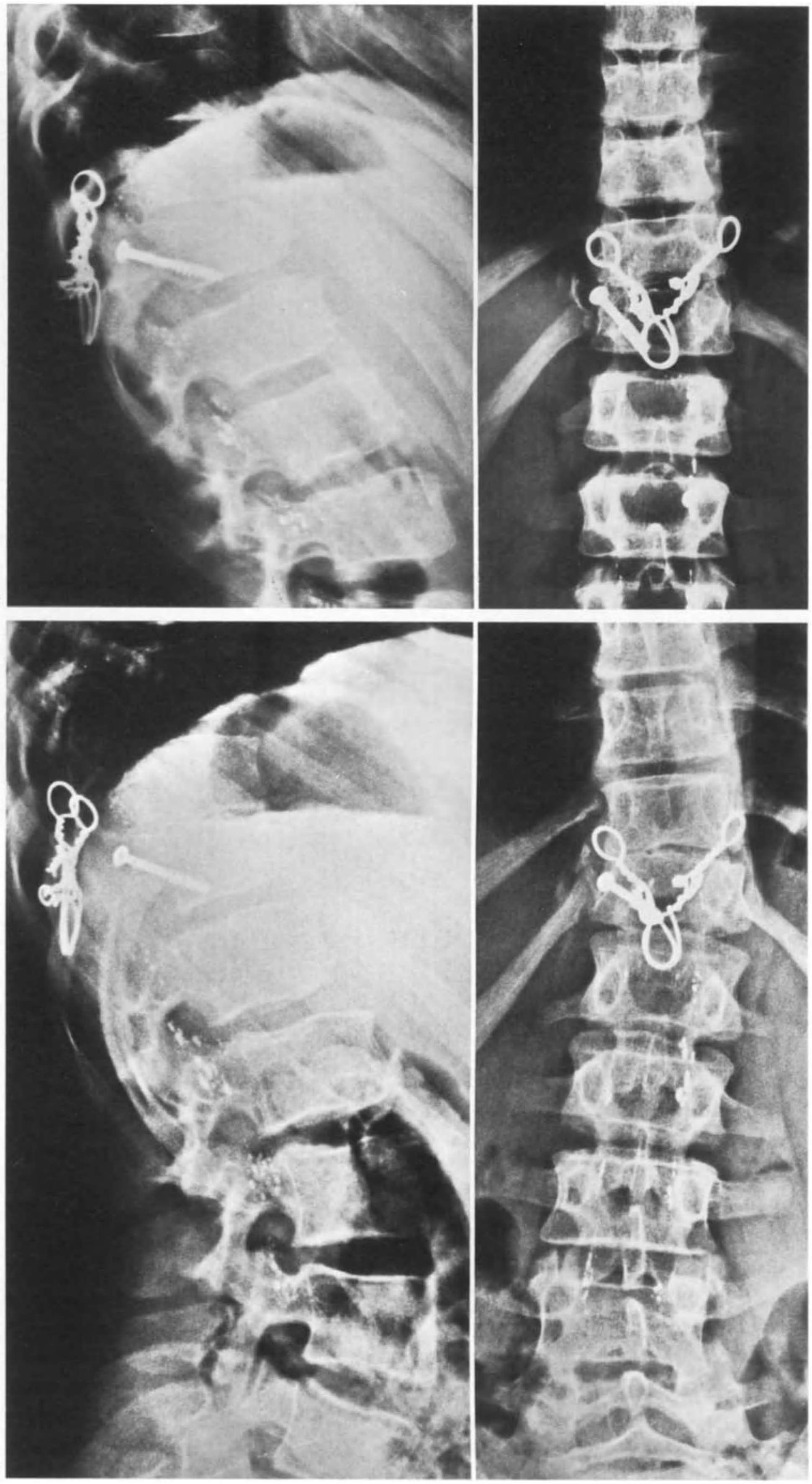
In *Table 2*, the 28 cases are classified by fracture type and vertebral level. The frequency with which

Table 2. Classification of the 28 cases by level and type of fracture and by the number of vertebrae involved. In 13 cases 2 or more vertebrae were affected, and in 5 cases there was dislocation with fracture of the subjacent vertebra



Symbols: ○ fracture × dislocation ⊗ dislocation with paraplegia

Fig. 13a, b



c

d

Fig. 13a–d. *Fracture dislocation with paraplegia*. B.A., ♂, aged $12^{1}/_{2}$ years, No. 183161.
a) Roentgenograms taken immediately after a tree had fallen on to the patient. Fracture dislocation of T 11–T 12 has occurred, with fracture of the articular process of T 12 on the right side, dislocation of the joint on the left, and fracture of the ventral part of the end plate of T 12. Subtotal paraplegia developed at the level of T 10 and subsequently became complete.
b) For the above reasons, open reduction and decompression was carried out, followed by internal fixation of the fractured articular process and temporary tension-band wiring of T 11 to T 12. The postoperative course was uneventful and complete remission of the neurological deficit occurred within 5 months.
c) 9 months after accident. The neurological findings are completely normal. The patient has no back complaints whatsoever and the internal fixation material causes no symptoms.
d) 2 years after the accident, prior to removal of the metal. The patient is symptom-free and indulges in competitive sport. The roentgenograms show slight scoliosis as a result of decrease in thickness of the intervertebral disks, wedge deformity of the vertebral body caused by injury to the end plate, and slight signs of compensatory growth in L 1

simultaneous fractures of several vertebrae occur is worthy of note. We assume that a vertical impact on the vertebral column of a child frequently leads to multiple compression fractures because plastic deformation more readily occurs than in the spine of an adult. Because the cancellous bone is very dense and its rigidity is increased by the compression fracture, the residual energy of the impact is dissipated in the neighboring vertebrae.

Results at Follow-up: All the compression and bursting fractures in children healed without leaving residual changes in the overall form or function of the vertebral column. In some cases, very marked degrees of compensatory growth were observed (Fig. 11). Only in the 15- and 16-year old children did this corrective growth fail to occur; the residual growth potential was apparently no longer sufficient at this age. Slight kyphosis remained in these cases, but was not yet causing symptoms at the time of follow-up. In two cases, *fracture dislocation* occurred and resulted in *paraplegia;* both were operated on immediately and the fracture united with correct alignment. In the first case, a fracture dislocation of T10/11 with progressive paralysis which ended in complete paraplegia (Fig. 13), visibly abnormal growth resulted from damage to the end plate, but the paralysis regressed completely over the course of 5 months; the youth concerned now takes part in competitive sports! The second case involved fracture dislocation of S1/2 with total interruption of the sacral innervation: the fracture healed with satisfactory alignment, but complete S1 paralysis remained and the recovery of the innervation of the remaining sacral roots was only partial (Fig. 10).

A patient with a fracture dislocation of L2/3 without neurological deficit was transferred to our service 4 weeks after the accident. This case arrived too late for the deformity to be corrected and severe kyphoscoliosis developed (Fig. 8).

5.2 Subluxations and Dislocations of the Cervical Spine

During the same period of time, we dealt with 14 children with dislocations or subluxations of the cervical spine. The cases can be summarized by vertebral level as follows:

C 1/2: Three boys aged 3–15 years, all with left-sided subluxation without neurological deficit. Treatment by *Glisson* traction for 3 weeks, followed by a *Schanz* collar for a further 6 weeks.

C 2/3: Seven boys and one girl, aged between 4 and 16 years. Three left-sided and three right-sided subluxations, and two dislocations. Three of the injuries were caused directly by dives or falls during play. One child was trapped by the neck in an automatic garage door. Four injuries occurred indirectly as a result of falls from bicycles, tricycles, and similar vehicles.

Treatment: Reduction under anesthesia, or *Glisson* traction for periods ranging from several days to 2 weeks, followed by a *Schanz* collar for 2–6 weeks (six cases) or a Minerva cast for 6 weeks (two cases).

C 3/4: Two boys and one girl, aged 3–13 years. The 3-year old girl suffered a flexion injury as a result of a fall onto the head during play. Fusion of C 2/3 was found (a mild case of *Klippel-Feil* disease) with dislocation of C 3/4, which was reduced by *Glisson* traction with the neck extended. Both the boys had suffered right-sided subluxation as a result of a severe blow to the head in the course of a fight. They were treated by *Glisson* traction followed by application of a *Schanz* collar.

The cases summarized above involved 12 boys and 2 girls. The injuries were mainly caused by indirect trauma. There were 11 unilateral subluxations and only three dislocations. In no case was a neurological deficit observed.

Of the 14 children, 12 could be followed-up at intervals ranging from 4 months to 12 years after the accidents. The results of clinical and radiological examination showed all of them to have recovered completely.

6 Summary

Fractures of the vertebral column rarely occur in children, a fact which is probably attributable to the flexibility and elasticity of the spine at this age. Severe violence or dislocation of the vertebral column is required for damage to be caused to the spinal cord or cauda equina.

In order to define the treatment and prognosis, fractures of the spine in children are classified in the same manner as those in adults, i.e., into stable and unstable fractures. *Simple compression fracture of the vertebral body* is the most frequent form of vertebral fracture in the child. Very frequently, several segments are involved.

Simple compression fractures are treated nonoperatively with early functional mobilization.

Bursting fractures with disruption of the vertebral body require prolonged bed rest with immobilization of the spine in a plaster shell.

Fracture dislocations of the thoracic or lumbar spine or of the sacrum should be treated by open reduction

and temporary internal fixation, if this procedure is likely to improve the prognosis. The treatment of *traumatic paraplegia* entails rigid observance of the therapeutic triad: decompression – reduction – stabilization. Firm adherence to these principles is absolutely necessary in order to make the most of the patient's chances of recovery.

7 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Braus, H.: Anatomie des Menschen. Berlin: Vogel 1921.

Cattell, H. S. and L. Filtzer: Pseudosubluxation and other normal variations in the cervical spine in children. J. Bone Jt Surg. **47 A**, 1295 (1965).

Chigot, P. L. et P. Estève: Traumatologie infantile. Paris: Expansion scientifique 1958.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Emminger, E.: Die Wirbelgelenksluxation. Mschr. Unfallheilk. **71**, 81 (1968).

Gelehrter, G.: In: Ehalt W.: Verletzungen bei Kindern und Jugendlichen, Stuttgart: Enke 1961.

Lob, A.: Die Ausheilungsvorgänge am Wirbelbruch. Dtsch. Z. Chir. **248**, 452 (1937).

Lob, A.: Die Wirbelsäulenverletzung und ihre Ausheilung. Thieme, Stuttgart, 1950.

Nicoll, A. E.: Fractures and dislocations of the spine. In: Modern trends in orthopeadics 3, Butterworth, London 1962

Rettig, H.: Frakturen im Kindesalter. München: Bergmann 1957.

Salter, R. B., R. Harris: Injuries involving the epiphyseal plate. J. Bone Jt Surg. **45 A**, 587 (1963).

Töndury, G.: Entwicklungsgeschichte und Fehlbildungen der Wirbelsäule. Stuttgart: Hippokrates 1958.

Weber, B. G.: Wirbelsäulenverletzungen und ihre Spätfolgen. In: Rheumatismus in Forschung und Praxis, Bd. II: Die Funktionsstörungen der Wirbelsäule, 102–108. Huber, Bern-Stuttgart, 1963.

Weber, B. G.: Operative Frühbehandlung bei traumatischer Paraplegie. In: Rehabilitation der Para- und Tetraplegiker, Fortbildungskurs Schweiz. Rehabilitationskommission, Bern, 1966.

Weber, B. G.: Die Behandlung der Wirbelfrakturen ohne neurologische Störungen. Z. Unfallmed. Berufskrh. **1,** 35–41 (1972).

Zöch, K., B. G. Weber: Das traumatische Querschnittsyndrom. Indikation, Technik und Ergebnisse der operativen Frühbehandlung. Arch. orthop. Unfall-Chir. **72,** 122–138 (1972).

Fractures of the Pelvis and Acetabulum

R. BLATTER

CONTENTS

1 Introduction

Fractures of the pelvis rarely occur in children, a fact which can be partially attributed to the elasticity of the bones at this age (*Ehalt*). In addition, the forces which tend to deform the pelvic ring are absorbed by the cartilaginous epiphyses which separate the bone segments (*Bürkle de la Camp, Blount, Rettig, Chigot,* and *Estève*). Nevertheless, in recent years, we have had to deal with an increasing number of pelvic fractures caused by road traffic accidents.

By far the most frequent *cause* of pelvic fracture in our series of cases was a direct impact, usually as a result of collision with a vehicle. Depending on the degree of violence and on the site of application of the force, the fracture may involve the *iliac bone* or the anterior or posterior part of the *pelvic ring*. Persons who have been run over by an automobile or who have fallen from a great height may sustain serious fractures of the pelvic ring, and in some cases the dislocation of the fragments may be considerable.

Finally, *avulsion fractures of the traction epiphyses* typically occur in adolescents, being particularly common in boys at the age of puberty. In boys, they are mainly sustained during sport and result from sudden contraction of the muscle which is inserted into the epiphysis concerned (*Blount, Dreiack, Devas, Ehalt*).

A severe blow to the greater trochanter or to a leg which is positioned in abduction and flexion may cause *fracture of the acetabulum*. However, these fractures are extremely rare in children.

2 Fracture Types and Treatment

A plain a-p film of the pelvis usually suffices for diagnosis of a pelvic fracture. However, on examining the film, account should be taken of the normal ossification processes and of the presence of accessory centers of ossification (os acetabuli). The epiphyseal plate between the inferior ramus of the pubic bone and the inferior ramus of the ischial bone ossifies around the 7th year of life. At this stage an increase in the radiodensity of the epiphyseal plate is sometimes seen. This *ischiopubic chondropathy* (*Van Neck*'s disease) may give rise to slight pain and cause the doctor to misinterpret the increase in density of the epiphyseal plate as callus resulting from an isolated fracture of the ischiopubic ramus (*Blount, Chigot,* and *Estève, Ehalt*).

If the extent of the injury cannot be clearly defined, alar and obturator films may be required. These addi-

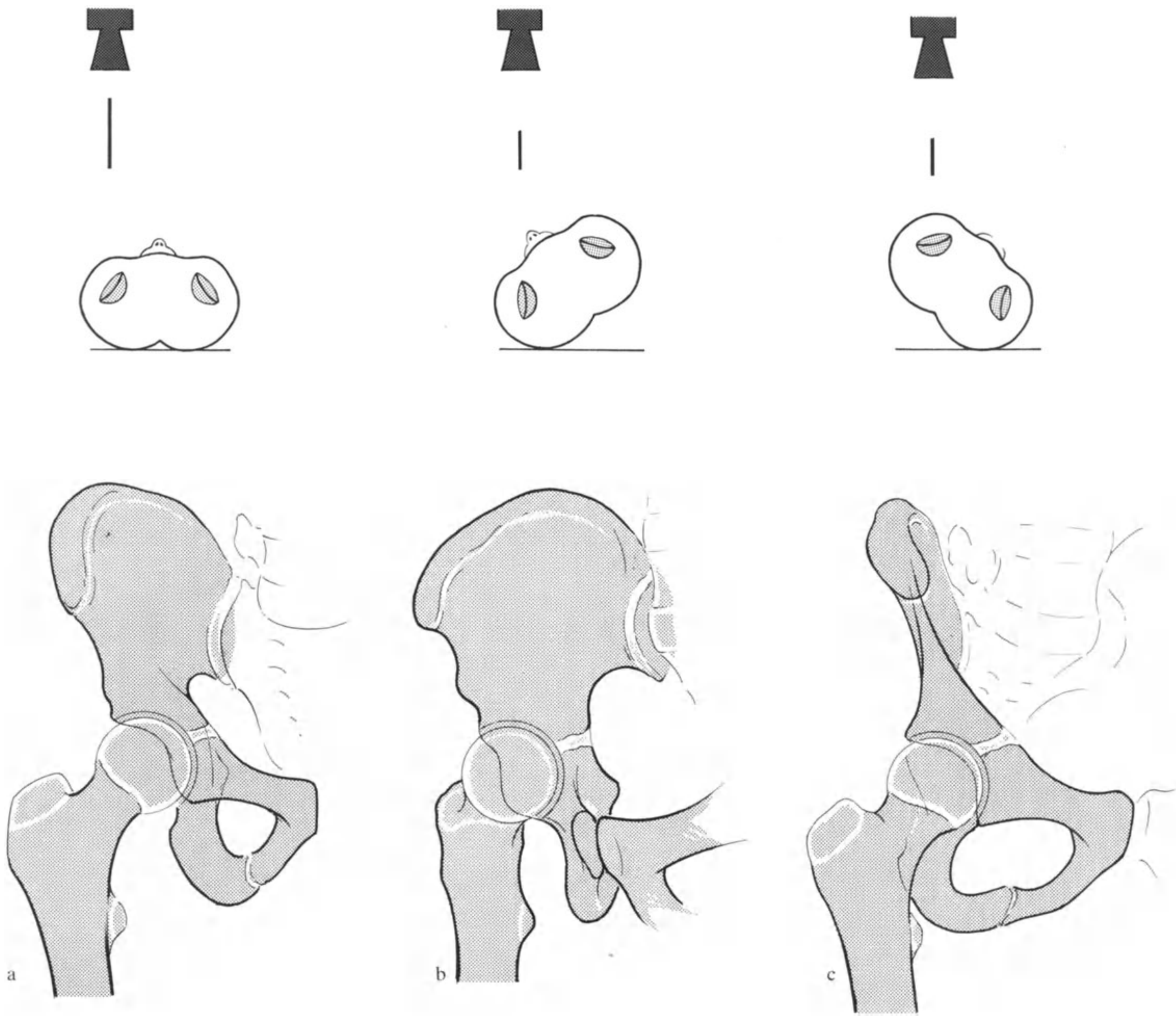


Fig. 1 a–c. *Roentgenogram of the hip joint according to Letournel.*
a) a-p view of the hip joint with the patient supine and the X-ray beam centered on the hip joint.
b) Alar projection. The patient is tilted at 45° towards the injured side and the X-ray beam is centered on the injured joint.
c) Obturator projection. The patient is tilted at 45° towards the noninjured side and the X-ray beam is centered on the injured hip joint. These three views allow visualization of the whole of the acetabulum

tional views are essential if fracture of the anterior or posterior column is to be excluded (Fig. 1).

Since pelvic fractures are usually caused by high-energy accidents, the possibility of injury to the pelvic contents should always be borne in mind. *Rectal injuries* are rare and can usually be excluded if the result of rectal palpation is normal. *Urethral and bladder injuries* are occasionally seen in conjunction with anterior fractures of the pelvic ring. Even if the fragments appear to be only slightly displaced on the roentgenogram, the urethra may be torn through completely. This is because the fracture was initially dislocated, but was then reduced by the pull of the muscles and ligaments, thus giving the radiological appearance of a relatively unimportant injury. The ability to urinate does not completely exclude injury to the urethra; partial rupture of the urethra is sometimes followed by difficulties with micturition which arise at a later stage as a result of swelling of the tissues. If in doubt, i.e., if the patient is unable to pass urine or there

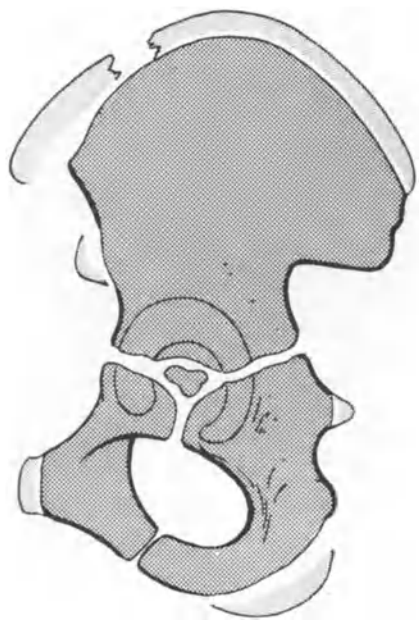


Fig. 2. *The secondary centers of ossification in the pelvis.* Avulsion fractures in the regions of the traction epiphyses may occur at the age of puberty. Typical sites: anterior superior iliac spine, anterior inferior iliac spine, ischial tuberosity

are red cells in the urine, retrograde urography with water-soluble contrast medium will define the site and extent of any urethral rupture which may be present. We consider diagnostic catheterization to be contraindicated since it may cause further injury and adds little useful information.

Fractures of the pelvis are categorized as follows:

Marginal fractures.
Fractures of the pelvic ring.
Fractures of the acetabulum.

2.1 Marginal Fractures

2.1.1 Pathological Anatomy

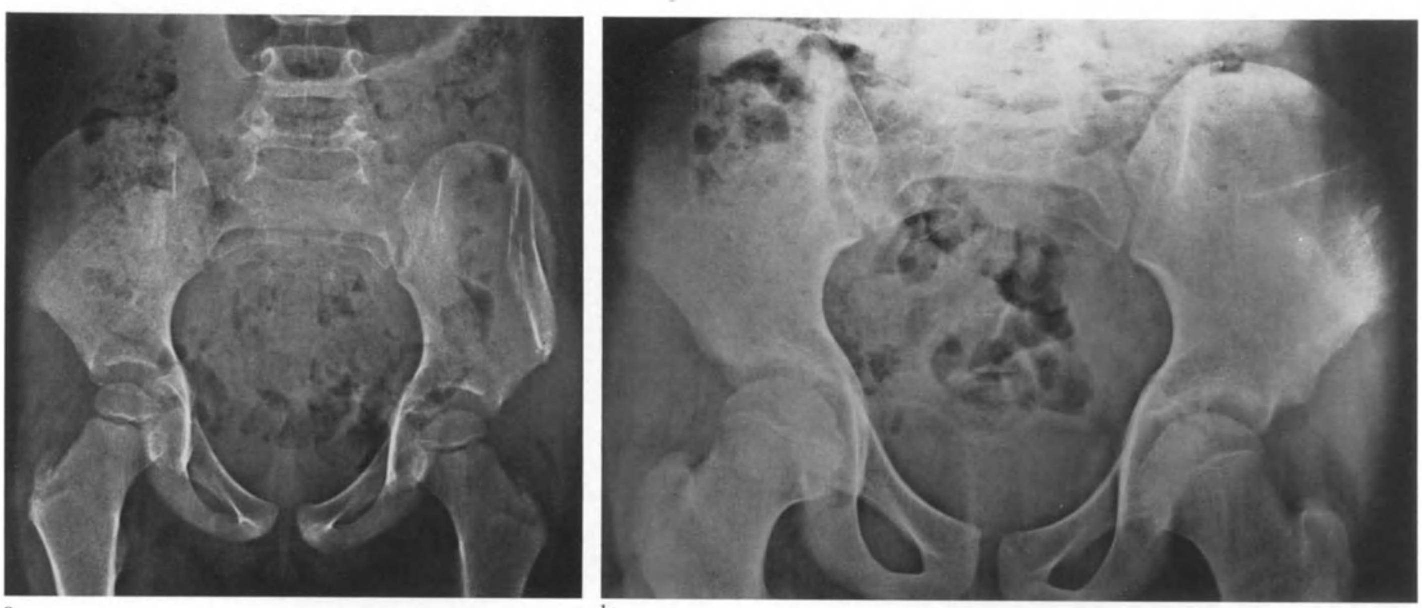
Marginal fractures are defined as those which do not interrupt the continuity of the pelvic ring. The strength and rigidity of the pelvis is not affected by the injury. *Fracture of the wing of the ilium* occurs most frequently; it is caused by a direct blow and there may be considerable dislocation of the fragments. *Avulsion fractures of the traction epiphyses* also belong to this group and result from sudden contraction of the attached muscles (Fig. 2).

2.1.2 Treatment

2.1.2.1 Fractures of the Iliac Bone (Fig. 3)

Treatment is generally nonoperative. Only in cases with severe dislocation is open reduction and internal fixation necessary to improve the aesthetic appearance of the hip and to restore normal muscle function.

Procedure: Bed rest until the pain has subsided (1–2 weeks in the majority of cases).



a b

Fig. 3a, b. *Fracture of the wing of the iliac bone*. S.W., ♂, aged $5^5/_{12}$ years, No. 75706.

a) Patient was hit by an automobile and sustained this left-sided fracture of the wing of the ilium.
b) 8 years and 1 month later. Complete recovery despite considerable initial displacement of the fragments

Fig. 4a, b. *Pseudarthrosis of an avulsion fracture.* E.B., ♂, aged 15 years, No. 120597.
a) 10 months after a collision while playing soccer. The fracture was not treated at the time and there is now a pseudarthrosis of the ischial tuberosity.
b) 2 years and 8 months later. Fully-developed pseudarthrosis with symptoms accompanying changes in the weather; otherwise, complaint-free

2.1.2.2 Avulsion Fractures of the Traction Epiphyses

Nonoperative Treatment: Ischial tuberosity: Bed rest for 2–3 weeks with the patient lying on a flat surface so as to reduce the load on the ischiocrural muscles. Markedly displaced fragments may heal by pseudarthrosis (Fig. 4), which necessitates operative fixation if symptoms arise.

Anterior superior and anterior inferior iliac spines (Fig. 5): Nonoperative treatment suffices if there is only slight dislocation. The patient is positioned with the hip and knee joints flexed at an angle of 90° so as to reduce the pull on the sartorius and rectus femoris muscles. Bed rest for 2–3 weeks.

Operative Treatment: Screw fixation of severely displaced, avulsed iliac spines is recommended, since painful fibrous pseudarthrosis otherwise results.

Postoperative management: The patient is positioned with the hip and knee joints flexed at an angle of 45° for 1 week and is then mobilized.

2.2 Fractures of the Pelvic Ring

2.2.1 Pathological Anatomy

Fractures of the pelvic ring are divided into three main categories which are the same as those of the corresponding fractures in the adult, i.e.,

a) Anterior fractures of the pelvic ring: these include separation of the pubic symphysis and unilateral or bilateral fracture of the pubic rami or of the inferior ramus of the ischium.
b) Posterior fractures of the pelvic ring: this category includes complete vertical fractures of the ilium, separation of the sacroiliac joint, and vertical fractures of the sacrum.
c) *Malgaigne* fracture: this is a combination of anterior and posterior fracture of the pelvic ring.

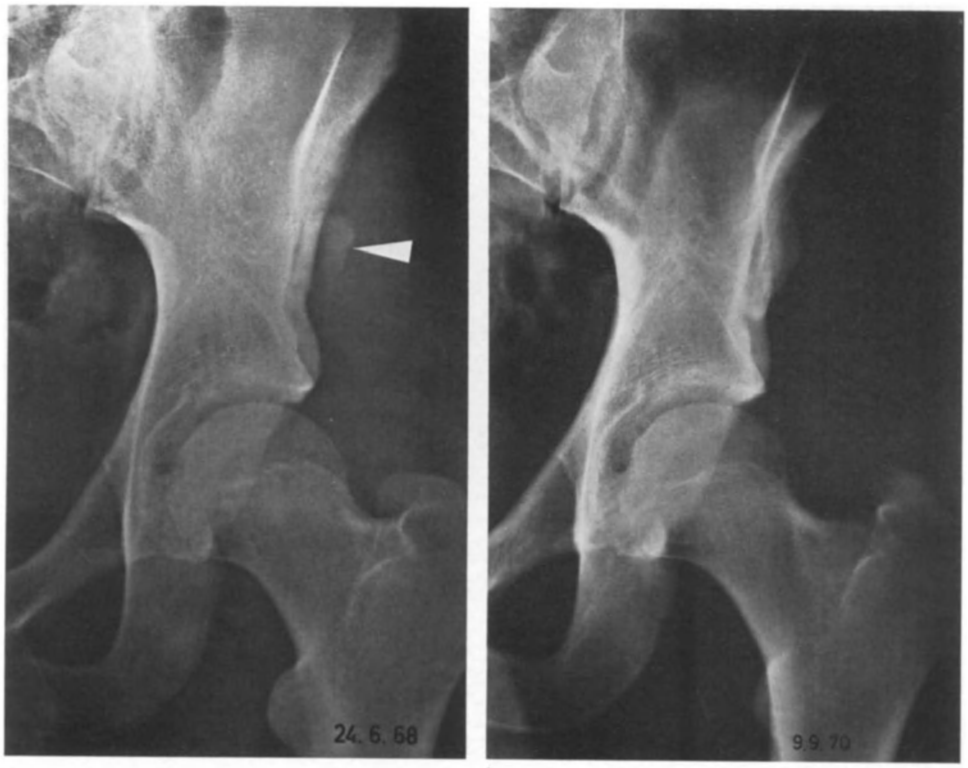
Each of the above fractures interrupts the continuity of the pelvic ring. The fractures are therefore *unstable* and decrease the strength and rigidity of the pelvis.

2.2.2 Treatment

2.2.2.1 Separation of the Symphysis

Nonoperative Treatment: Isolated separation of the pubic symphysis is hardly ever seen in children. The interpubic fibrocartilaginous plate seems to possess considerable tensile strength at this age and is particularly well anchored to the bone. Accidents more often lead to avulsion of the bone or shedding of the periosteum on one side of the symphysis than to tearing of the symphysis itself.

Procedure: Application of a pelvic sling (Fig. 6) which is a modified version of the conventional hammock device. The modification allows controlled compression to be exerted on the pelvis at the position desired. A padded calico belt, 10–20 cm in width, with a slit in the middle is pulled under the buttocks and crossed over the abdomen so as to lie directly over the greater trochanter. The ends are connected



a b

Fig. 5a, b. *Spontaneous healing of an avulsion fracture*. S.P. ♂, aged 16 years, No. 123210.
a) Roentgenogram immediately following the accident. This avulsion of the anterior inferior iliac spine was sustained while playing soccer.
b) 2 years and 3 months after the accident. Uneventful healing of the fracture following nonoperative treatment

via pulleys to weights of 2–10 kg; the precise values of the latter vary according to the age of the child and the degree of dislocation of the fragments (*Freuler, Wiedmer*, and *Bianchini*).

Duration of fixation: 3–4 weeks.

Operative Treatment: Open reduction is only indicated if operative treatment of an injury to the bladder or urethra is intended. A few deep sutures which pass through the periosteum and adjacent soft tissues will then suffice to hold the symphysis together. In an older child with multiple pelvic injuries, it may be better to use a cerclage wire which is looped around the heads of screws inserted into the bones on each side of the symphysis (Fig. 7).

Postoperative treatment: Pelvic sling.

Duration of fixation: 3–4 weeks.

2.2.2.2 Anterior or Posterior Fractures of the Pelvic Ring

Nonoperative Treatment: Slight dislocation: Bed rest for 3–5 weeks, depending on the age of the child.

Marked lateral displacement of the fragments: pelvic sling, with the belt applied to the wings of the pelvis (Fig. 6).

Duration of fixation: 3–5 weeks.

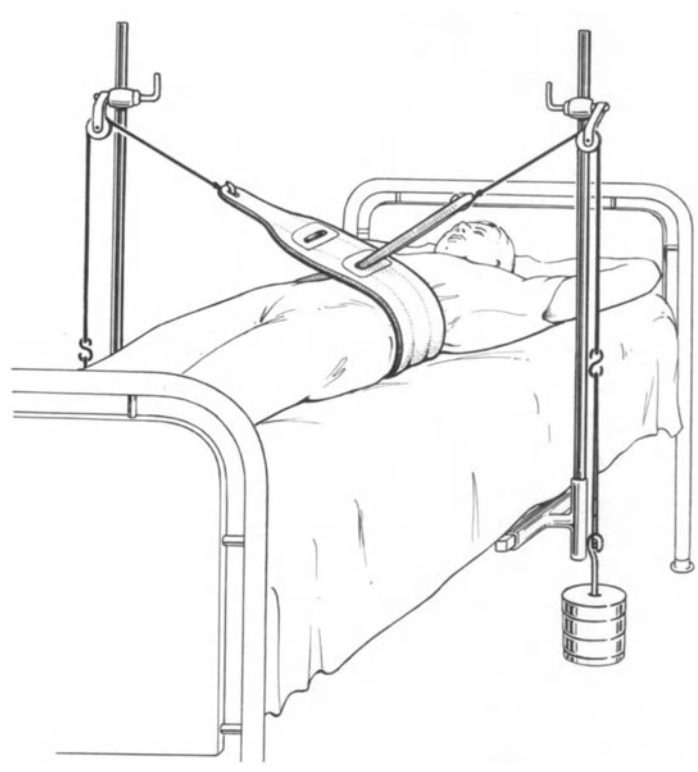
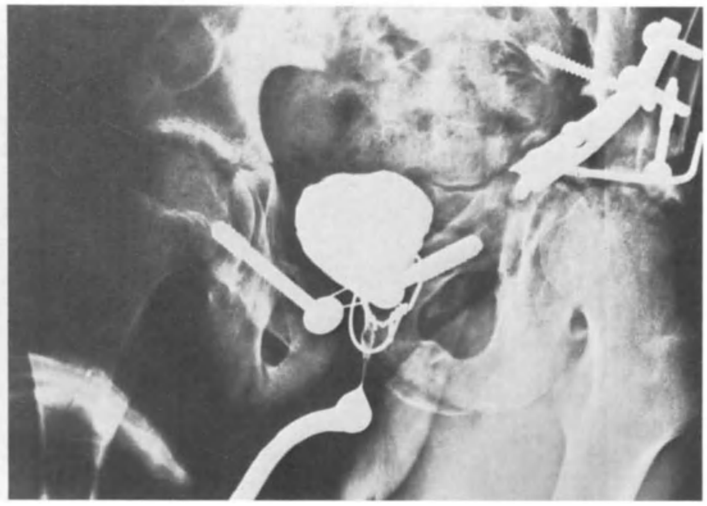


Fig. 6. *Pelvic sling (modified hammock suspension)*. The belt consists of a padded strip of linen, 10–20 cm in width, with a slit which allows it to be crossed over the abdomen. Weights are attached to the end of the belt by means of cords which pass over pulleys. 2–10 kg are applied, depending on the age of the child and the degree of dislocation of the fragments

a



b

c

Fig. 7a–c. *Fracture of the acetabulum with separation of the symphysis.* E.U., ♂, aged 12 years, No. 174557.
a) A skiing accident (collision with a skilift pylon). There is severe comminution of the acetabulum with fracture of the pelvic ring, complete rupture of the symphysis, and separation of the iliosacral joint on the left side.
b) Stabilization of the iliosacral joint on the left side, internal fixation of the acetabular fracture, open reduction of the symphyseal separation, screw fixation of the fracture of the pelvic ring, and tension-band wiring of the symphysis.
c) 3 years after the operation. The patient is symptom-free. There is slight displacement in the region of the symphysis which is of no functional significance. Ossification has occurred in the region of the ischial tuberosity on the left side. The left hip joint is clinically satisfactory, but not quite perfect from the radiological point of view. Pelvic asymmetry has resulted in 2 cm leg shortening on the left side

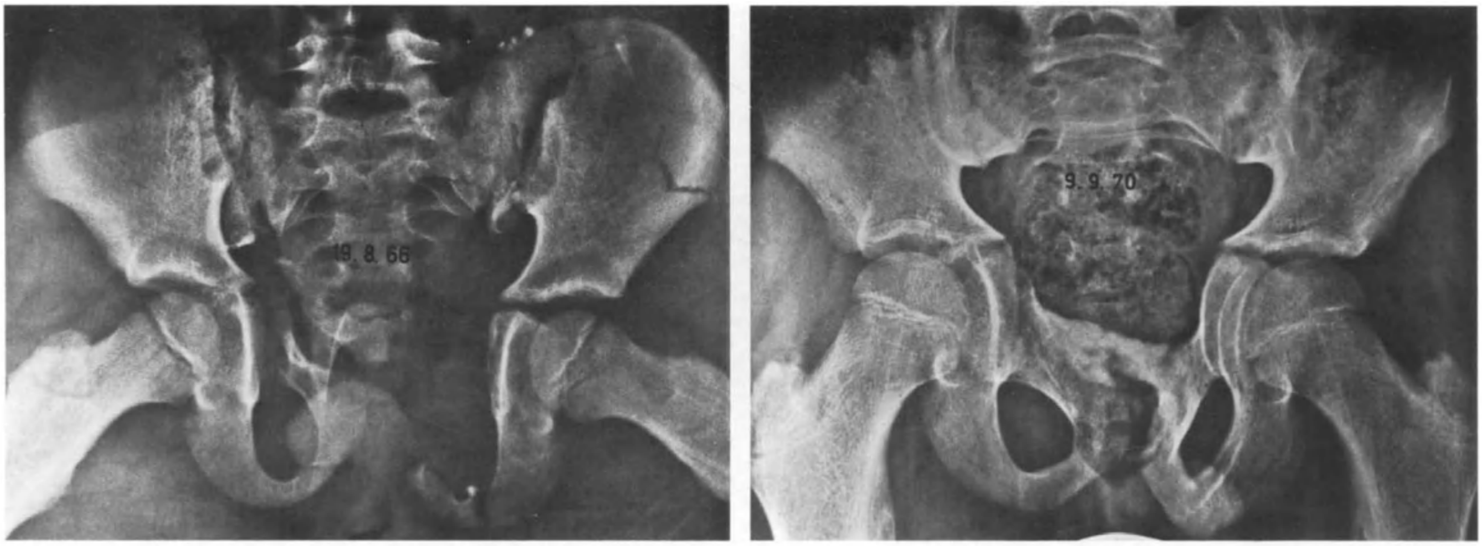
Operative Treatment: In female patients, great care should be taken to ensure accurate reduction, since obstruction may otherwise result during child birth. A severely dislocated anterior fracture of the pelvic ring which cannot be reduced by nonoperative means may require open reduction followed by simple fixation with periosteal sutures; screw or plate fixation is unnecessary.

2.2.2.3 Malgaigne Fracture (Combined Anterior and Posterior Fractures of the Pelvic Ring)

Nonoperative Treatment: Fractures with slight dislocation: Bed rest for 3–5 weeks.

If the side of the pelvis which has broken away is displaced cranially (Fig. 8), traction must be applied to the leg on the side of the fracture. We use adhesive plaster traction in children up to 4 years of age, and traction applied to a supracondylar *Steinmann* pin in older children. It is widely and erroneously assumed that traction will bring about reduction of a fracture; in fact, it does little more than maintain the status quo. A severely dislocated fracture, therefore, requires preliminary reduction under general anesthesia in the following manner: The patient lies on the intact side. An assistant exerts steady pull on the leg on the side of the fracture and the surgeon reduces the fracture by pressing on the iliac crest in a downward and ventral direction (*De Palma*). Traction is then applied using weights equivalent to $^1/_7$ of the body weight of the patient.

Duration of traction: 2–4 weeks, depending on the age of the child, followed by bed rest for a further 2–4 weeks.



a b

Fig. 8a, b. *Malgaigne fracture*. K.E., ♂, aged $7^{11}/_{12}$ years, No. 106595.
a) The patient was run over by a tractor, causing this bilateral *Malgaigne* fracture and a fracture of the wing of the left ilium. Treatment: reduction under general anesthesia, supracondylar traction on the left with a *Steinmann* pin, bed rest.
b) $4^1/_2$ years after the accident. The patient has no symptoms whatsoever and the ranges of joint movement are normal. The bone strut above the symphysis is of no functional significance

2.3 Fractures of the Acetabulum

2.3.1 Pathological Anatomy

In children three epiphyseal plates of the iliac, pubic, and ischial bones join at the acetabulum to form the triradiate cartilage. This structure is relatively weak and is therefore almost always included in injuries to the acetabulum. Since it is an epiphyseal plate, fractures usually cause abnormal growth (Fig. 9). The affected part should therefore be X-rayed at prolonged, but regular intervals.

2.3.2 Nonoperative and Operative Treatment

Nonoperative Treatment: In accordance with the general principles of treatment of epiphyseal fractures, a fracture of the acetabulum requires anatomically precise reduction. If this is possible using nonoperative methods, traction is applied using a supracondylar *Steinmann* pin.

Duration of traction: 3–4 weeks, followed by bed rest for a further 2–4 weeks.

Operative Treatment: The results of nonoperative treatment are not encouraging and we therefore advise open reduction if the position of the fragments is not perfect. However, an acetabular fracture should only be operated on by a surgeon who has had adequate operative experience in this region in the adult.

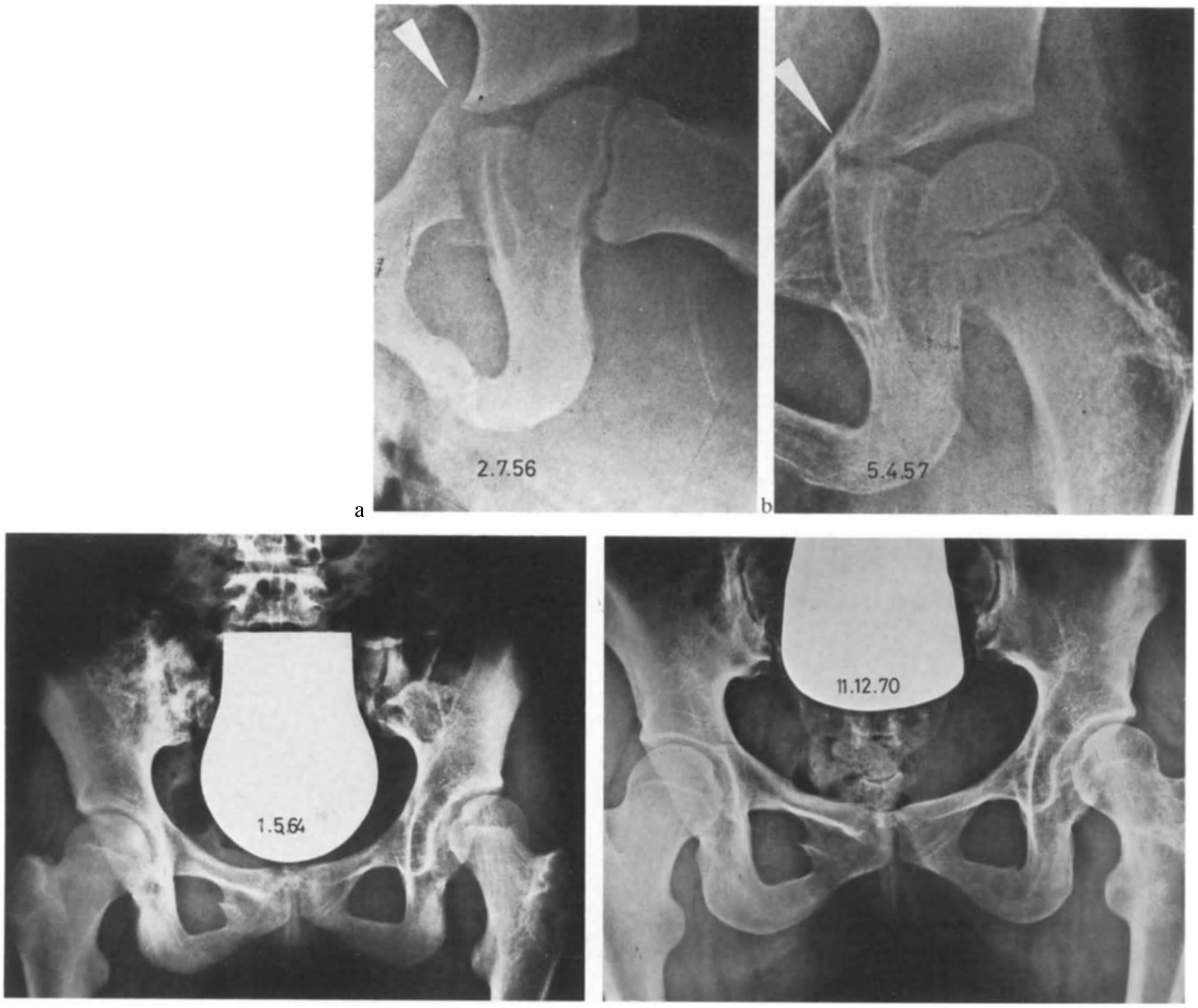
Operative procedure: Dorsal approach to the hip joint. The short external rotators are divided and the joint capsule is opened by means of a longitudinal incision which extends up to the limbus. The fragments are precisely reduced and are then fixed with lag screws or a small plate.

3 Prognosis

Fractures of the margin of the iliac bone are generally regarded as straightforward. If the wing of the ilium is not severely dislocated immediately following the accident, its original shape will be restored by subsequent growth (Fig. 3).

Similarly, the majority of *avulsion fractures of the traction epiphyses* have a good prognosis. Avulsion of the ischial tuberosity with serious dislocation is occasionally followed by pseudarthrosis (Fig. 4), but surgery is reserved for cases with serious symptoms.

Fractures of the acetabulum are serious injuries which have a grave prognosis if incorrectly treated. Anatomically imprecise reduction is followed by premature ossification of one limb of the triradiate cartilage or, in some cases, of the whole epiphyseal plate. This epiphyseal fusion leads to cessation of growth which, in turn, causes deformation of the acetabulum. In a typical case, the acetabulum is flattened, with thickening of the floor and inadequate coverage of the head of the femur (Fig. 9). An acetabulum which has been



a b c d

Fig. 9a–d. *Ossification of the triradiate cartilage following a fracture.* K.V., ♀, aged $6^3/_{12}$ years, No. 51633.
a) The patient was hit by a truck, causing this fracture in the vicinity of the triradiate cartilage and a fracture of the pelvic ring.
b) 9 months after the accident. The ossification in the vicinity of the triradiate cartilage is clearly visible.
c) 7 years and 10 months after the accident. Posttraumatic dysplasia of the acetabulum on the left as a result of bone fusion across the triradiate cartilage. The acetabular coverage of the head of the femur is reduced, with coxa valga and increased growth in thickness of the floor of the acetabulum. Treatment: left-sided intertrochanteric varus osteotomy.
d) 14 years and 5 months after the accident and 6 years and 7 months after the osteotomy. The patient is completely free of symptoms. The hip joint is freely mobile and there is no difference in leg length

fractured should therefore be checked radiologically at regular intervals in order to detect subluxation of the head of the femur, which can be corrected if necessary by acetabuloplasty, pelvic osteotomy, or intertrochanteric varus osteotomy.

4 Results

In our series of cases (1961–1969), there were 17 pelvic fractures in children. The distribution according to age group and fracture type is shown in *Table 1.* The fractures were treated nonoperatively in 16 cases. An anterior fracture of the pelvic ring with disruption

Table 1. Patient ages and fracture types in 17 cases of pelvic fracture

Ages in years	0–5	5–10	10–16
Marginal fractures		2	1
Avulsion fractures			2
Fractures of the pelvic ring	2	3	7

a

b

Fig. 10a, b

of the symphysis in an 11-year old girl required open reduction, but no internal fixation.

A total of 14 patients were followed-up. Five children (three with fractures of the pelvic ring and two with avulsion fractures) reported occasional slight pain following marked exertion or changes in the weather. In one patient with a fracture of the pelvic ring, hip flexion was limited by 15° on the side of the fracture. As expected, we found no differences in leg length which could be attributed to the pelvic fracture. One girl with an acetabular fracture at the age of 1 year was initially treated in another hospital. Ten years after the accident, she was referred to us because of posttraumatic acetabular dysplasia. We performed pelvic osteotomy immediately above and below the acetabulum and moved the latter 1.5 cm medially. The acetabular segment was then fixed with two *Kirschner* wires which were drilled in through the iliac crest. The girl now has a normal gait with no symptoms, and the range of motion of the hip joint is normal (Fig. 10).

A 6-year old girl with a fracture of the triradiate cartilage was brought to our clinic in 1956. The child had just been run over by a reversing truck and had suffered numerous injuries including a left-sided fracture of the acetabulum, a right-sided anterior fracture of the pelvic ring, an open left-sided supracondylar fracture of the femur, and a left-sided greenstick fracture of the proximal tibia. All the fractures were treated nonoperatively. Ossification subsequently occurred in the triradiate cartilage, resulting in posttraumatic dysplasia of the acetabulum (Fig. 9). Eight years after the accident, intertrochanteric varus and derotation osteotomy was carried out in order to improve the function of the hip joint. The patient is now symptom-free and the range of motion in the hip joint is normal.

5 Summary

Fractures of the pelvis rarely occur in children. They can be divided into three groups, as follows:

a) Fractures of the margin of the ilium, which do not affect the stability of the pelvis.
b) Fractures of the pelvic ring, which cause transient instability of the pelvic ring.
c) Fractures of the acetabulum. These are rare, but very serious injuries which endanger the congruence of the hip joint and always involve damage to the growth cartilage.

As long as there are no accompanying injuries, treatment is nonoperative in all the cases in group 1 and in the majority of those in group 2. We consider open reduction and stabilization to be indicated for fractures of the acetabulum and for fractures of the margin of the ilium which are severely dislocated.

6 References

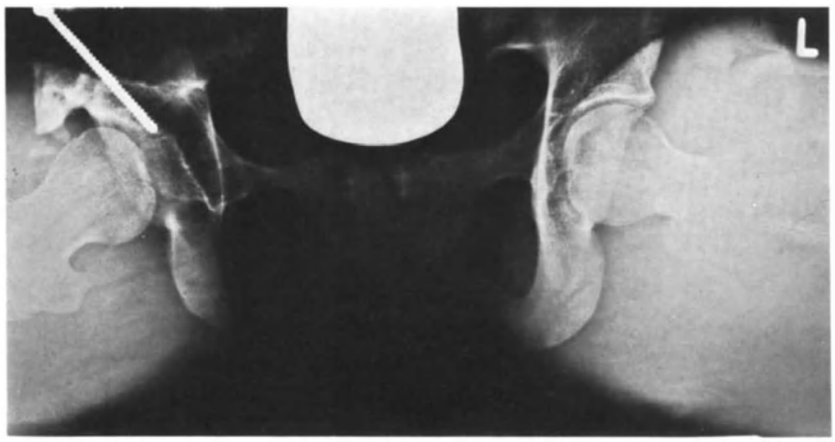
Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Buerkle de la Camp, P.: Handbuch der gesamten Unfallheilkunde. Rostock 1956.

Fig. 10a–e. *Acetabular dysplasia following fracture of the acetabulum.* B. Ch., ♀, aged 11 years, No. 141324.
a) This patient was run over by an automobile at the age of 1 year. Now, 10 years later, there is typical acetabular dysplasia with broadening of the floor of the acetabulum.
b) Treatment: Double pelvic osteotomy.
c) 3 years and 9 months after the osteotomy. Improvement in the biomechanical function of the hip by medialization of the center of rotation of the head of the femur. Treatment: *Chiari* pelvic osteotomy.
d,e) 4 months after *Chiari* osteotomy. The roofing-over of the head of the femur has been significantly improved. The patient is symptom-free and there is no difference in leg length


c


d



e

Chigot, P. L., Estève, P.: Traumatologie infantile. Paris: Expansion Scientifique 1958.

De Palma: The management of fractures and dislocations. Philadelphia: Saunders 1970.

Devas, M. B.: Stress fractures in children. J. Bone Jt Surg. **45 B**, 528–41 (1963).

Dreiack, D.: Über Apophysenlösungen und Ossifikationsstörungen der Sitzbeinapophyse. Arch. orthop. Unfallchir. **68**, 370–77 (1970).

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke 1961.

Freuler, F., Wiedmer, U., Bianchini, D.: Cast manual for adults and children. Berlin-Heidelberg-New York: Springer, 1979.

Howard, F. M. et. al.: Fractures of the apophyses in adolescent athletes. J. Amer. med. Ass. **192**, 842–844 (1965).

Rettig, H.: Frakturen im Kindesalter. München: Bergmann 1957.

Van Neck, M.: Arch. provenc. de chirurg. (Brüssel) **238**, 1924.

Weber, B. G.: Verletzungen des Hüftgelenkes. Chirurgie der Gegenwart, Band IV, 1975.

Fractures of the Proximal Femur

A. Boitzy

CONTENTS

1 Introduction

Fractures of the femoral neck are rarely seen in children, but have been increasing in frequency in recent years. This is partly a result of the increased risk of road traffic accidents. This type of fracture occurs more frequently in boys than in girls (*Tachdjian*).

1.1 Fracture Causes

The bone of the femoral neck of a child is tougher than that of an older person and a much greater degree of violence is required to cause a fracture. The majority of fractures are caused by falls from varying heights or by road traffic accidents. They are frequently accompanied by injuries to the skull, pelvis, vertebral column, or abdomen. A fracture which is caused by relatively slight trauma may well be associated with pathological changes in the bone, such as an aneurysmal bone cyst, an osteofibroma, or disuse atrophy (*Nöh* and *Akalin*).

Occasionally, avulsion fractures of the greater or lesser trochanter result from sudden isometric contraction of a muscle.

1.2 Fracture Mechanisms

A fracture of the femoral neck may be caused by one of two mechanisms, i.e.:

a) Forces of excessive magnitude which are directed along the normal physiological paths cause varus deformity of the proximal end of the femur. The medial or lateral fractures which result are caused by the same mechanism as those in adults.

b) The second fracture mechanism is specific to children and results from the relatively large angle between the femoral neck and the shaft of the femur. Since the head of the femur is firmly buttressed by

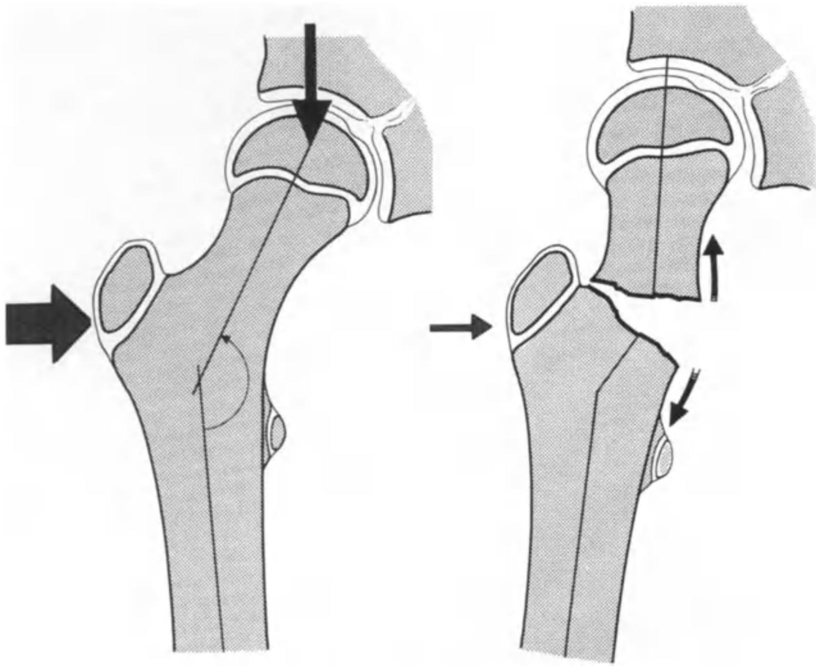


Fig. 1. *The mechanism of fracture of the femoral neck in a child.* Force applied to the lateral side of the greater trochanter causes valgus fracture of the lateral part of the femoral neck

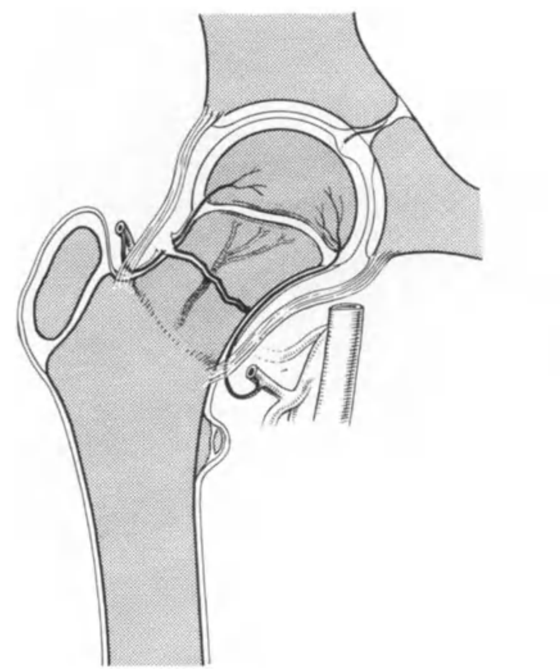


Fig. 2. *Blood supply of the proximal femur in a child.* The vessels supplying the proximal part of the head run along the femoral neck under the synovial membrane and cross the epiphyseal plate to reach the epiphysis of the head. The vessels are seriously endangered by a fracture which may cause them to be torn, angulated, or compressed by the resulting hemarthrosis. The small vessel in the ligament of the head of the femur cannot supply the proximal part of the head on its own

the acetabulum, a force which acts directly on the greater trochanter will tend to produce valgus angulation at the junction between the femoral neck and the trochanter, and a lateral fracture of the femoral neck may result (Fig. 1).

2 Anatomy

2.1 Structure of the Neck of the Femur

The cancellous bone trabeculae in the femoral neck of a child are not oriented along the lines of tension and compression as in the adult, but are distributed in a more or less homogeneous manner (*Müller* and *Ganz*, *Boitzy*). Furthermore, the cancellous bone is much harder and denser than that in the adult, so that the fracture surfaces are usually relatively smooth and impaction and interlocking of the fragments does not occur. Thus, anatomically precise reduction is required in order to render a fracture stable. In view of the consistency of the cancellous bone, it is understandable that it is difficult to drive a nail into the head of the femur, but that screws obtain a good hold in the femoral neck.

2.2 Vascular Supply

The femoral head and the neck of the femur are supplied by blood vessels with a characteristic arrangement. Since the femoral head and femoral neck are intraarticular, they are supplied by blood vessels which pass along the neck of the femur, and there is no direct supply from the surrounding soft tissues. In addition, the epiphyseal plate presents an impermeable barrier to blood vessels and the latter therefore have to pass around it, since the vessels in the ligament of the head of the femur are unable to completely satisfy the nutritional needs of the head itself (Fig. 2). Thus, the arrangement of the blood vessels is such that the vascular supply to the head and neck of the femur may easily be interrupted if a fracture occurs in its vicinity. Some of the vessels may be torn at the time of the accident and the resulting intracapsular hematoma compresses the veins and, as the pressure increases, the arteries. This is known as a tension hemarthrosis (*Weber*). The result is avascular necrosis which, because of the distribution of the blood vessels in the child, may be limited to the head or neck of the femur or include both the latter structures.

3 Fracture Types and Treatment

Fractures of the proximal femur are divided into three morphological types as follows:

Fractures of the femoral neck.
Fractures of the greater and lesser trochanters.
Subtrochanteric fractures.

3.1 Fractures of the Femoral Neck

Fractures of the femoral neck are classified morphologically (*Boitzy, Colonna*).

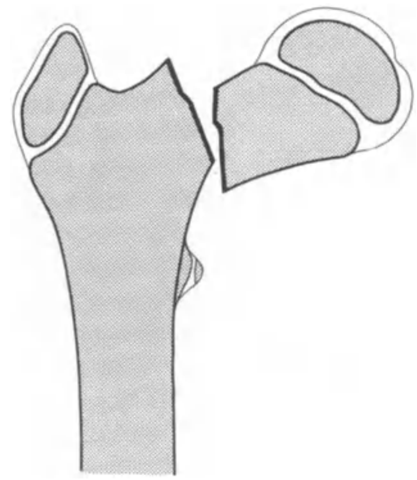


Fig. 4. *Transcervical fracture (Type II)*. This is a femoral neck fracture in the more restricted sense

3.1.1 Simple Traumatic Epiphyseal Separations (Type I) (Fig. 3)

In common with epiphyseal separations at other sites, this lesion transects the epiphyseal plate in the zone of hypertrophic cartilage cells. This type of injury must be clearly distinguished from epiphyseal separation in the adolescent which is caused by loosening of the epiphyseal plate shortly before puberty. Thus, the diagnosis of traumatic dislocation of the epiphysis can only be made with certainty in small children. Since the epiphysis of the head of the femur is well protected by the surrounding acetabular cartilage, separation hardly ever occurs. In a dysplastic hip, this protection is incomplete and the head of the femur is more exposed to shear force. There were no cases of true traumatic epiphyseal separation in our series, and it is found extremely rarely in series published by other authors (*Ratliff*).

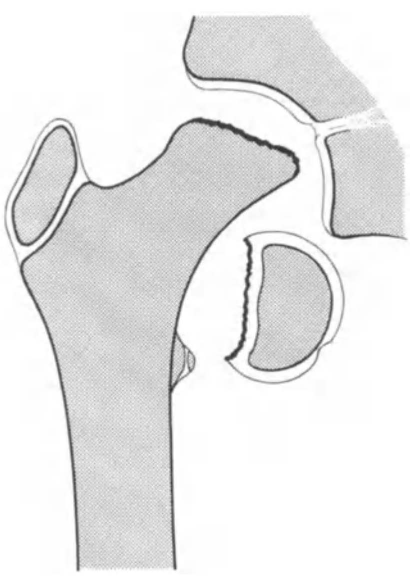


Fig. 3. *Traumatic epiphyseal separation (Type I)*. This lesion, especially the form which involves dislocation of the proximal head segment, is extremely rare

3.1.2 Transcervical Fractures (Type II) and Lateral Fractures of the Femoral Neck (Type III)

The problems posed by the treatments and complications of these two types of fractures are identical and are therefore discussed together.

3.1.2.1 Pathological Anatomy

Type II (Fig. 4): These are true fractures of the femoral neck. The group includes all fractures which transect the bony neck of the femur, leaving a lateral stump of varying size. The arrangement of the blood vessels is such that this type of fracture may lead to necrosis of the femoral head.

Type III (Fig. 5): In contrast to the fractures in the previous group, which may be located anywhere along the femoral neck, Type III fractures are always situated at the base of the femoral neck and do not usually involve the trochanter. In the child, the femoral neck is very thin and its junction with the trochanteric bone mass constitutes an abrupt transition which is a site of relative weakness. This is the reason why Type III fractures predominate in children up to the age of approximately 13 years. Lateral fractures of the femoral neck may lead to isolated necrosis of the femoral neck while leaving the blood supply to the head intact. Type II and III fractures are always accompanied by a large intracapsular hematoma which may progress to tension hemarthrosis with compression of the intact blood vessels (*Weber*).

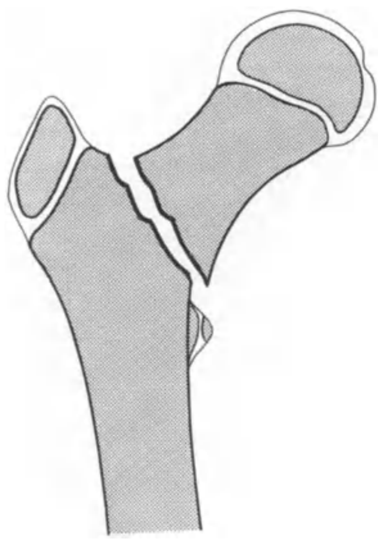


Fig. 5. *Cervicotrochanteric or basilar fracture of the femoral neck.* This is the typical fracture form in children under 13 years of age

3.1.2.2 Treatment

The treatment of a Type II or Type III fracture of the neck of the femur in a child must fulfill the following three criteria:

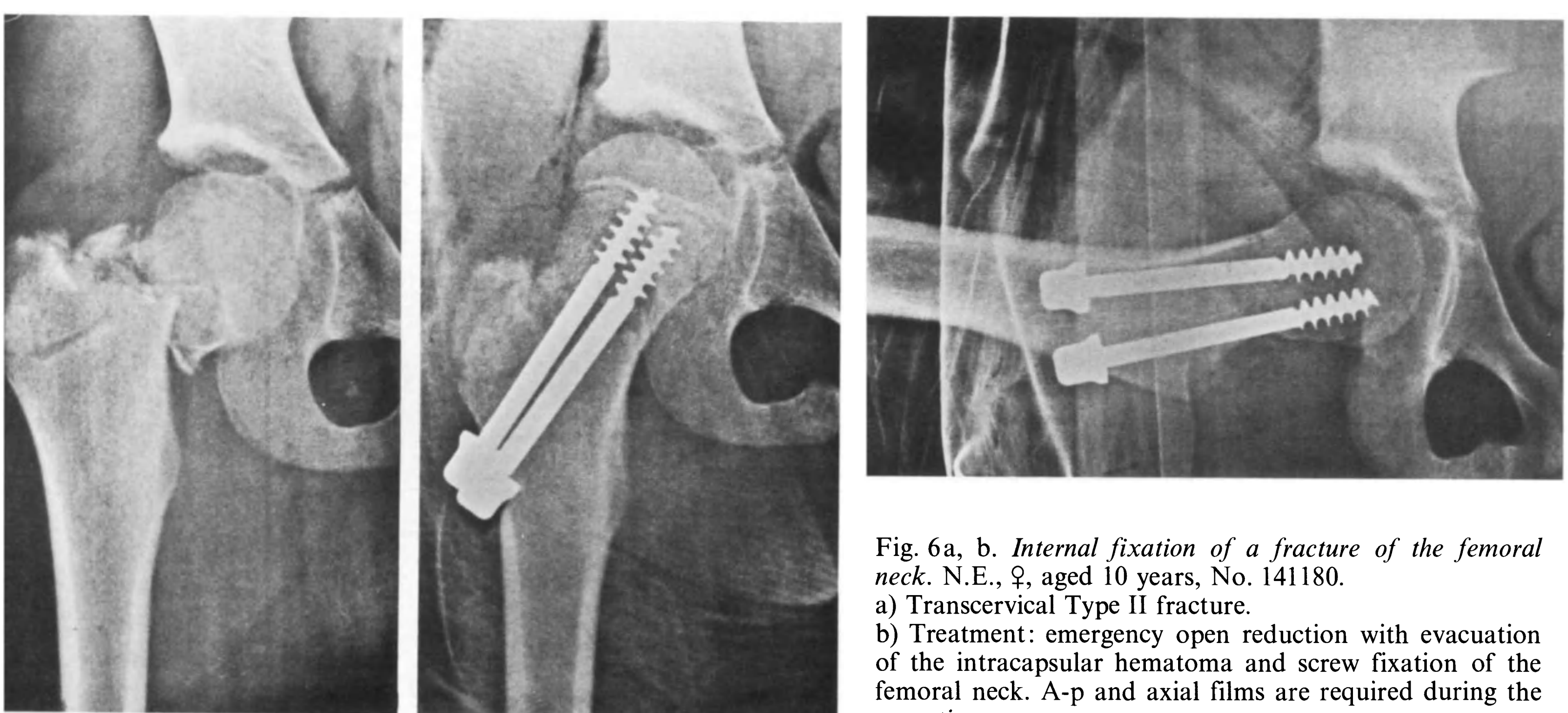
Relief of the tension hemarthrosis.

Anatomically precise reduction of the fracture without damage to the intact blood vessels.

Stabilization of the reduced fracture for several weeks until union has taken place.

Nonoperative Treatment: The above criteria are hardly ever fulfilled by closed reduction and immobilization with a plaster cast or by traction. The danger of vascular injury is very great, and malunion with delayed healing frequently occurs. Furthermore, nonoperative treatment does not entail evacuation of the hemarthrosis which is always present and which restricts the circulation. Thus, aseptic necrosis may even follow nonoperative treatment of a nondislocated fracture of the femoral neck. For the above reasons, it is clear that nonoperative treatment is associated with an increased risk of avascular necrosis and is no longer justifiable.

Operative Treatment: We regard every fracture of the femoral neck in a child as an *emergency* situation which requires operative intervention with a minimum of delay. Rapid action is essential to allow anatomically precise reduction and stabilization as well as evacuation of the intracapsular hematoma. *Trifin nails* and *angled plates* are used in adults, but are totally unsuitable in children and may even be dangerous. The cancellous bone in a child is very hard, and an attempt to drive in an implant of the above type may cause separation of the fragments with tearing of those blood vessels which have remained intact. Unfortunately, necroses and pseudarthroses resulting from unsuitable internal fixation procedures are frequently seen. *Kirschner* wires are too flexible to allow adequate stabilization; they assure neither good contact between the fracture surfaces nor compression of the fracture.



a b

Fig. 6a, b. *Internal fixation of a fracture of the femoral neck.* N.E., ♀, aged 10 years, No. 141180.
a) Transcervical Type II fracture.
b) Treatment: emergency open reduction with evacuation of the intracapsular hematoma and screw fixation of the femoral neck. A-p and axial films are required during the operation

The only implant which is suitable for internal fixation of a fracture of the femoral neck is the *lag screw*, which ensures adequate stability by interfragmentary compression.

Operative procedure: The patient is placed in the supine position and the limb is draped so as to allow it to be moved freely during the operation. The *Watson-Jones* approach is used. The joint capsule is incised longitudinally and the hemarthrosis, which is usually under pressure, is evacuated and rinsed out. The fracture is reduced with the aid of a periosteal elevator applied gently to the proximal fragment combined with appropriate traction, and internal rotation of, the extremity. The fracture is then temporarily stabilized with *Kirschner* wires and the reduction is checked at the level of the calcar. The fracture is then fixed permanently with cancellous bone screws fitted with washers. The screw thread should obtain its hold exclusively in the proximal fragment and the screw should never be allowed to cross the epiphyseal plate of the femoral head. The number of screws is determined by the size of the femoral neck. A radiological check is carried out during the operation (a-p and axial [*Dunn-Rippstein*] views of the hip as shown in Fig. 6). The joint capsule is closed with catgut (Fig. 7).

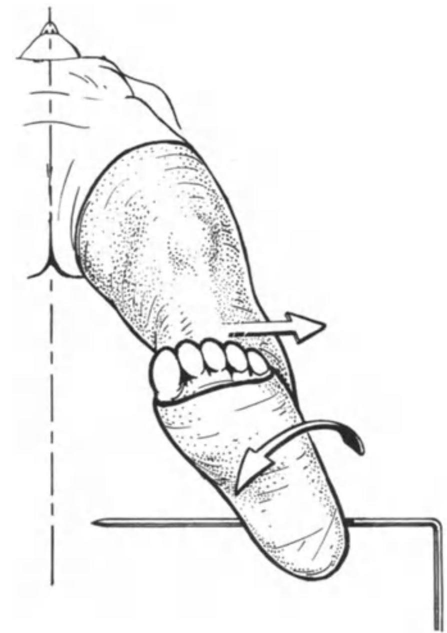


Fig. 8. *Postoperative positioning of the leg*. The leg is placed in slight abduction and internal rotation and fixed with a long leg cast with a transverse bar. Immobilization for 2 weeks is followed by active mobilization

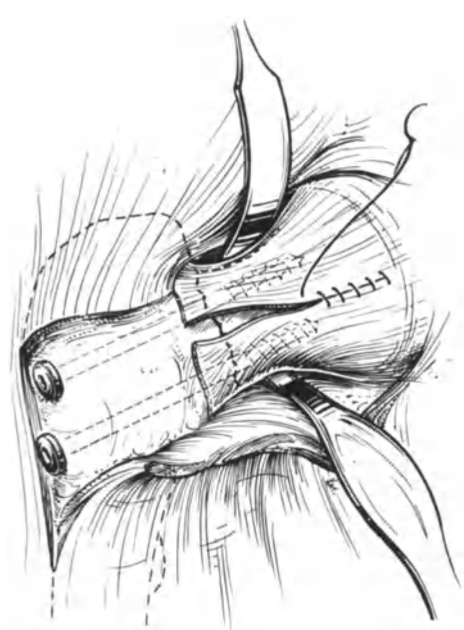


Fig. 7. *Final stage of the operation*. Following reduction of the fracture and screw fixation, the joint capsule is partially sutured; the lateral part is kept open to drain and decompress the joint cavity

Postoperative management: A padded below-knee cast with a transverse bar is applied with the leg in 10°–15° internal rotation and slight abduction (Fig. 8); this prevents adhesion of the joint capsule in external rotation. After 2 weeks, the cast is removed and active mobilization of the patient is begun without weight bearing. A *Thomas* weight-relieving caliper is then worn for 8–10 months, i.e., until there is less probability of necrosis of the femoral head. In order to detect necrosis, radiological checks are carried out at 3, 6, and 12 months; roentgenograms of the intact side are always made for comparison. The metal is removed after 12 months.

If severe accompanying injuries prevent emergency surgery from being carried out on the fractured hip, punction of the hemarthrosis is necessary and temporary traction is applied with a supracondylar *Steinmann* pin. As soon as the condition of the child has improved, the hip is operated on as described above.

3.1.3 Trochanteric Fractures (Type IV)

3.1.3.1 Pathological Anatomy (Fig. 9)

This type of fracture very rarely occurs in children, since the narrow femoral neck breaks more readily than the stout trochanter. The fracture line usually runs between the greater and lesser trochanters and thus lies outside the joint. The blood supplies to the femoral head and neck are not affected and avascular necrosis is therefore unlikely to occur.

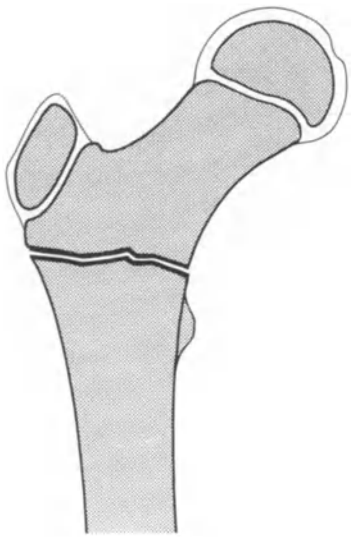


Fig. 9. *Type IV intertrochanteric fracture*. A rare type of fracture. The patient is usually a small child

3.1.3.2 Treatment

Operative Treatment: The aim of treatment is anatomically precise reduction followed by stabilization until fracture healing has taken place. This aim is best fulfilled by open reduction and stabilization.

Operative procedure: A longitudinal incision is made over the hip and the vastus lateralis muscle is partially freed and retracted. The fracture is reduced, and stabilized with *Kirschner* wires inserted through the greater trochanter. The ends of the *Kirschner* wires are bent over and a cerclage wire is looped around them and anchored to the proximal femur so as to create a tension loop (Fig. 10).

Postoperative management: Hip spica for 5 weeks, followed by bed rest for a further 2–3 weeks. Mobilization after a total period of 7–8 weeks.

Fig. 10a–d. *Internal fixation of an intertrochanteric fracture.*
a) Technique of internal fixation: anatomically precise reduction, transfixation with *Kirschner* wires, and tension-band wiring of the pelvitrochanteric muscles to the shaft of the femur.
b) B.E., ♀, aged 3 years, No. 202213. A road traffic accident (the child ran into a car) caused cerebral concussion and this left-sided intertrochanteric fracture of the femur.
c) Treatment: emergency, anatomically precise, open reduction followed by *Kirschner* wire transfixation and tension-band wiring.
d) Normal anatomical appearance 7 months after the accident

3.2 Fractures of the Greater and Lesser Trochanters

3.2.1 Pathological Anatomy (Fig. 11)

Fractures of the greater or lesser trochanters are of the avulsion type and result from sudden excessive contraction of the gluteus medius, gluteus minimus, or iliopsoas muscle against resistance. They mainly occur during sports (*Breitner*). The traction of the muscle almost always causes severe dislocation of the avulsion fragment. Direct violence is a less common cause of fracture of the greater trochanter, and it frequently causes concomitant lateral fracture of the femoral neck (Fig. 12).

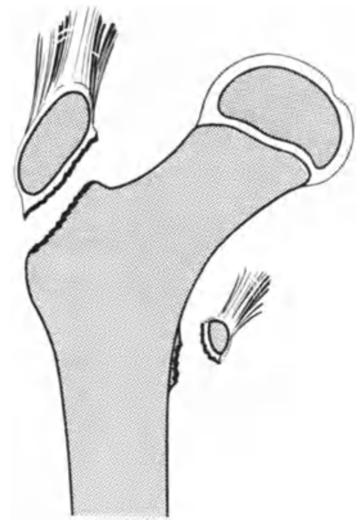


Fig. 11. *Avulsion fracture of both trochanters.* These are simple apophyseal separations

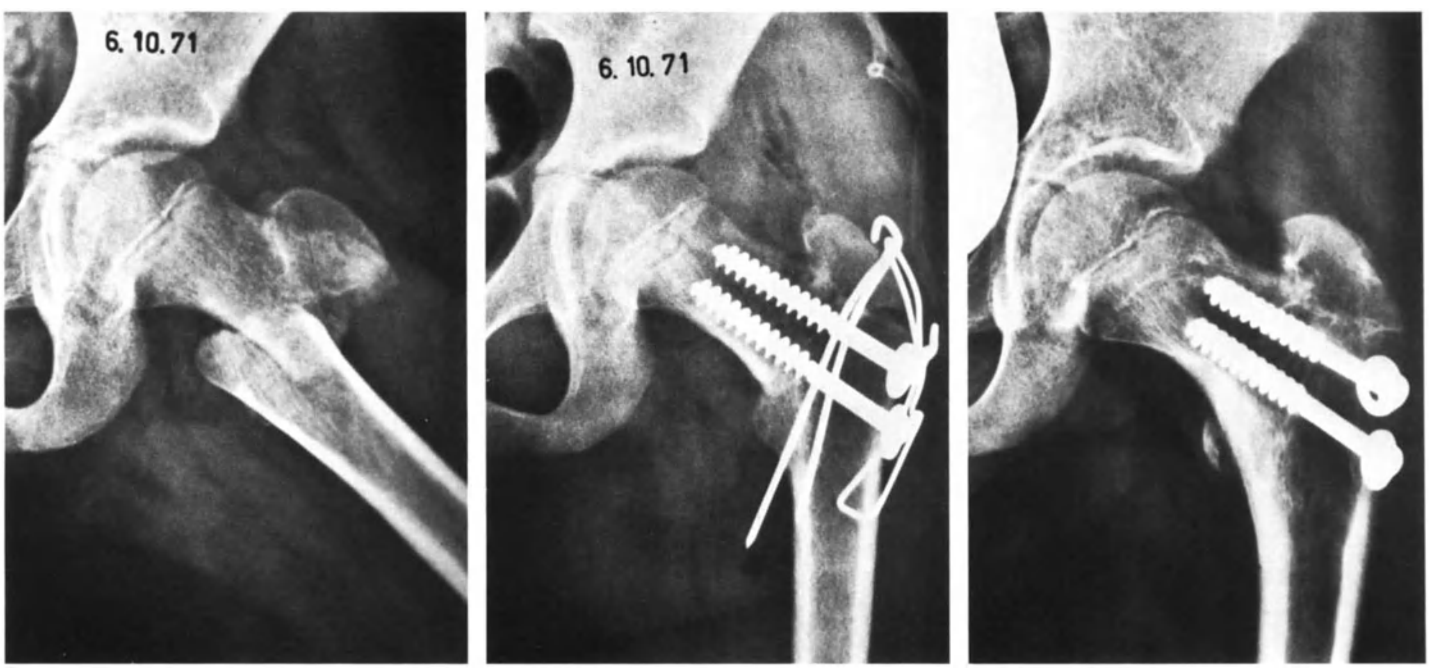
3.2.2 Treatment

Nonoperative Treatment: Avulsion fractures of the greater or lesser trochanters which are only slightly dislocated are treated nonoperatively.

Immobilization: a) Greater trochanter: A plaster boot with a transverse bar is applied so as to keep the leg in abduction and thus reduce the tension on the gluteus medius and gluteus minimus muscles. b) Lesser trochanter: A plaster boot with a transverse bar is applied, but the leg is immobilized without abduction.

Duration of fixation: 4–5 weeks, followed by mobilization with crutches. Partial weight bearing for a total of 6 weeks.

Operative Treatment: Greater degrees of dislocation of the greater or lesser trochanters require operative reduction and fixation. These fractures heal with no serious sequelae following nonoperative treatment, but the latter involves subjecting the child to several weeks bed rest in an unphysiological position.



a b c

Fig. 12a–c. *Lateral fracture of the femoral neck with separation of the greater trochanter.* K.P., ♀, aged 8 years, No. 152998.
a) Lateral fracture of the femoral neck combined with avulsion fracture of the greater trochanter.
b) Emergency open reduction and internal fixation (lag screw fixation of the lateral fracture of the femoral neck and tension-band fixation of the avulsed greater trochanter.
c) 4 months after the accident, following removal of the tension-band implants. Both fractures have healed

a b

Fig. 13a, b. *Avulsion fracture of the lesser trochanter.*
a) T.S., ♂, aged 14 years, No. 70038. Severe dislocation of the lesser trochanter.
b) W.G., ♂, aged 14 years, No. 191108. An analogous case (6 months following internal fixation). The trochanter was fixed with a wire loop which was pulled through the shaft of the femur and fixed with a screw

a) Greater trochanter: the trochanteric fragment is reduced and is then fixed with *Kirschner* wires which are introduced from the proximal side. It is then further secured with a cerclage wire which is laid around the ends of the *Kirschner* wires and anchored in the shaft of the femur so as to create a tension loop.

b) Lesser trochanter: The trochanteric fragment is fastened with a cerclage wire which passes through transverse drill holes in the shaft of the femur; the ends of the wire are secured on the lateral side with a screw (Fig. 13).

Postoperative management: Bed rest for 4 days followed by mobilization with crutches. Partial weight bearing for 4 weeks. Removal of the metal after 1 year.

3.3 Subtrochanteric Fractures

3.3.1 Pathological Anatomy (Fig. 14)

Here the fracture line transects the bone just distal to the lesser trochanter. The fractures at this level are almost always dislocated, but the medial periosteum may be intact and simply peeled off the bone (Fig. 15). The gluteus medius, gluteus minimus, iliopsoas, and small external rotator muscles pull the proximal fragment into abduction, flexion, and external rotation. The fragment is therefore considerably foreshortened on the roentgenogram. Awareness of the tendency of this type of fracture to dislocate in this manner is of practical importance in treatment.

3.3.2 Treatment

Nonoperative Treatment: Nonoperative treatment may be tried if the periosteum is intact on the medial side. The periosteum resists traction, and the fracture is more or less stable following reduction (Fig. 16).

Immobilization: Traction is applied to the fractured limb with a supracondylar *Steinmann* pin, and adhesive plaster traction is applied to the intact leg. The

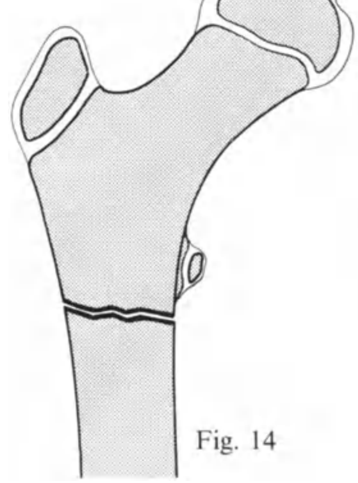


Fig. 14

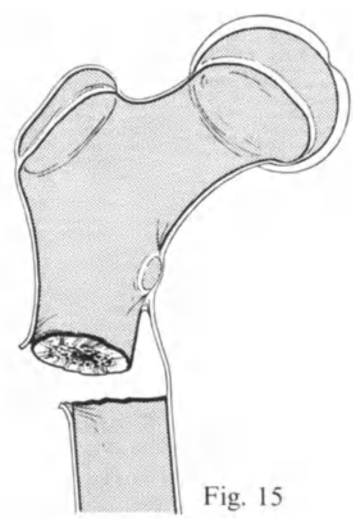


Fig. 15

Fig. 14. *Subtrochanteric fracture (usually transverse)*

Fig. 15. *Angulation of the proximal fragment.* The fracture is frequently transverse and dislocated, with intact periosteum on the medial side and varus, flexion, and external rotation deformity

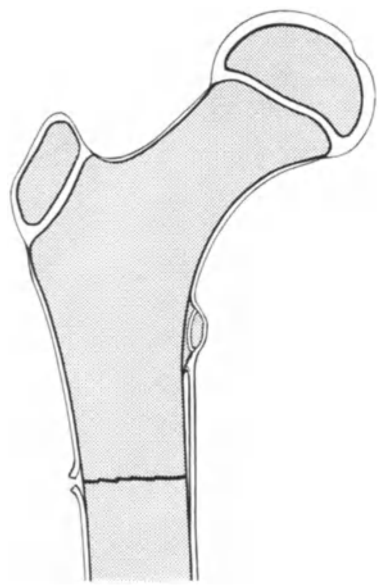


Fig. 16. *Reduced subtrochanteric fracture*. Following reduction, the fracture resists valgus stress, since the medial periosteum prevents lateral displacement. The fracture is subsequently treated on the *Weber* traction frame

patient is positioned with the hips in abduction and flexed at 90° on a *Weber* table (see chapter on fractures of the shaft of the femur). The rotation position of the leg is the most important factor at this stage. A radiological check is carried out after 3 days and any rotation error is corrected. Operative stabilization must then be carried out if the position of the leg is unsatisfactory.

Duration of traction: 4–5 weeks, followed by bed rest for a further 2–3 weeks.

Operative Treatment: Nonoperatively treated subtrochanteric fractures frequently unite at an incorrect angle because of the muscle pull and we therefore prefer to treat them by immediate open reduction and fixation with a small plate (Fig. 17).

Postoperative treatment: a) Small children: hip spica for 4–6 weeks followed by bed rest for a further 3–4 weeks. b) Older children: a plaster boot with a transverse bar is applied for 2 weeks, and the child is then mobilized with partial weight bearing up to the 10th postoperative week.

a b c d

Fig. 17a–d. *Internal fixation of an unstable subtrochanteric fracture*. B.E., ♀, aged 4 years, No. 96478.
a) The proximal fragment appears markedly foreshortened and is in pronounced flexion, external rotation, and abduction.
b) Following internal plate fixation. The proximal fragment is longer than it appears to be on the roentgenogram taken immediately after the accident.
c) 3 months after the accident. The fracture has healed.
d) $6^1/_2$ years after the accident. Healing is complete and the bone has recovered its normal appearance

4 Prognosis

The prognosis of a femoral neck fracture in a child is determined by the type of fracture and by the treatment. The following complications may arise.

4.1 Malunion

The most frequent type of posttraumatic deformity is varus hip, which also involves retrotorsion of the femoral neck. Until union is complete, the fragments have a tendency to go into varus as a result of muscle action. This is particularly the case in the course of nonoperative treatment, since the fracture is insufficiently stable to resist muscle pull. This type of deformity results in shortening of the leg. It also adversely affects growth, since the epiphysis of the head of the femur is no longer correctly oriented in relation to the lines of physiological pressure. On the other hand, the growth at the level of the trochanteric epiphysis remains unchanged, causing the proximal femur to become misshaped (Fig. 18). Posttraumatic coxa vara with retrotorsion is treated by intertrochanteric valgus and rotation osteotomy (*M.E. Müller*).

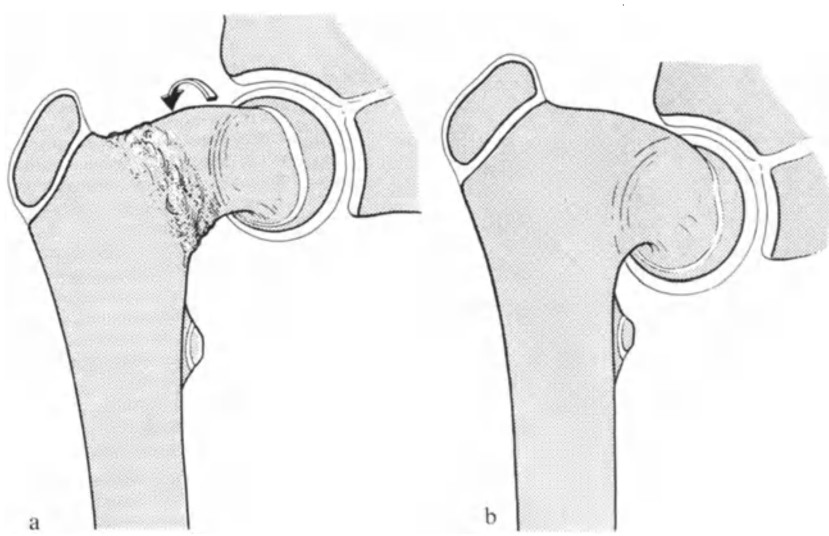


Fig. 18a, b. *Abnormal healing of a nonoperatively treated fracture of the femoral neck.*
a) The spontaneous varus angulation and retrotorsion combine to form a coxa vara retrotorta.
b) The malunion is not corrected by subsequent growth, and shepherd's crook deformity results

4.2 Necrosis of the Head of the Femur and of the Femoral Neck

Aseptic necrosis is the most serious of the complications of fracture of the femoral neck. It is directly related to disturbance of the blood supply and is thus determined by the fracture type and by the treatment.

4.2.1 Fracture Type

The distribution of the blood vessels is such that the fracture itself may interrupt the circulation to the proximal femur and the different types of fracture of the femoral neck give rise to characteristic necroses (Fig. 19).

Type I: Necrosis limited to the surface of the head which extends distally as far as the epiphyseal plate.

Type II: Necrosis of the whole of the proximal fragment.

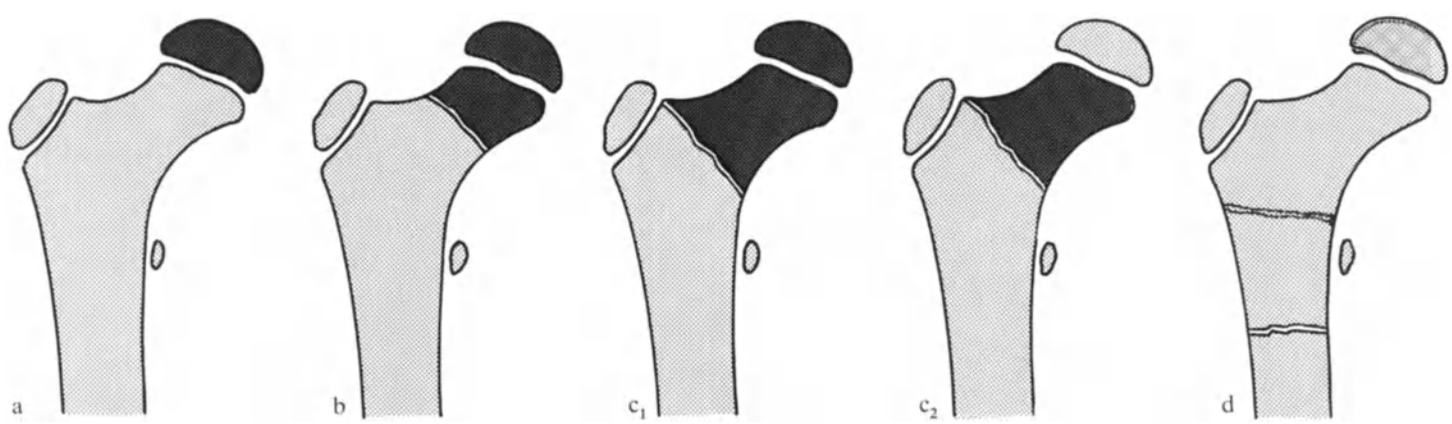
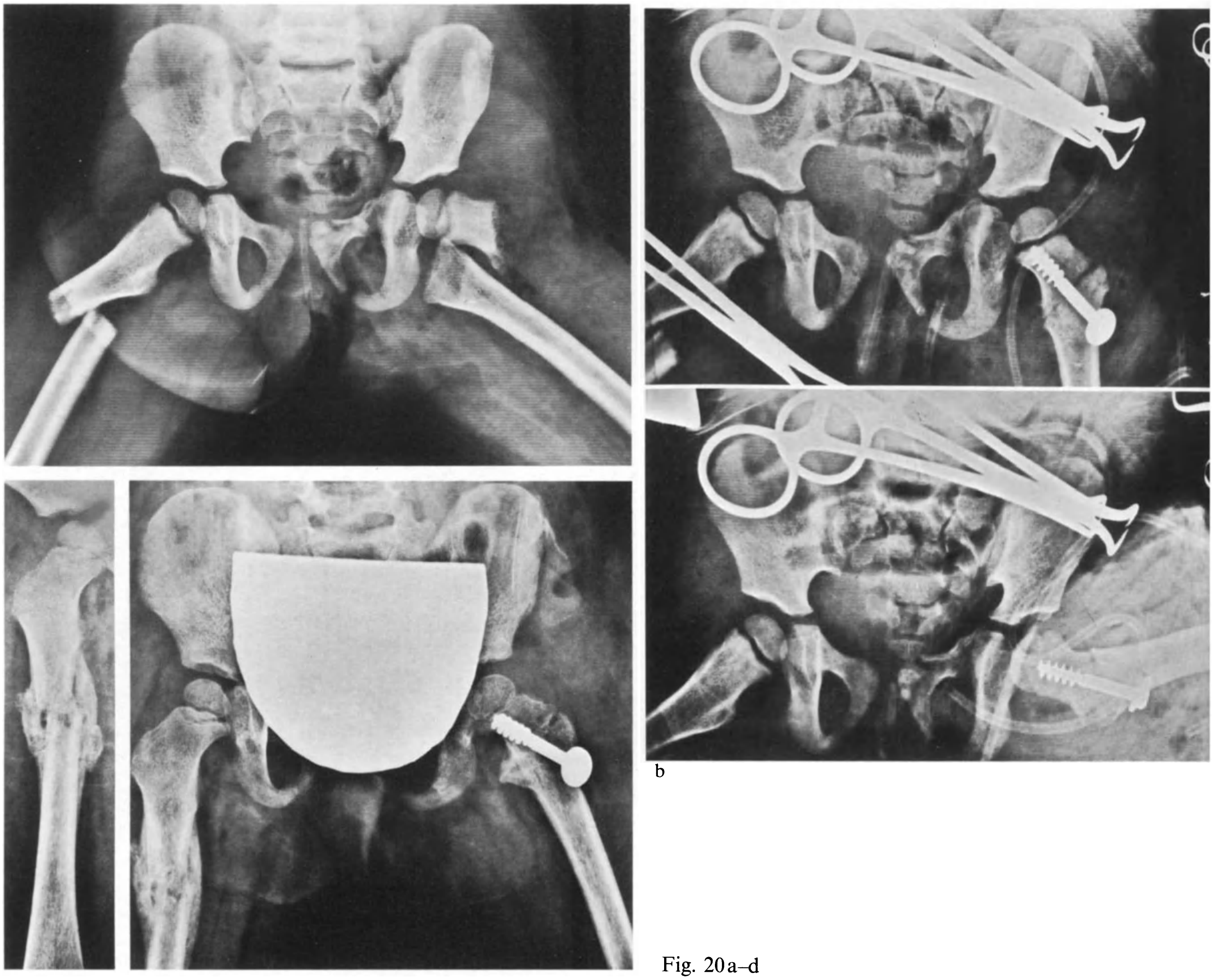


Fig. 19a–d. *Types of necrosis.*
a) Simple epiphyseal separation: results in necrosis of the proximal segment of the head.
b) Transcervical fracture: results in necrosis of the whole of the proximal fragment.
c) Basilar fracture of the femoral neck: *1.* Necrosis of the whole of the proximal fragment; *2.* Necrosis restricted to the femoral neck, leaving a viable proximal head segment.
d) Intertrochanteric and subtrochanteric fractures are not followed by necrosis



b

c d

Fig. 20a–d

Type III: Either necrosis which is limited to the femoral neck, or necrosis of the whole of the proximal fragment.

Type IV: Since the fracture is extraarticular, necrosis almost never occurs.

4.2.2 Treatment

In our opinion, avascular necrosis occurs more frequently following nonoperative treatment. The surgeon should have a clear view of the fracture during the reduction maneuver in order to avoid tearing or stretching of intact blood vessels. Furthermore, open reduction allows evacuation of the intraarticular hematoma, which interrupts the blood supply by compressing the vessels. Internal fixation by nailing is just as unsuitable as closed reduction, since it compromises the blood supply by driving the fragments apart and stretching the vessels which bridge the fracture gap.

The treatment of choice is emergency arthrotomy with relief of the tension hemarthrosis, followed by compression fixation with screws. Reduction in the nutrition of the epiphyseal plate causes abnormal growth which has serious consequences, since the rate of longitudinal growth of the femoral neck is decreased. The necrotic head of the femur becomes flattened, and this is accompanied by mirror-image changes in the acetabulum. In such cases, the continuation of normal growth in the greater trochanter leads to severe hip deformity.

e

f

g

Fig. 20a–g. *Open fracture of the femoral neck combined with a closed subtrochanteric fracture.* K.G., ♀, aged $2^1/_2$ years, No. 89771.
a) This child was run over by a truck and suffered multiple injuries, including a left-sided open (second degree) fracture of the femoral neck and a right-sided closed subtrochanteric fracture of the femur.
b) Treatment: Emergency open reduction of the left-sided fracture of the femoral neck, followed by lag screw fixation (interoperative roentgenogram). The right-sided femoral fracture was placed in traction on the *Weber* frame.
c) 5 weeks after the accident: the right-sided femoral fracture has united.
d) 9 weeks after the accident: both fractures have united.
e, f) 7 months after the accident: there is evidence of continued growth of the femoral neck and there are no signs of avascular necrosis of the head of the femur. The soft tissue injuries have healed completely.
g) $2^1/_2$ years after the accident: undisturbed growth and normal function

If avascular necrosis has occurred, the hip should be completely immobilized and weight bearing should be prevented for several months in order to optimize the chances of revascularization. If the recovery is incomplete, secondary surgical procedures, such as osteotomy, arthrodesis, or arthroplasty are usually necessary at a later date in order to improve the function of the hip.

4.3 Pseudarthrosis

Pseudarthrosis may be caused by inadequate reduction or stabilization, or by avascular necrosis. The etiology is similar to that of posttraumatic coxa vara. It can be induced to heal by transposition osteotomy using the *Pauwels* technique (*Boitzy*) (Fig. 21).

5 Results of Treatment of Fractures of the Femoral Neck

We treated a total of 11 fractures of the femoral neck in children between 1961 and 1969. They were all fresh fractures, and emergency open reduction and screw fixation were carried out in each case. This treatment resulted in full recovery in all cases and avascular necrosis, pseudarthrosis, or posttraumatic deformity did not occur. An extensive documentation of these cases can be found in the monograph by *Boitzy A.* entitled: La fracture du col du femur chez l'enfant et l'adolescent (Paris: Masson 1971).

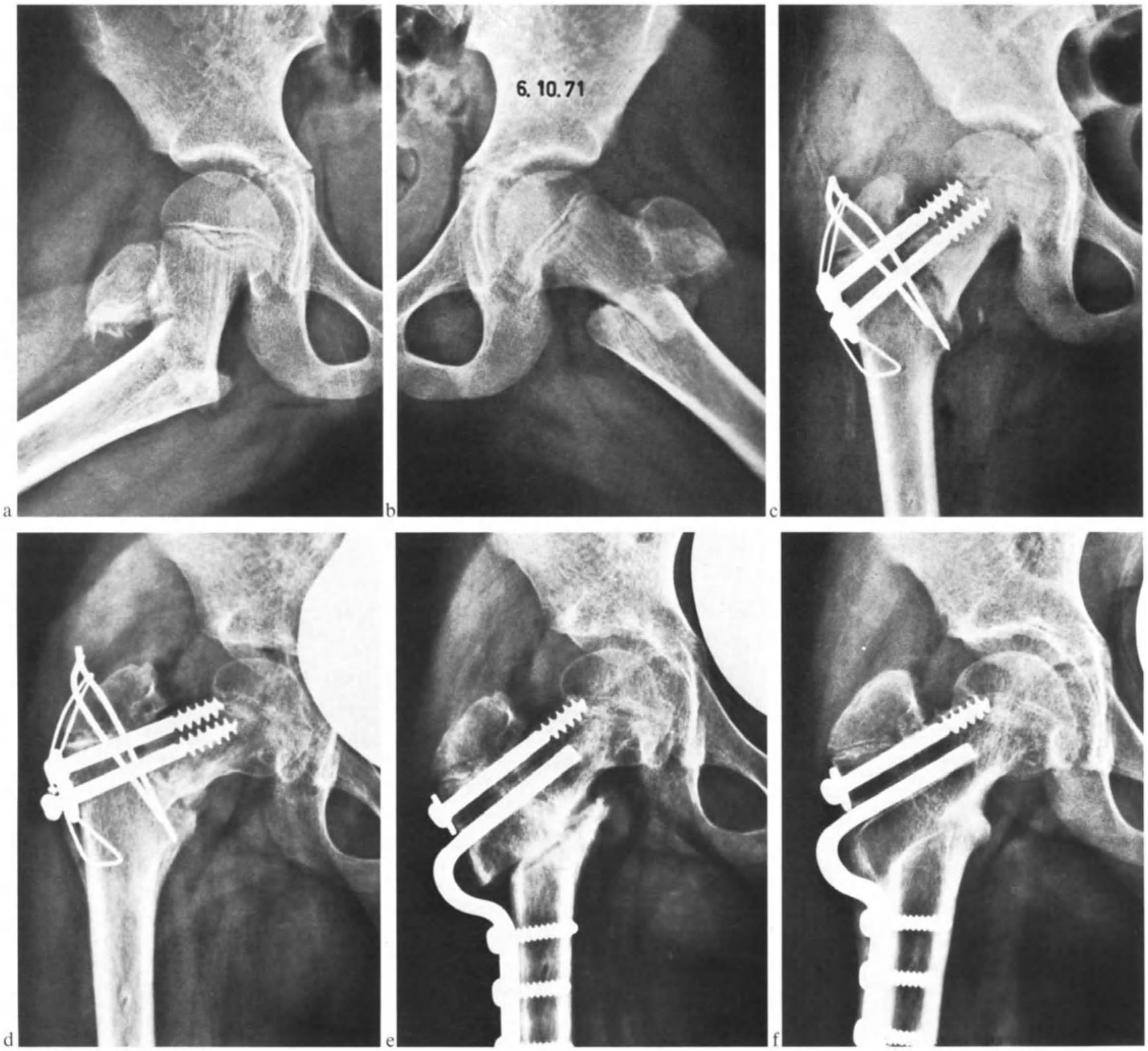


Fig. 21 a–f. *Bilateral basilar fracture of the neck of the femur with bilateral separation of the epiphysis of the greater trochanter; pseudarthrosis of the neck of the femur.* K.P., ♀, aged 8 years, No. 152998 (same case as in Fig. 12).
a, b) Bilateral basilar cervical fractures of the femur with bilateral avulsion of the greater trochanter.
a) Right femur immediately following the accident.
c) Treatment by emergency open reduction, screw fixation of the fracture of the femoral neck, and tension-band osteosynthesis of the avulsion fracture of the greater trochanter.
d) 3 months after the accident. Pseudarthrosis of the lateral part of the femoral neck has occurred as a result of partial necrosis of the bone fragments in that region.
e) Treatment of the pseudarthrosis by transposition osteotomy (*Pauwels* technique) followed by fixation with a double-angled plate.
f) 2 years and 4 months after the accident. The fracture of the greater trochanter has healed with no sequelae. The pseudarthrosis of the lateral part of the femoral neck has healed

6 Summary

Fracture of the femoral neck in a child is a rare injury, but has serious consequences. The fracture may be accompanied by tearing of the adjacent blood vessels and, in addition, intracapsular bleeding may lead to a tension hemarthrosis which further restricts the blood supply. The distribution of the blood vessels is such that this vascular damage may seriously compromise the nutrition of the proximal femur and lead to avascular necrosis. This particularly applies to fracture Types I–III. Thus, the aims of treatment are an anatomically precise reduction and stabilization of the fracture, carried out in such a manner as to prevent damage to those blood vessels which have remained intact. These aims are not fulfilled by nonoperative treatment, and blind manipulation of the fragments increases the danger of avascular necrosis. Open reduction and stabilization with suitable metal implants are mandatory. A fracture of the femoral neck in a child must be regarded as an emergency, and prompt action is imperative. The intraarticular hematoma has to be evacuated as quickly as possible, and anatomically precise reduction should be followed by fixation with cancellous bone screws. We have achieved good results using this operative approach and are enthusiastic proponents of the guidelines laid down in this chapter.

7 References

Boitzy, A.: La Fracture du col du fémur chez l'enfant et l'adolescent. Paris: Masson 1971

Breitner, R.: Sportschäden und Sportverletzungen. Stuttgart: Enke 1953.

Colonna, P. C.: Fracture of the neck of the femur in children. Amer. J. Surg. **6**, 793 (1929).

Müller, M. E.: Die hüftnahen Femurosteotomien. Stuttgart: Thieme 1957.

Müller, M. E., und Ganz, R.: Luxationen und Frakturen: Untere Gliedmaßen und Becken. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New-York: Springer 1974.

Nöh, E., Akalin, M.: Die Behandlung von Schenkelhalsfrakturen am wachsenden Skelett. Acta traumatol. **5**, 141–146 (1975).

Ratliff, A. H. C.: Fractures of the femoral neck in children. A clinical study of 120 cases. In: 10^{e} congrès international de chirurgie orthopédique et traumatologie (M. J. Delcheff, Bruxelles) Acta. med. belg. **151**, 1967.

Ratliff, A. H. C.: Traumatic separation of the upper femoral epiphysis in young children. J. Bone Jt Surg. **50** B, 757 (1968).

Tachdjian, M. O.: Pediatric orthopedics. Philadelphia-London-Toronto: Saunders 1972.

Fractures of the Shaft of the Femur

U. SAXER

CONTENTS

1 Introduction

Fracture of the shaft of the femur are frequently seen in children and are regarded as serious injuries because of the blood loss which they cause. Considerable force is required to fracture the femur, and the *accident mechanism* involves either severe *direct* violence or *indirect* leverage on the particularly vulnerable lower extremity. The type of fracture is largely determined by the type, direction, and magnitude of the force acting on the bone. Direct violence tends to cause a transverse fracture or, if considerable energy is involved, a comminuted fracture, whereas twisting forces applied indirectly to the bone cause long spiral or short oblique fractures (*Tachdjian*).

Table 1. Causes of femoral diaphyseal fractures in children (182 cases)

	Age groups (years)				
	1–4	4–7	7–10	10–13	13–16
Play	21	6	2	1	2
Sport	1	6	3	6	6
Road traffic	21	45	17	12	9
Falls	7	6	3	6	2
Totals	50	63	25	25	19

The trauma mechanisms described are most often associated with road traffic accidents, accidents occurring during play and sport, and falls from a great height (Table 1). The statistical relationship between the *causes of the accidents* and the ages of the victims is especially interesting. A particularly large proportion of the severe injuries occurring in children of preschool age result from road traffic accidents (36% of all fractures of the shaft of the femur in children). In young children, a fall caused by tripping over a carpet may suffice to fracture the femur, but the degree of violence which caused the fracture tends to increase with the age of the victim. The shaft of the femur increases in diameter in the course of growth and thus gains in strength.

Patients with fractures of the femur caused by road traffic accidents frequently have *accompanying injuries*. In our series of 182 patients, the following injuries were seen (percentages related to the total number of patients):

Head injuries (slight or moderate degrees)	29 (16%)
Severe injuries to the soft tissues of the broken leg	17 (9%)

Severe head injuries	15	(8%)
Additional fractures of the lower extremities	12	(6%)
Severe maxillofacial injuries	8	(4%)
Fractures of the upper extremities	8	(4%)
Severe abdominal injuries	5	(2%)
Severe thoracic injuries	5	(2%)
Injuries to the vertebral column	3	(1%)

Thus, in many cases, the fracture of the femur was just one of a number of injuries sustained by the patient and was not necessarily given first therapeutic priority. In order to simplify the nursing and monitoring of a multiply injured child, the treatment of the femoral fracture must be simple and rapid; it should not be allowed to obstruct other important diagnostic or therapeutic procedures.

2 Fracture Types

Fractures of the femur are classified according to their site as follows:

Fractures of the proximal third of the shaft.
Fractures of the middle third of the shaft.
Fractures of the distal third of the shaft.

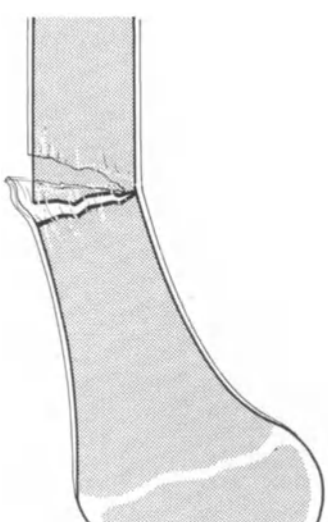


Fig. 1

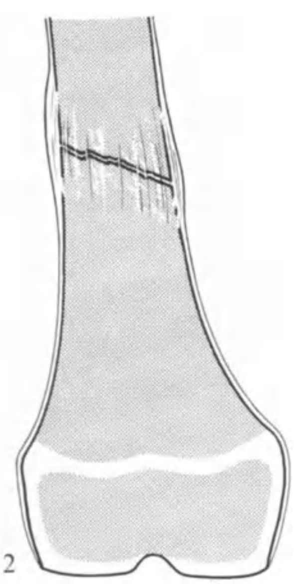
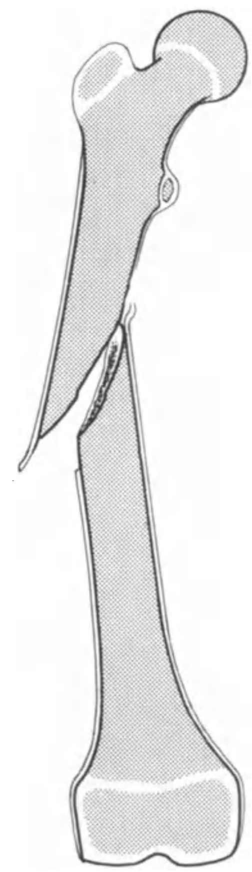


Fig. 2

Fig. 1. *Greenstick fracture*. The periosteum is torn on one side and has remained intact on the opposite side. Angulation of the bone occurs, but there is no tendency to shortening

Fig. 2. *Subperiosteal fracture*. This type of fracture occurs in young children. There is no dislocation, no tendency to shortening, and no angulation of the bone

Fig. 3. *Dislocated fracture of the shaft*. The periosteum is torn around the whole circumference and is stripped from the bone in places. The fracture is unstable and the bone tends to shorten



Of the 182 fractures in our series, 71.8% were in the middle third, 18.7% in the proximal third, and 9.5% in the distal third. These figures largely agree with others published in the literature (*Blount, Le Mesurier, Neer* and *Cadman, Staheli, Tachdjian*).

Depending on the accident mechanism, the fracture may be of the *greenstick* type, *subperiosteal*, or *dislocated*.

Greenstick fractures (Fig. 1): In young children, the bone is very resilient and the periosteum is thick. An abnormal bending moment or a force applied directly to the bone may cause partial fracture of the cortex which is limited to one side of the bone and which is accompanied by tearing of the overlying periosteum. The opposite cortex is only bent and the overlying periosteum remains intact. This type of fracture is inherently stable and most frequently occurs in the distal third of the shaft of the femur in small children.

Subperiosteal fractures (Fig. 2): These fractures usually occur in young children. The cortex is broken, but the surrounding periosteal cuff remains completely intact. Thus, dislocation does not occur and fractures of this type are stable.

Dislocated fractures (Fig. 3): The cortex is completely fractured and, in addition, the periosteum is almost completely disrupted and is stripped off the bone for a considerable distance. Fractures of this type are

Table 2a. Types of femoral shaft fractures (children under 7 years of age; 114 cases)

	Trans-verse	Spiral	Com-minuted	To-tals
Proximal femur	16	6	–	22
Middle of femur	34	46	2	82
Distal femur	5	4	1	10
Totals	55	56	3	114

Table 2b. Types of femoral shaft fractures (children over 7 years of age; 68 cases)

	Trans-verse	Spiral	Com-minuted	To-tals
Proximal femur	3	4	5	12
Middle of Femur	18	15	16	49
Distal femur	4	2	1	7
Totals	25	21	22	68

unstable and considerable shortening frequently occurs. The dislocation is determined by the pull of the attached muscles and thus depends on the level of the fracture, i.e.:

Proximal third of the shaft: the proximal fragment is flexed by the iliopsoas muscle, and drawn into abduction and external rotation by the gluteal muscles. The distal fragment is pulled proximally and medially by the ischiocrural muscles and by the adductors. The severity of the dislocations described is inversely proportional to the length of the proximal fragment (*Tachdjian*).

Middle third of the shaft: no hard and fast rules apply to fractures at this level, since the forces exerted by the attached muscles balance each other almost completely.

Distal third of the shaft: the main dislocation is that of the distal fragment, which is tilted backwards by the pull of the gastrocnemius muscle. This type of fracture may therefore be accompanied by injury to the adjacent vessels or nerves.

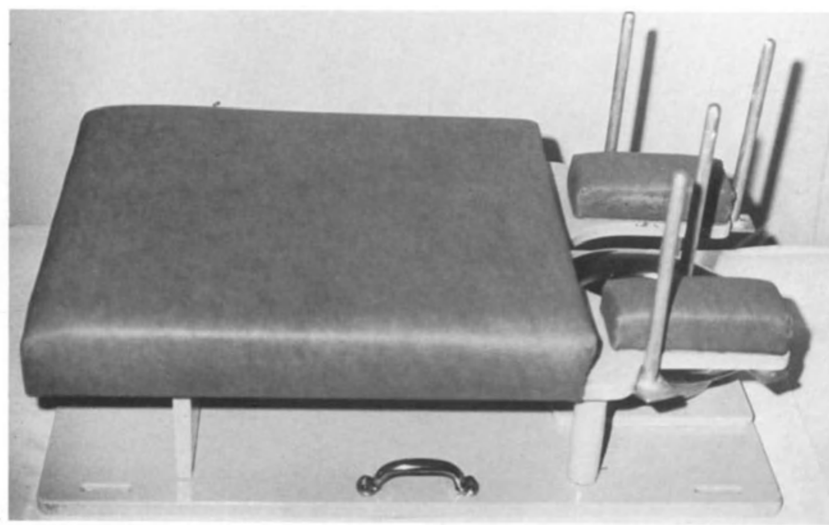
The fractures diagnosed in two different age groups are summarized in Tables 2a and 2b. In small children, transverse or spiral fractures of the middle third of the shaft are particularly common and usually result from direct violence. Comminuted fractures are seen more frequently in older children, and the accident mechanisms involved are more complicated.

3 Treatment

3.1 Nonoperative Treatment

In common with other diaphyseal fractures in children, those of the femur heal under nonoperative treatment within 3–6 weeks. The exact period is determined by the skeletal age of the child. The complications seen in adults, such as joint stiffness, prolonged muscle atrophy, and *Sudeck's* dystrophy hardly ever occur in children. In accordance with the general principles of management of diaphyseal fractures in children, internal fixation of femoral shaft fractures should always be avoided if the alternative nonoperative treatment can be expected to fulfill the following criteria:

a) Union of the fracture with slight shortening (overriding of the fragments by approximately 2 cm).
b) Minimum possible angular deformity in all planes.



a

b

Fig. 4a, b. *Special frame for nursing patients with a double hip spica.*
a) The frame is mounted on a flat board.
b) The design of the board is such that the child can be placed prone or supine. Nursing is simplified by the provision for simple removal and replacement of the bedpan under the frame

c) Elimination of rotation deformity, and fixation in such a manner as to prevent the latter from recurring.

Furthermore, since the child will remain in hospital for several weeks, the method of treatment should facilitate simple, safe nursing care. The method of treatment is determined by the fracture type (greenstick, subperiosteal, or dislocated) and, in the case of a dislocated fracture, by the age of the child.

3.1.1 Greenstick Fractures and Subperiosteal Fractures

Greenstick fractures with severe angulation have to be reduced under general anesthesia by completely fracturing the largely intact cortex. A subperiosteal fracture can be fixed without prior reduction.

Immobilization: A *long bilateral hip spica* is applied and the patient is nursed on a special table (Fig. 4). The lightly padded circular cast extends from the xiphoid process down to the malleoli of both legs and covers the anterior and posterior iliac spines on both sides. The nates, perineum, and periumbilical area are left exposed. The hip and knee joints are slightly flexed, and the legs are placed in slight abduction. To improve the rigidity of the cast, a transverse wood-

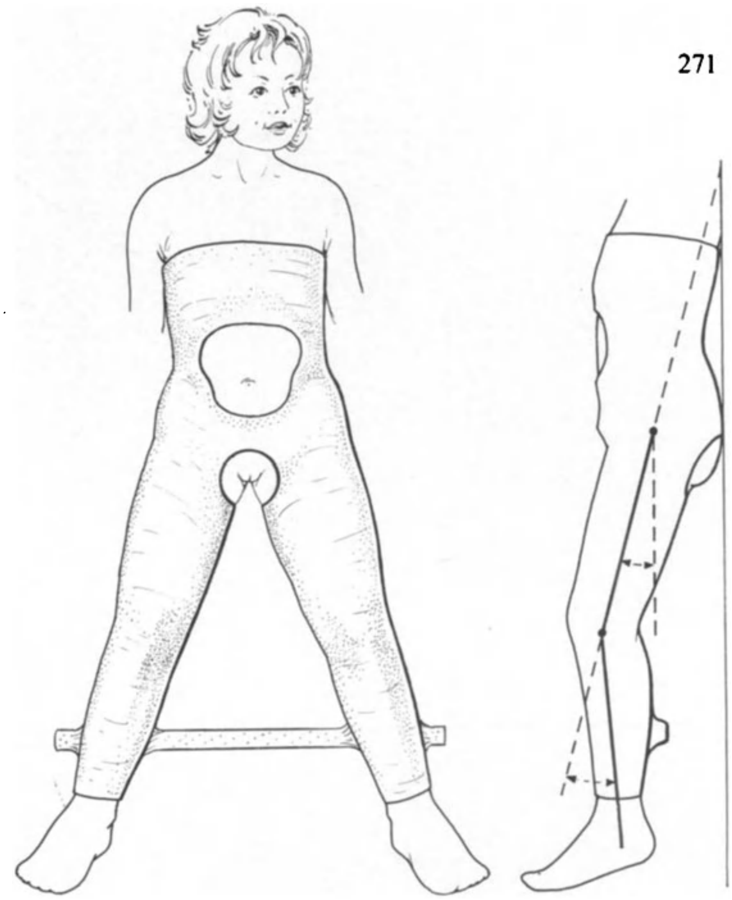
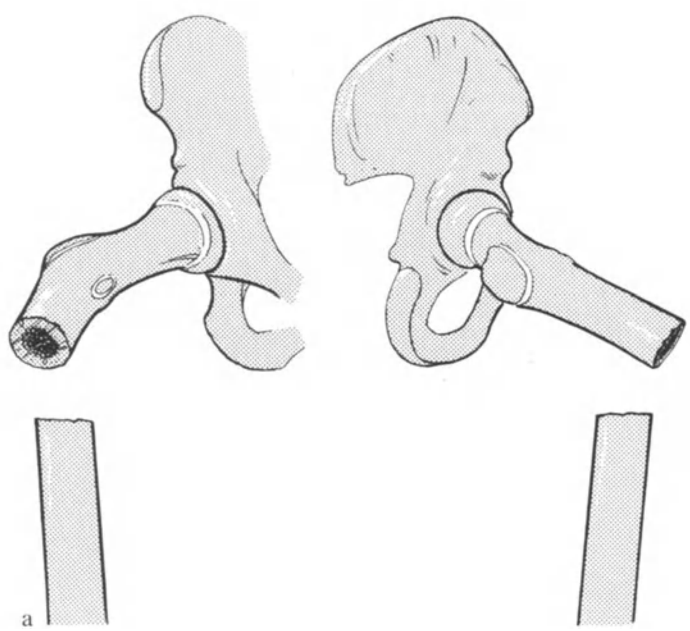


Fig. 5. *Bilateral long hip spica.* In a small child, it reaches up to the axilla and the abdomen is left free to allow respiratory movement. The legs are joined by a posterior transverse bar. The hip and knee joints are slightly flexed in order to control rotation



a

b

Fig. 6a, b. *Short proximal fragment.*
a) On the a-p roentgenogram, the proximal fragment appears to be severely shortened as it is drawn into flexion, external rotation, and abduction by the pull of the attached muscles. In the lateral view, the true length of the proximal fragment becomes apparent.
b) B.E., ♀, aged 4 years, No. 96478. Typical dislocation with extreme flexion, abduction, and external rotation deformity

a

b

Fig. 7a, b. *Severe residual rotation deformity following nonoperative treatment.* F.R., ♂, aged 7 years, No. 96284.
a) One year after fracture of the femoral shaft. The deformity seen in the a-p and lateral films is acceptable for this stage of healing. The films do not allow assessment of malrotation.
b) The rotation films (*Dunn-Rippstein* technique) show 40° malrotation

en bar is applied dorsally (Fig. 5) (*Freuler, Wiedmer,* and *Bianchini*). A bilateral hip spica simplifies nursing and stabilizes the fracture to a greater degree than a cast which only encloses the fractured leg.

Duration of fixation: 4–6 weeks. The fracture is checked radiologically and the child is then mobilized in the usual manner.

3.1.2 Dislocated Fractures

The great majority of diaphyseal fractures of the femur in children show considerable dislocation. If the proximal fragment is short, it is frequently pulled into flexion, external rotation, and abduction by the attached muscles (Fig. 6). Interposed soft tissues seldom prevent reduction of the fracture since they can usually be extracted by closed manipulation. On the other hand, the detection and elimination of torsional deformity is less straightforward. The proximal fragment, which is deeply embedded in soft tissue, is relatively mobile, and its position about the vertical axis is more or less randomly determined by muscle pull. The angle between the femoral neck and the frontal plane cannot be determined clinically or from a roentgenogram of the fracture itself. Since the rotational deformity is not corrected by subsequent growth, it is essential that it be eliminated during the initial management of the fracture, but this is not possible using the conventional methods of nonoperative treatment (plaster cast, traction). The assessment of angular deformity

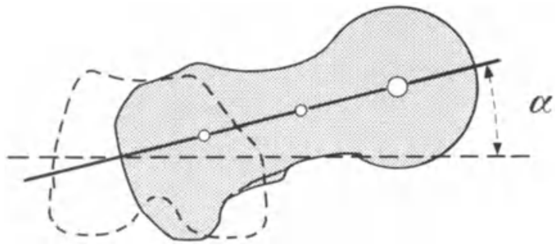


Fig. 8. *Anteversion*. The angle between the long axis of the femoral neck and the transverse axis of the femoral condyles (shown here in a vertical projection) is the anteversion angle of the femoral neck. This angle corresponds to the torsion of the femur about its long axis

is relatively easy, but femoral torsion is much more difficult to detect, as shown by the number of cases in which the antetorsion angles of the fractured and intact sides differed by up to 40° (Fig. 7) (*Von Tobel, Weber*).

The torsional angle of the femur (Fig. 8) is assessed radiologically using the method of *Dunn* and *Rippstein* (Figs. 30 and 31). One of the views, which shows the proximal femora in axial projection, is used to check rotational alignment during treatment by traction (Fig. 11).

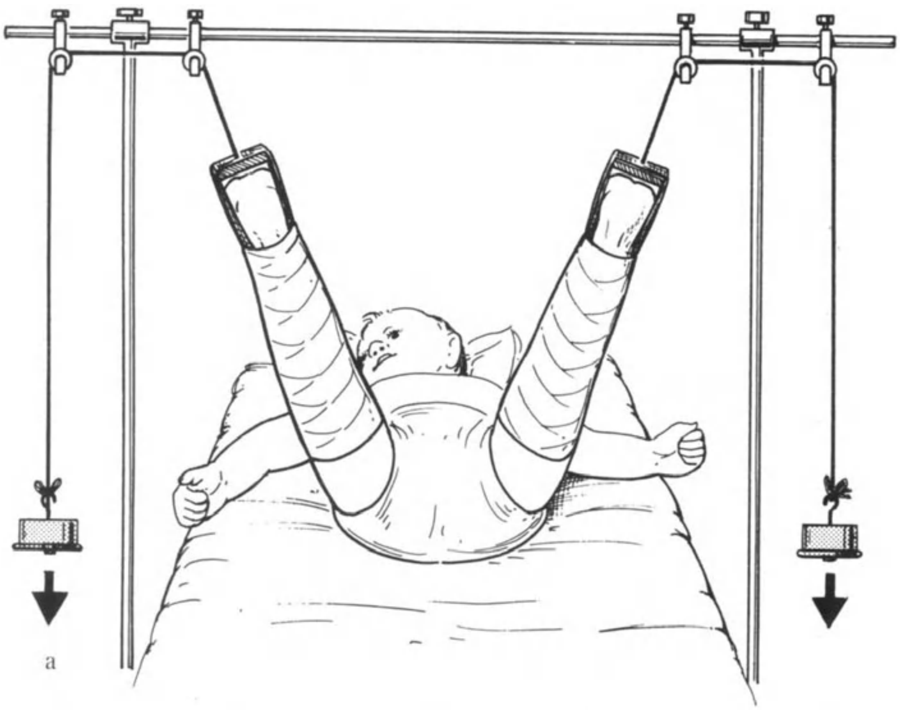
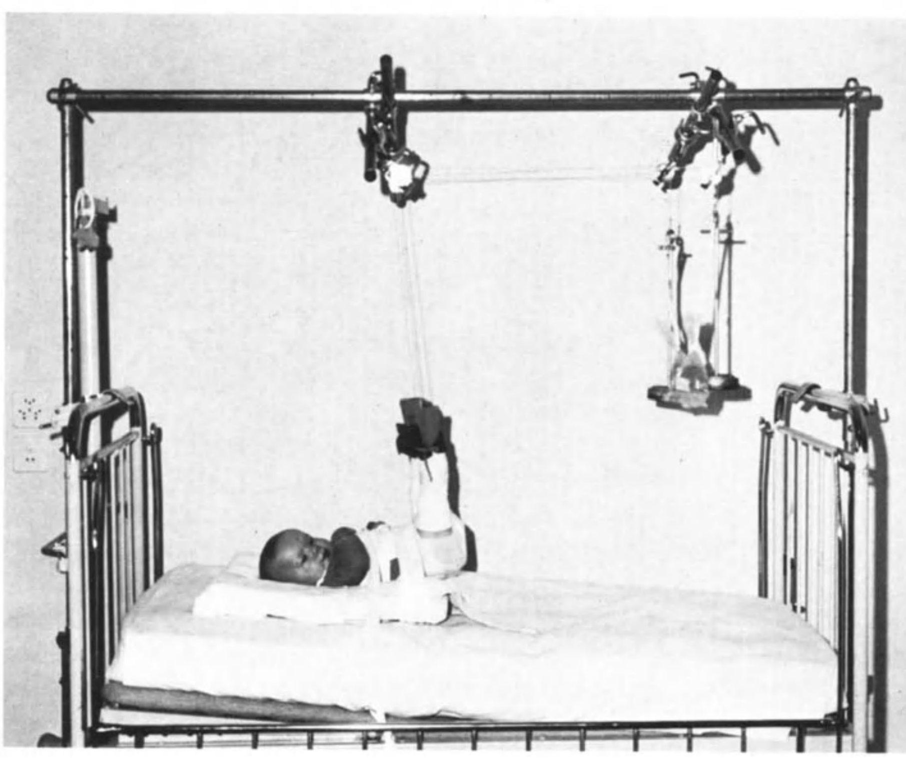
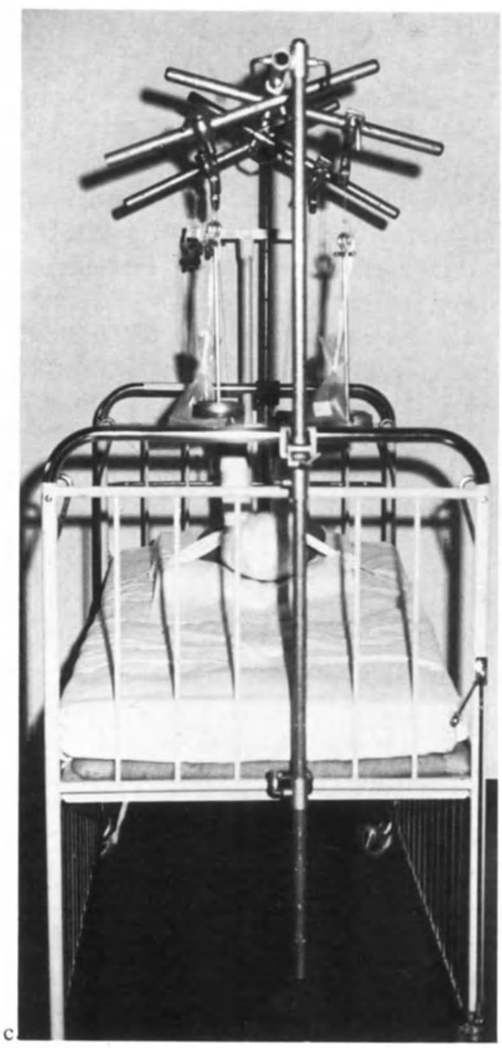

a

Fig. 9a–c. *Overhead traction by the Bryant method.*
a) Slight splaying of the legs, free rotation, 90° hip flexion. Traction weight per leg = $^1/_4$ of the body weight.
b, c) A patient in *Bryant* traction


b


c

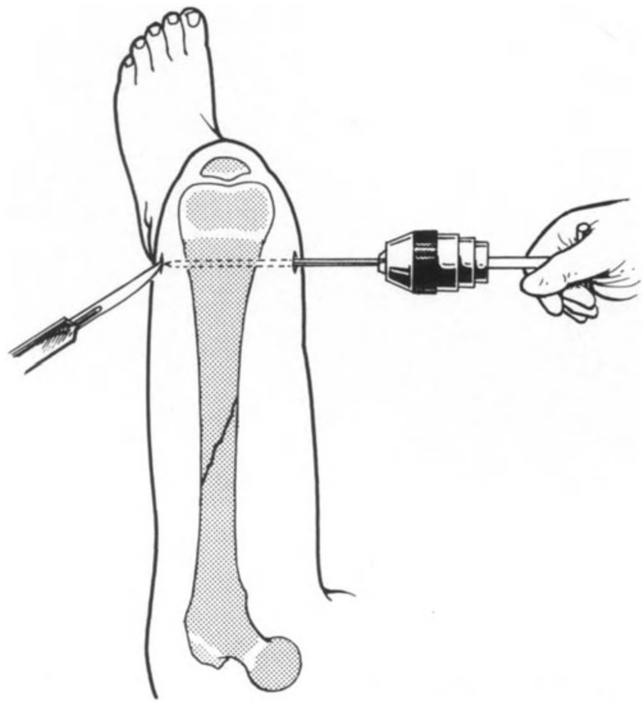


Fig. 10. *Insertion of the Steinmann pin.* A stab incision is made and the pin is inserted at right angles to the femoral diaphysis, one- to two-finger breadths proximal to the distal epiphyseal plate of the femur. The pin is drilled in with the hand chuck. A stab incision is made at the point of exit

3.1.2.1 Dislocated Fractures in Children up to 2 Years of Age

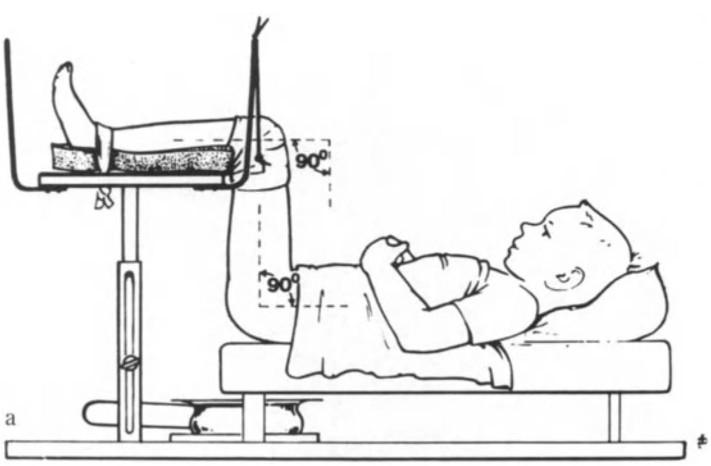
Overhead Traction by the Bryant Method (Fig. 9): Technique: U-shaped adhesive strips are applied to both legs, followed by elastic bandages. The traction cords are attached to wooden spacer blocks which spread the adhesive bandages under the soles of the feet. Vertical traction is applied with the legs slightly splayed. Weights are chosen which just lift the buttocks from the bed. In addition, the upper part of the trunk should be bound to the bed with a calico belt (*Freuler, Wiedmer,* and *Bianchini*).

Subsequent treatment: Fractures in small children unite very rapidly, and a radiological check should therefore be carried out within the first 2–3 days. Shortening of 1–1.5 cm at this stage may be neglected, since acceleration of longitudinal growth can be expected to occur. The traction and the circulation, sensation, and active movement of the toes should be checked daily. The children rapidly become accustomed to the unusual posture, and the traction technique does not cause nursing problems. The traction can be discontinued after 2–3 weeks and bed rest is then continued for 1–2 weeks. No further treatment is necessary.

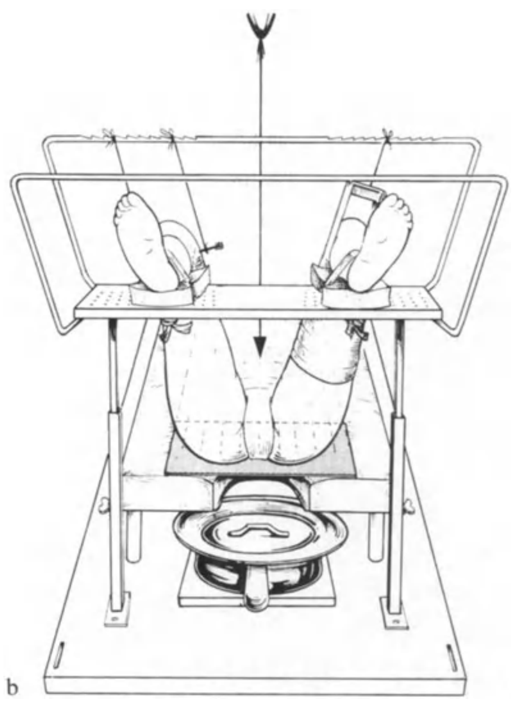
3.1.2.2 Dislocated Fractures in Children Between 2 and 12 Years of Age

Vertical Traction by the Weber Method: This technique allows easy correction of axial and rotational deformity and also greatly simplifies nursing care (*Freuler, Wiedmer,* and *Bianchini*).

Technique: General anesthesia is required, together with strict antiseptic and aseptic precautions. The skin is displaced during flexion and this in turn creates tension around the points of entry and exit of the traction pin, so an assistant holds the fractured leg in the position in which it will subsequently be main-



a



b

Fig. 11a, b. *Weber traction frame.* The knee and hip joints are positioned at right angles with both femora in 20° abduction and the lower legs parallel to each other, i.e., symmetrical rotation of the distal femora. This position allows the torsional alignment of the fracture to be checked radiologically. The axis of the X-ray beam is shown in the second sketch

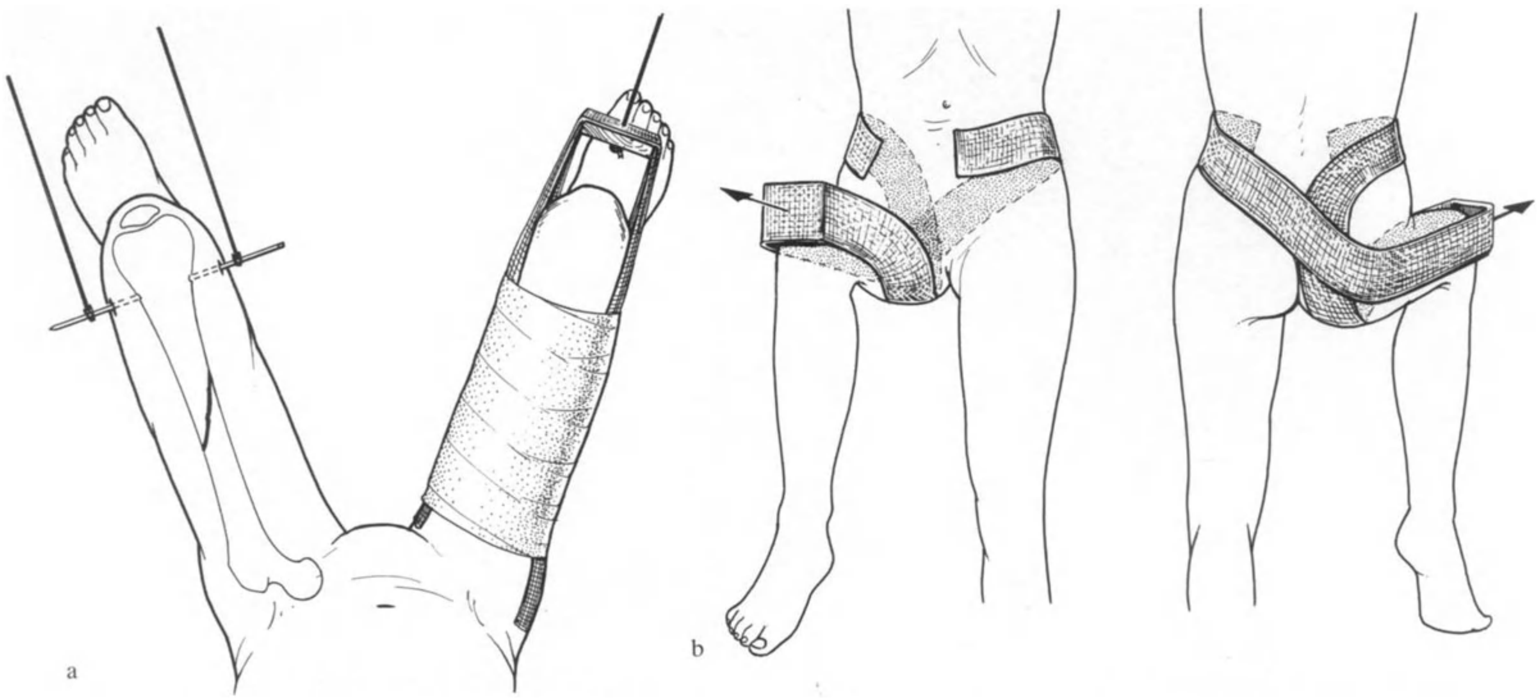


Fig. 12a, b. *Traction technique*.
a) Traction is applied to the fractured femur with a *Steinmann* pin and to the intact femur by means of adhesive plaster.
b) Application of the adhesive plaster traction bandage. Starting at the iliac crest on the intact side, the bandage passes over the buttock without entering the median cleft, along the medial side of the thigh, over a square plate with a central hole, back along the lateral side of the thigh, and over to the iliac crest on the opposite, fractured side. In this manner, the rather short attachment is secured medially by the crossed posterior band which pulls on the opposite side. An elastic bandage is applied over the adhesive plaster

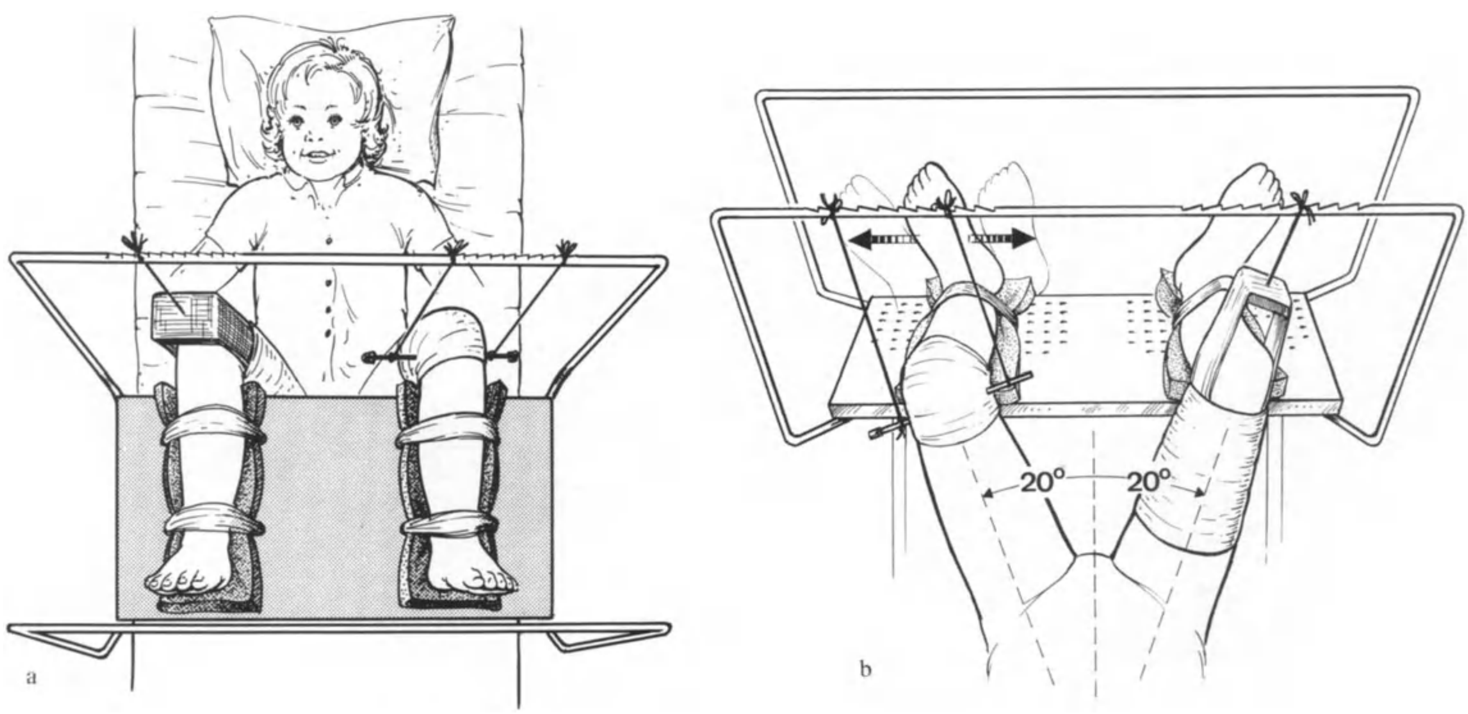


Fig. 13a, b. *Parallel positioning of the lower legs*.
a) The lower legs are placed parallel to each other in grooved foam rubber pads on the traction table. The foam rubber pads and legs are secured with calico loops which pass through holes in the table.
b) The position may be corrected by moving the leg through an arc (shown on the fractured side)

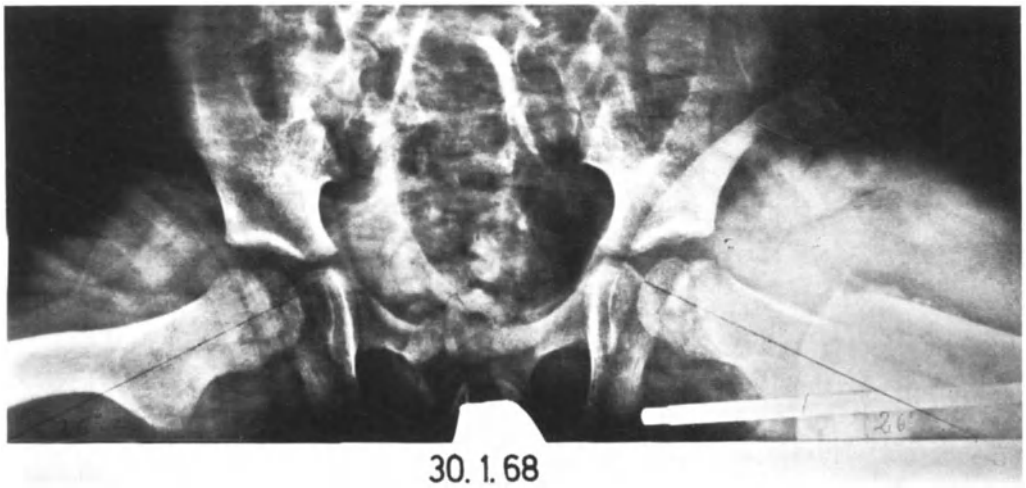


Fig. 14. *Radiological assessment of femoral torsion.* The film cassette is placed under the buttocks. The X-ray beam is centered on the symphysis (see Fig. 11b). The femoral neck is shown in *Dunn-Rippstein* projection. This example shows projected angles of 26° on both sides, i.e., the fracture fragments are not malrotated

tained by traction, i.e., with the hip and knee joints flexed at right angles and the thigh in 20° abduction. A stab incision is made on the medial side and a 4.5 mm supracondylar *Steinmann* pin is drilled in at right angles to the long axis of the femur (Fig. 10). The hand chuck is used to insert the pin, since a power drill would cause thermal damage to the bone and soft tissue. The child is then placed on a special traction table (Fig. 11) and the legs are suspended symmetrically; the fractured leg by traction applied to the *Steinmann* pin and the intact leg by adhesive plaster traction (Fig. 12). The traction should just suffice to lift the buttocks off the table with the hip and knee joints flexed at right angles and the thighs in 20° abduction. The lower legs are placed parallel to each other in two short foam rubber splints (Fig. 13). This ensures that the axes of the knees and the femora are positioned symmetrically, so that any rotation error is now limited to the proximal fragment. After setting up the traction, the general anesthesia is maintained and roentgenograms of the fractured femur are made in two projections so as to show the positions of the fragments and the orientation of the *Steinmann* pin. Shortening of 1–1.5 cm is desirable, since the fracture will stimulate longitudinal growth, and any ad latus dislocation which may be present is of no consequence. The precise degree of shortening which should be aimed for is given in Table 5.

Checks on the positions of the fragments: Pelvic roentgenograms are made on the third day using the method of *Dunn* and *Rippstein*, and the angles of rotation of the two proximal femoral fragments about their longitudinal axes are measured by reference to the transverse axes of the condyles of the knee (Fig. 14). These films show the hip joints and proximal femora in axial projection, and the femoral neck on each side makes an angle with the transverse axis of the corresponding knee joint. Since the knee joints are positioned symmetrically and their axes are parallel to the metal bar which appears in the projection, the latter angle corresponds to the angle of rotation of the femur.

Following *perfect* reduction, the projected angles between the femoral necks and the transverse axes of the knee joints are equal. Thus, there is no rotational deformity to correct (Fig. 15).

Imperfect reduction with residual rotational deformity manifests itself radiologically as follows (*Weber*):

a) The angle on the side of the fracture is *greater* than that on the intact side, i.e., there is an increase in the projected antetorsion angle (Fig. 16). The proximal fragment is rotated externally with respect to the distal fragment. Since the position of the proximal fragment cannot be adjusted, the deformity has to be corrected by moving the distal fragment.

Correction of the rotation error: The leg is used as a lever and is swung towards the midline through

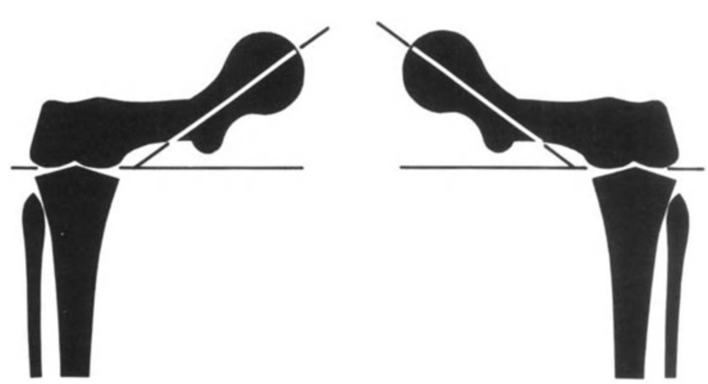
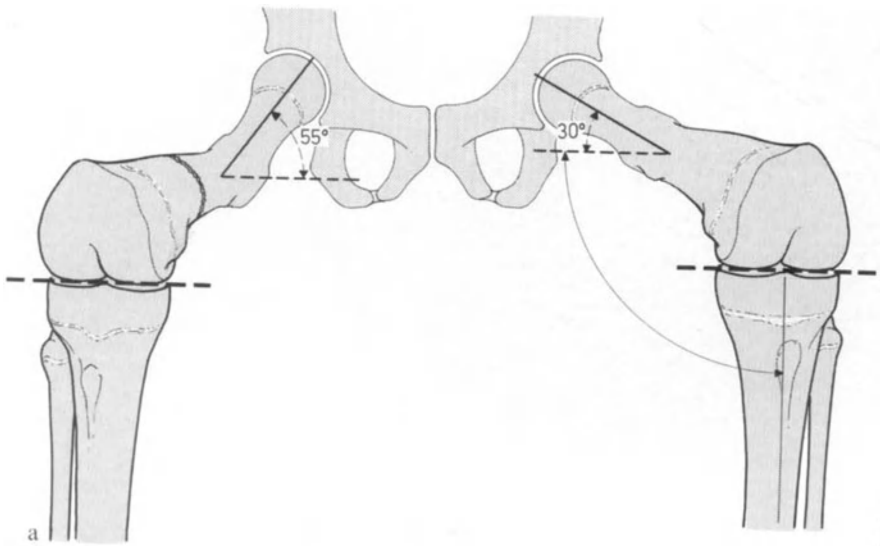


Fig. 15. *Projection of symmetrical anteversion*, i.e., correct torsional alignment of the fracture fragments



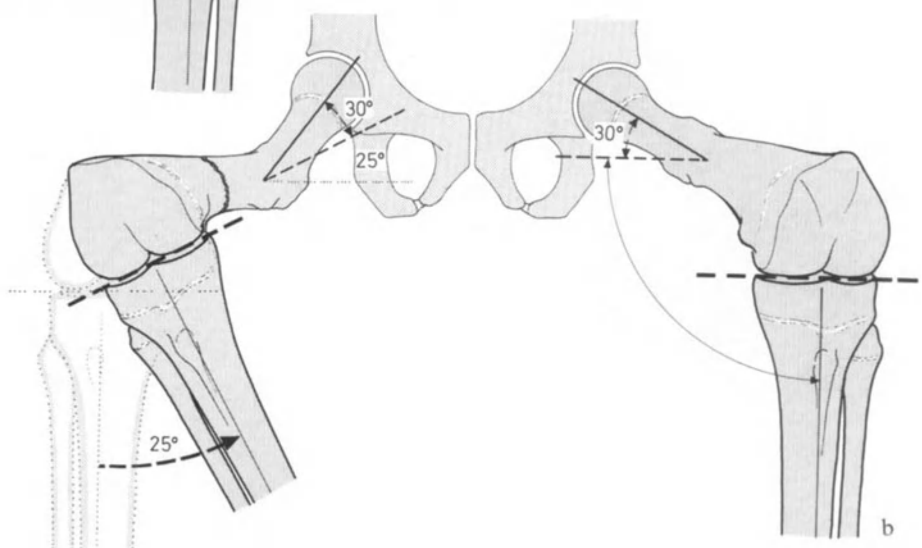
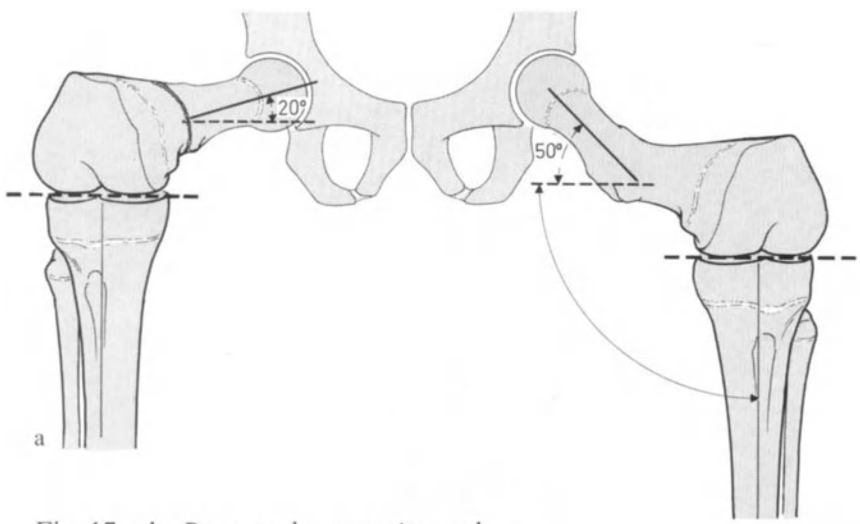


Fig. 16a, b. *Increased anteversion and its correction.*
a) On the unbroken left side, the anteversion of the neck of the femur measures 30 degrees, on the broken right side 55 degrees. This corresponds to an internal rotation of the distal fragment of 25 degrees.
b) To correct the 25 degrees of internal rotation of the distal fragment, the lower leg is rotated externally 25 degrees and fixed in that position to the fracture frame (see Fig. 13b)



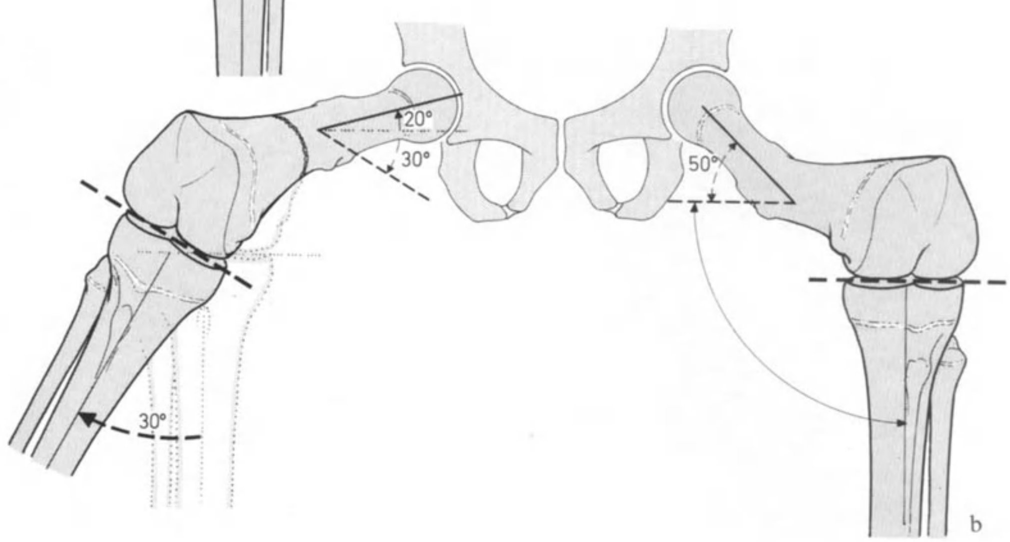


Fig. 17a, b. *Decreased anteversion and its correction.*
a) On the unbroken left side, the anteversion of the neck of the femur measures 50 degrees, on the broken right side 20 degrees. This corresponds to an external rotation of the distal fragment of 30 degrees.
b) To correct the 30 degrees of external rotation of the distal fragment, the lower leg is rotated internally 30 degrees and fixed in that position to the fracture frame (see Fig. 13b)

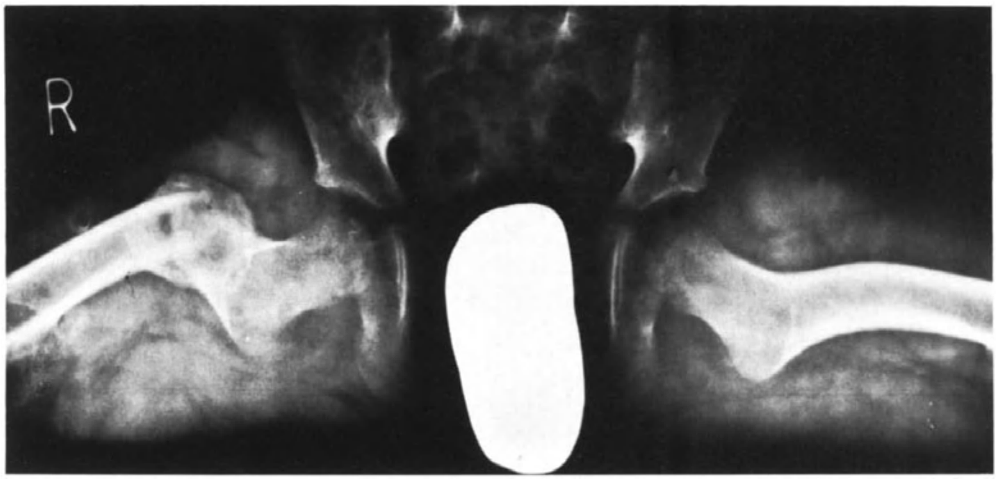


Fig. 18. *Measurement of anteversion following bone union.* This roentgenogram was made with the limbs held in the *Rippstein* positioning frame (Fig. 30). The anteversion of the femoral neck on the right side is seen to be slightly reduced when compared with the intact left side

an angle equal to the difference between the projected antetorsion angles. This maneuver rotates the distal femoral fragment *externally* (Fig. 16).

b) The angle on the side of the fracture is *smaller* than that on the intact side, i.e., the projected antetorsion angle is decreased (Fig. 17). Thus, the proximal fragment is rotated internally with respect to the distal fragment.

Correction of the rotation error: The leg is used as a lever and swung *outwards* through an angle equal to the difference between the antetorsion angles, thus rotating the distal femoral fragment internally (Fig. 17).

The maneuvers for the correction of rotational deformity are based on the empirical fact that the proximal fragment, which is deeply embedded in soft tissues and which may be severely dislocated, is not displaced to any significant degree when the distal fragment is rotated about its longitudinal axis. An *immediate* radiological check is mandatory; if the *difference between the projected antetorsion angles is unchanged,* the reduction maneuver has been successful. During the first week, the position can be corrected in the manner described without causing pain and therefore without an anesthetic, since all that is required is a change in the position of the leg. During the subsequent course of fracture healing, readjustment should be avoided, since it has to be carried out under anesthesia and, in addition, may lead to disturbances of bone union.

Subsequent treatment: The immobilization by vertical traction is maintained for 4–5 weeks, followed by 1–2 weeks bed rest. The child is then gradually mobilized with crutches. In older children, it is advisable to apply a hip spica for 3 weeks following the cessation of vertical traction. Since the rotation angle of the femur is unlikely to change, the result can be checked radiologically by the method of *Dunn* and *Rippstein* following removal of the traction (Fig. 18).

Complications: The following complications may result from errors of treatment.

a) Infection: This results from carelessness and incorrect technique. By the strict use of aseptic and antiseptic precautions during the insertion of *Steinmann* pins, we have greatly reduced the infection rate in our clinic in recent years.

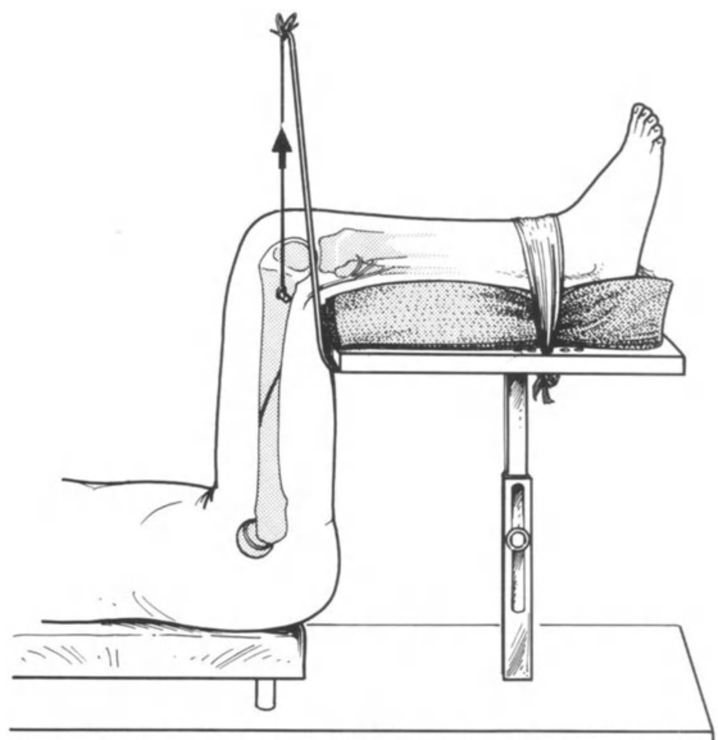


Fig. 19. *Femoral traction.* The traction cords are tied to a bar which is mounted on the table and the legs are laid loosely on foam rubber splints. Care should be taken to prevent pressure on the lateral popliteal nerve or the heel. The height of the table can be adjusted. Traction is always applied via the table, traction bar, cord, and *Steinmann* pin or adhesive plaster; on no account should the table be raised so as to exert upward pressure on the leg and thus apply traction via the knee joint

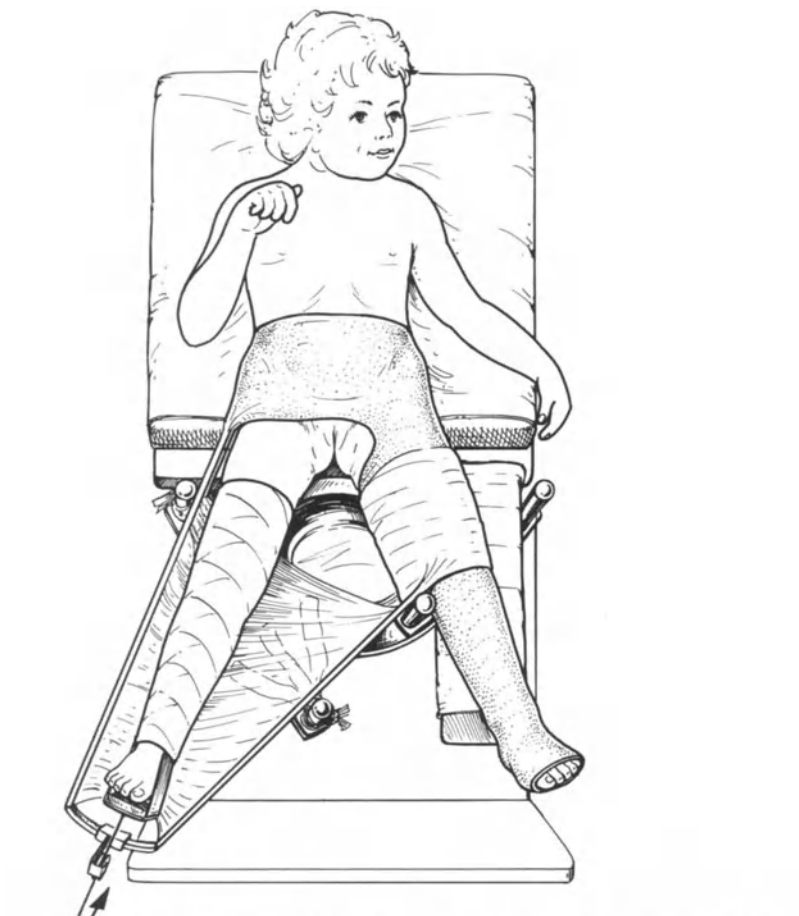


Fig. 20. *Push-and-pull traction by the Hoke method.* On the intact side, a long hip spica is applied which reaches down to the toes. The fractured leg rests on a towel stretched across a metal frame which is attached to the cast. Adhesive plaster traction is applied to the fracture via a pulley

Fig. 21. *Patient in push-and-pull traction*

b) Complications due to incorrect positioning of the *Steinmann* pin: *Injury to the epiphyseal plate* may result if the pin is placed too far distally, or the pin may tear through the bone if it is positioned too far ventrally. Infection of the epiphyseal plate could well have serious consequences, but we have never experienced a complication of this type.

c) Complications due to pressure on the leg: When positioning the legs on the traction table, care should be taken to ensure that the calves and the popliteal regions are not subjected to excessive pressure. The only traction forces acting on the femora should be the upward pull of the pin on the distal fracture fragment or intact femur, and the downward pull on the proximal fragment or intact femur due to the weight of the child's trunk (Fig. 19); under no circumstances should the traction be increased by forcing the extension table up under the calves of the legs, since this will cause serious injury to the soft tissues, and, in particular, to the lateral popliteal nerve.

d) Delayed fracture healing: The traction should bring about healing with correct axial alignment and slight shortening. Excessive traction may cause nonunion.

e) Complications resulting from repeated readjustment of the fracture. As a rule, a single readjustment during the first few days suffices to eliminate malunion. Repeated repositioning of a fragment is unnecessary and may lead to delayed healing with concomitant excessive longitudinal growth.

Push-and-Pull Traction (Hoke Method). This technique is used if a *Steinmann* pin cannot be inserted into the femur for some reason.

Technique: The procedure is carried out under general anesthesia with the patient supine. The intact leg is enclosed in a long hip spica which reaches down to the toes (Fig. 20). The broad metal frame which serves to support the fractured limb is then attached to the spica and adhesive plaster traction is applied to the limb. The traction cord passes over a small pulley which is attached to the apex of the frame (Fig. 21). Care should be taken to ensure that the axes of the legs are symmetrical. As soon as the traction has been set up, roentgenograms are taken to check the axial alignment and rotation of the femur. The

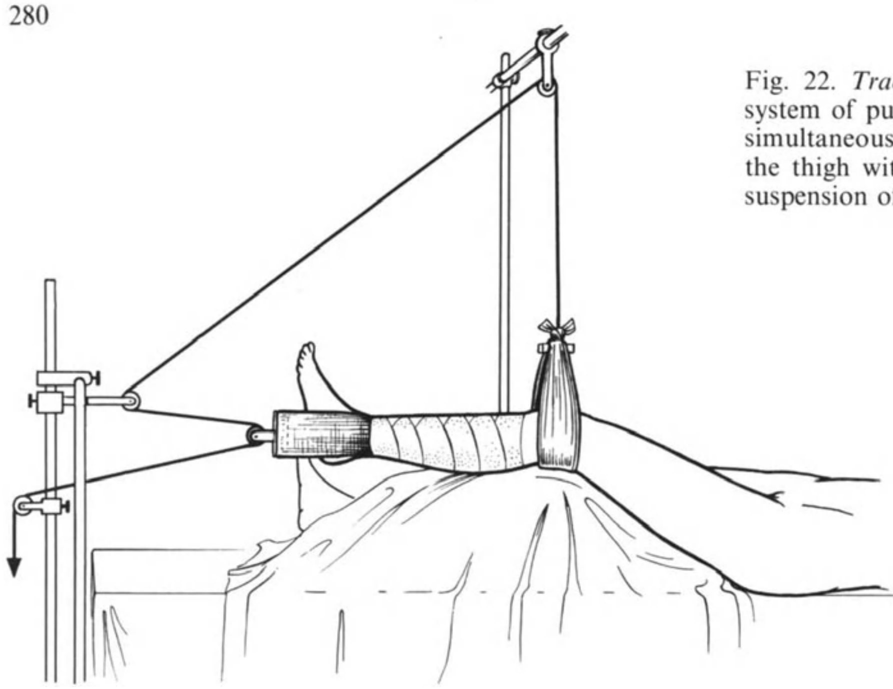


Fig. 22. *Traction by the Russell method.* By means of a system of pulleys, traction is applied to the lower leg and simultaneously flexes the knee. Pillows are placed under the thigh with 30°–40° hip flexion. The net result is free suspension of the leg by counter-balanced traction

rotation has to be assessed indirectly and the following two types of malrotation are possible:

a) On the side of the fracture, the angle of the femoral neck is greater and the lesser trochanter is more prominent than on the intact side. Thus, the proximal fragment is rotated externally with respect to the distal fragment. This increase in the projected angle of the femoral neck is the more frequent of the two forms of malrotation.

b) On the side of the fracture, the angle of the femoral neck is less than that on the intact side and the lesser trochanter disappears behind the shaft of the femur. Thus, the proximal fragment is internally rotated with respect to the distal fragment. This decrease in the projected angle of the femoral neck is the less frequent of the two forms of malrotation.

The relative positions of the fragments can be adjusted by changing the direction of traction. However, the reduction is relatively imprecise and slight posttraumatic rotational deformity may well result.

Subsequent treatment: Immobilization by traction for 4–5 weeks. Roentgenograms are then taken and bed rest is continued for 1–2 weeks. The child can then be mobilized without further ado.

3.1.2.3 Dislocated Fractures in Children over 12 Years of Age

Traction by the Russell Method: This method is indicated in older children, for whom vertical traction with the *Weber* table is unsuitable. However, open reduction and fixation is usually more suitable, as growth has almost ceased; spontaneous correction of residual axial deformities is unlikely to occur, and the precision required for complete elimination of axial misalignment and malrotation is usually impossible using nonoperative techniques.

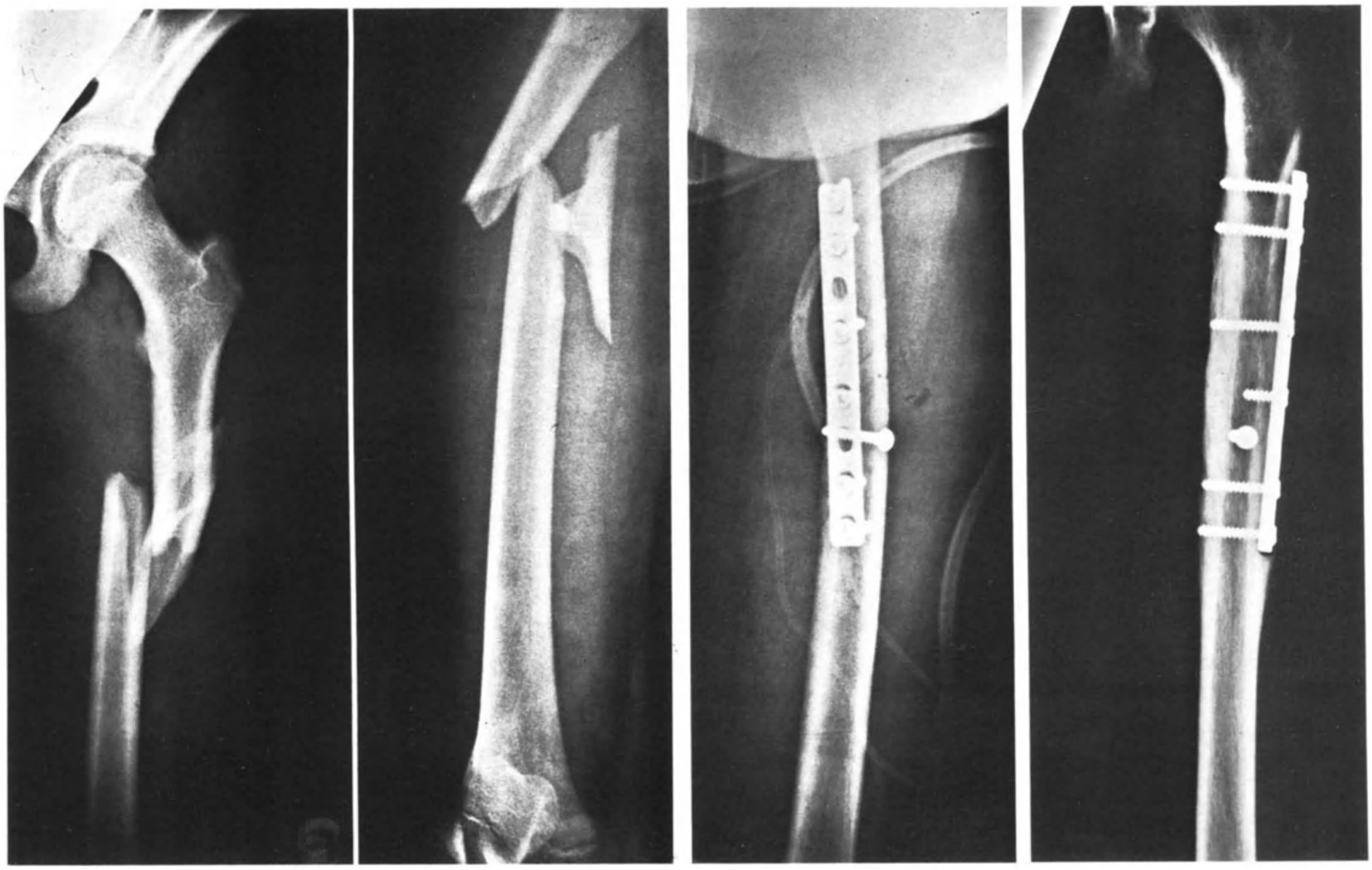
Technique (*Freuler, Wiedmer,* and *Bianchini*): General anesthesia is required. Traction is applied to the lower leg on the side of the fracture using a broad strip of adhesive plaster, and the limb is suspended in a padded sling which passes around the knee (Fig. 22). The sling and the adhesive plaster traction are then connected by means of a traction cord passing over pulleys as shown in the illustrations. The amount of traction should be chosen so as to keep the leg freely suspended above the bed (usually 8–12 kg).

If the child is particularly restless, traction should be applied to the intact leg in the same manner. Upward traction on the toes may be needed to prevent equinus deformity.

As with the previous technique, this method does not allow precise determination of the femoral torsion, and the alignment of the fracture has to be corrected by changing the direction of traction.

→

Fig. 24a–d. *Internal fixation of bilateral femoral diaphyseal fractures.* H.P., ♂, aged 13 years, No. 142977.
a, b) Bilateral fractures of the femoral diaphyses in an older child. Nonoperative treatment was not attempted.
c) 6 weeks following internal fixation. The fractures have already united.
d) 8 months following the accident. Uneventful healing with no sequelae



a b c

Fig. 23a–c. *Plate fixation following an attempt at nonoperative treatment.* R.U., ♀, aged 13 years, No. 142613.
a) This multifragment fracture of the femur could not be successfully reduced by traction.
b) 2 weeks after the accident. Internal plate fixation.
c) 8 months after the accident. Uneventful healing with no sequelae

c

a b

c

Fig. 25a–c. *An irreducible proximal fracture of the femoral diaphysis*. K.O., ♂, aged 8 years, No. 167862.
a) Typical dislocation of the proximal fragment. Satisfactory alignment of the fragments could not be achieved with the traction appliance.
b) Internal fixation with a short narrow plate.
c) 1 year after the accident. Satisfactory healing with no sequelae

3.2 Operative Treatment

The aim of operative treatment is anatomically precise reduction of the fragments and direct bone healing with simultaneous mobilization of the fractured limb. The operative treatment of femoral diaphyseal fractures in children is reserved for exceptional cases in which nonoperative treatment cannot be expected to bring about satisfactory healing or has resulted in complications. It is therefore restricted to the following situations:

a) Wide open, severely dislocated fractures with extensive soft tissue injury.
b) Fractures of the shaft of the femur which are combined with fracture of the femoral neck or dislocation of the hip.
c) Fractures of the shaft of the femur in adolescents shortly before cessation of growth.
d) Fractures which cannot be adequately reduced by closed techniques (Fig. 23).
e) Bilateral femoral diaphyseal fractures in children over 10 years of age (Fig. 24).
f) Concomitant disease, such as spastic hemiplegia or systemic skeletal disease, such as osteogenesis imperfecta.
g) Refractures of the femoral shaft, particularly if there is a considerable difference in leg length.

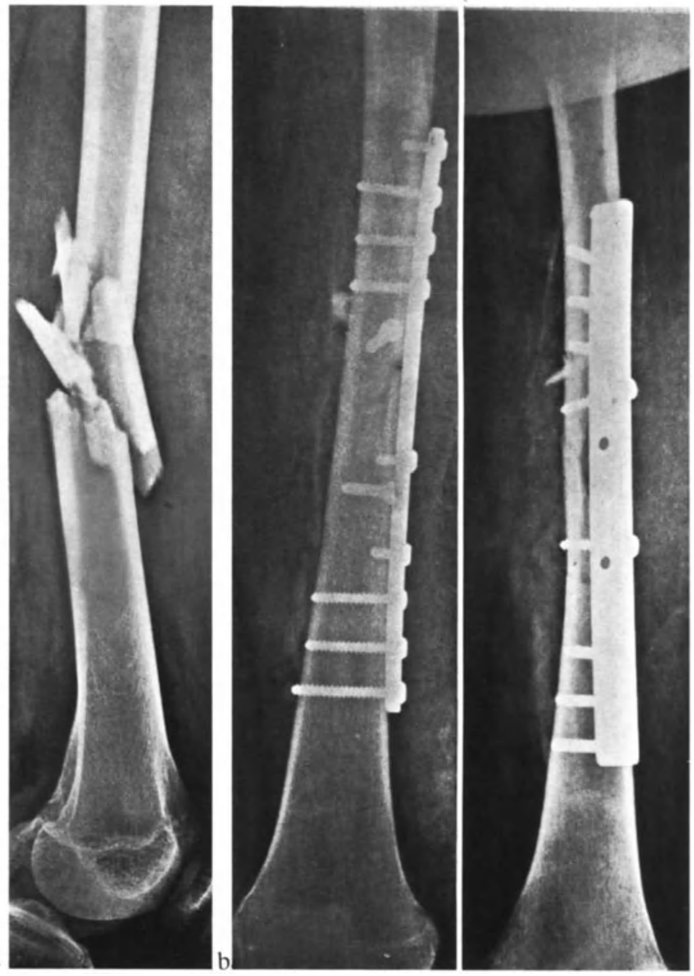
3.2.1 Operative Procedures

Plate fixation or medullary nailing are carried out, depending on the site and type of the fracture.

3.2.1.1 Plate Fixation

Operative technique: A lateral incision is made and the fascia lata is split longitudinally. The lateral side of the femoral shaft is approached by passing behind the vastus lateralis muscle with simultaneous ligation of the perforating arteries. The fragments are reduced precisely and fixed by compression plating according to the AO principles. A narrow 4-hole or 6-hole plate suffices in a small child (Fig. 25), but broad AO plates should be used in older children (Fig. 26).

Fig. 26 a–e. *Fracture of the femoral shaft shortly before cessation of skeletal growth.* St. F., ♀, aged 14 years, No. 121790.
a) Comminuted fracture of the femoral diaphysis.
b) Internal fixation with a broad plate.
c) Preliminary fracture healing by formation of a periosteal callus cuff. Partial necrosis of the intermediate fragments has occurred.
d) 1 year after the accident. The intermediate fragments are revascularized and the fracture has healed.
e) 1 year and 10 months after the accident. The bone structure is almost normal



a b

c d e

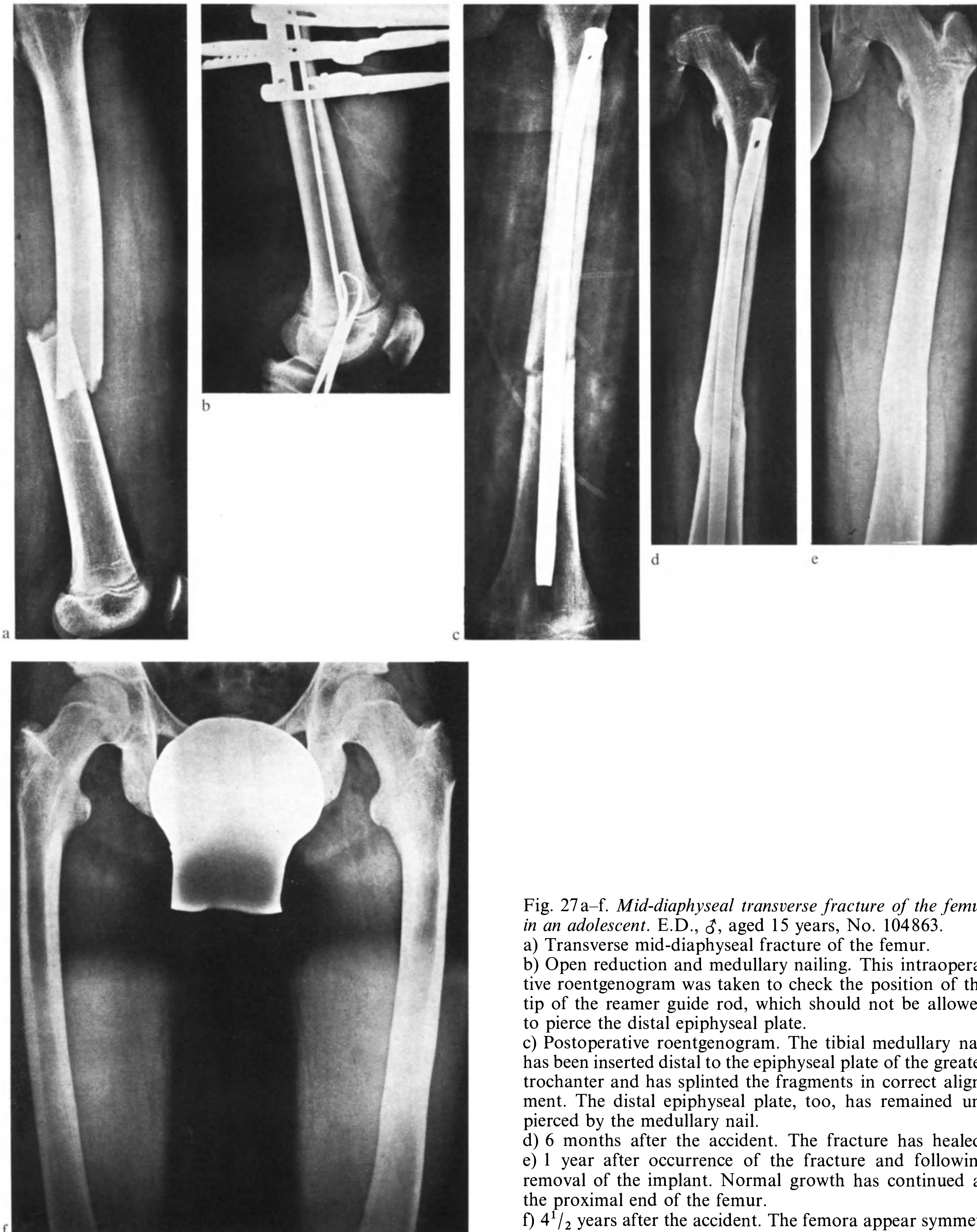


Fig. 27a–f. *Mid-diaphyseal transverse fracture of the femur in an adolescent.* E.D., ♂, aged 15 years, No. 104863.
a) Transverse mid-diaphyseal fracture of the femur.
b) Open reduction and medullary nailing. This intraoperative roentgenogram was taken to check the position of the tip of the reamer guide rod, which should not be allowed to pierce the distal epiphyseal plate.
c) Postoperative roentgenogram. The tibial medullary nail has been inserted distal to the epiphyseal plate of the greater trochanter and has splinted the fragments in correct alignment. The distal epiphyseal plate, too, has remained unpierced by the medullary nail.
d) 6 months after the accident. The fracture has healed.
e) 1 year after occurrence of the fracture and following removal of the implant. Normal growth has continued at the proximal end of the femur.
f) $4^1/_2$ years after the accident. The femora appear symmetrical. Increase in leg length: 0.3 cm

Postoperative positioning of the leg: The hip and knee are kept flexed at right angles for 4 days. This prevents adhesions of the vastus lateralis muscle from forming with the femur in the extended position and thus preventing subsequent flexion of the knee.

Subsequent treatment: If wound healing is satisfactory, the patient is mobilized and partial weight bearing (10 kg) is begun. Full weight bearing is allowed after 6–8 weeks. Complications of wound healing or fracture healing hardly ever occur, but aesthetically displeasing hypertrophic scars sometimes form. The implant is removed after 4–6 months in small children and after 8–12 months in older children.

3.2.1.2 Medullary Nailing

This technique is reserved for transverse and pathological fractures. The AO tibial medullary nail is used (*Weber*).

Operative technique: A small skin incision is made and the fracture is reduced precisely. A lateral skin incision is then made over the innominate tubercle, the fascia is split, and the epiphyseal plate of the greater trochanter, which must be carefully protected, is located. The medullary cavity is opened just distal to and dorsal to the epiphyseal plate and is reamed out by hand to a diameter of 8–10 mm. A tibial medullary nail is then driven in. Straight medullary nails (AO femoral nail, Rushpin, *Küntscher* nail) are unsuitable for use in children, since they cause damage to the epiphyseal plate of the greater trochanter and thus lead to disturbances of growth (valgus deformity of the femoral neck).

Postoperative positioning of the leg: The hip and knee joints are kept at right angles for 4 days.

Subsequent treatment: The patient is mobilized after 5 days, and full weight bearing is begun early if there are no contraindications. The nail should be removed after 6–12 months (Fig. 27).

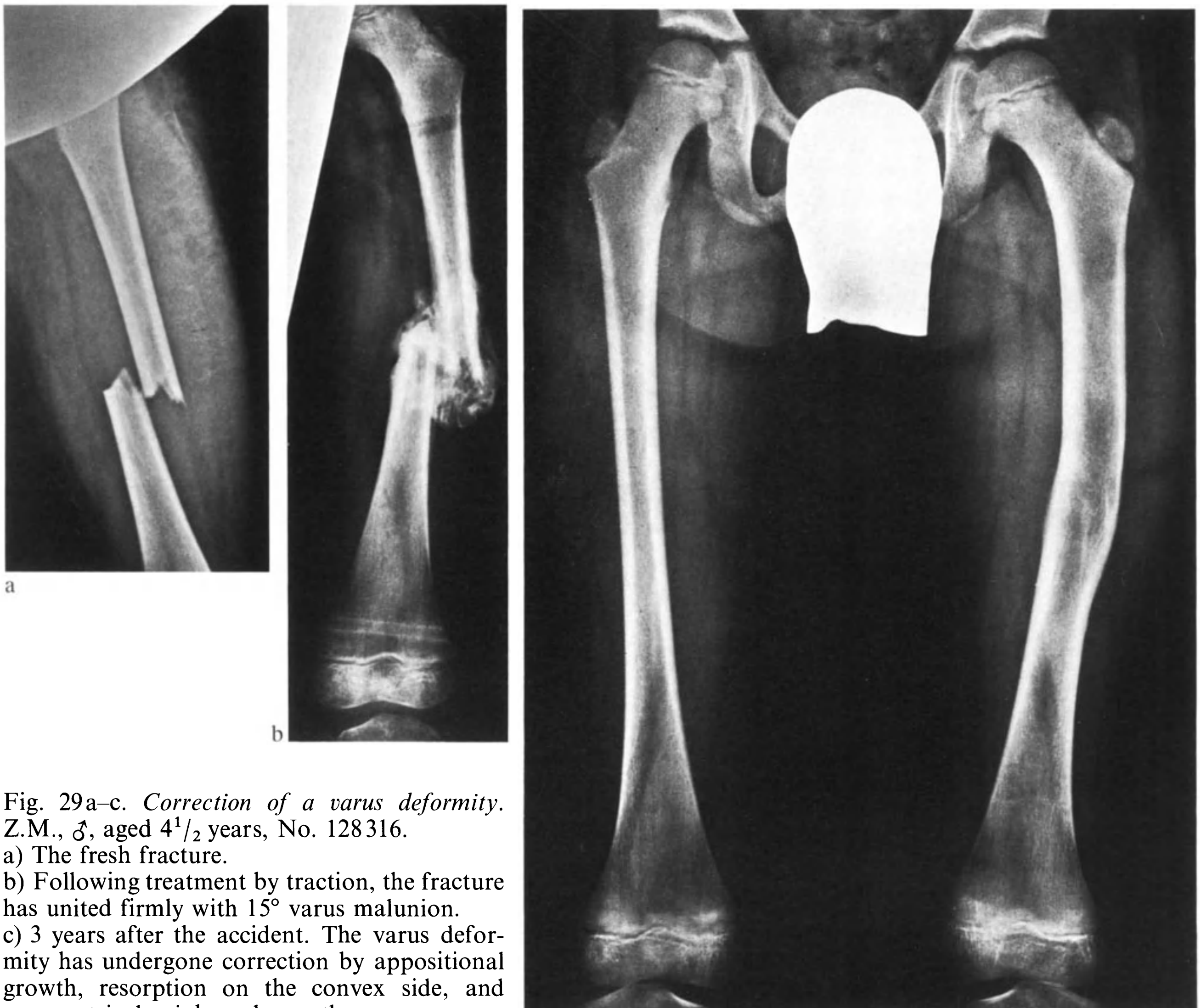
a b c

Fig. 28a–c. *Remodelling of the bone following healing of a dislocated fracture*. St. C. ♂, aged 11 years, AK No. 51095.
a) This multifragmented fracture of the femoral diaphysis healed in slight varus with shortening and lateral dislocation.
b) 1 year after the accident. The excessive callus has been resorbed and remodelled, and correction of the moderate degree of malunion has occurred.
c) 3 years after the accident. There are few residual signs of the severely dislocated fracture. The axial misalignment has been completely corrected in accordance with *Wolff's* transformation law

4 Prognosis

4.1 Primary and Posttraumatic Angular Deformities

During fracture healing, any axial misalignment of the fragments is corrected to a degree which is inversely proportional to the age of the child. During this process, the epiphyseal plates tend to align themselves at right angles to the direction of the forces to which they are subjected (*Pauwels*). Healing starts with the appearance of callus at the site of the fracture followed by periosteal bone apposition. The shaft of the bone then undergoes remodelling in accordance with *Wolff*'s principle of minimum wastage of structural bone (Fig. 28). In younger children, more time is available during which residual deformity can be corrected by compensatory growth, and relatively severe malunion may be eliminated in this manner. Thus, in the majority of young children initial axial misalignment of 20°–30° is hardly detectable 2 years after the accident (Fig. 29). This capacity for realignment is much reduced in children over 10 years of age, particularly in those who have already completed their second phase of accelerated growth. Shortly before closure



a b c

Fig. 29a–c. *Correction of a varus deformity.* Z.M., ♂, aged $4^1/_2$ years, No. 128316.
a) The fresh fracture.
b) Following treatment by traction, the fracture has united firmly with 15° varus malunion.
c) 3 years after the accident. The varus deformity has undergone correction by appositional growth, resorption on the convex side, and asymmetrical epiphyseal growth

of the epiphyses, the compensatory growth potential of the bone is almost completely exhausted. For this reason, care should be taken to ensure anatomically precise reduction of a diaphyseal fracture of the femur in an adolescent.

When reducing a femoral shaft fracture, any *malrotation* should be completely eliminated, since rotation deformity is not corrected by subsequent growth (Fig. 7). To detect malrotation of the femur, roentgenograms are made in two planes and used to determine the projected angle between the femoral neck and femoral diaphysis and that between the femoral neck and the transverse axis of the condyle of the knee. By means of a table, the true angles can be deduced from those measured on the roentgenograms (Fig. 30). The roentgenograms (an a-p film of the pelvis with the lower legs hanging down vertically, and an axial view) are made according to the method of *Dunn* and *Rippstein,* as shown in Fig. 31. As mentioned above, malrotation does not undergo spontaneous correction, and malrotation in the form of excessive antetorsion of the femoral neck causes malrotation of the whole leg with secondary pes planus and osteoarthrosis of the subtalar joints. Furthermore, malrotation of the lower extremity frequently leads to secondary changes in the hip and knee joints which often remain latent for many years, e.g., patellar chondropathy, osteoarthrosis of the hip. *Increased* torsion of the femur imposes abnormal valgus loads on the hip and knee joints, while *decreased* torsion imposes abnormal varus loads (*Weber*).

4.2 Posttraumatic Disturbances of Growth

Diaphyseal fractures of the femur, particularly those which have been operated on, cause acceleration of longitudinal growth. This occurs most frequently fol-

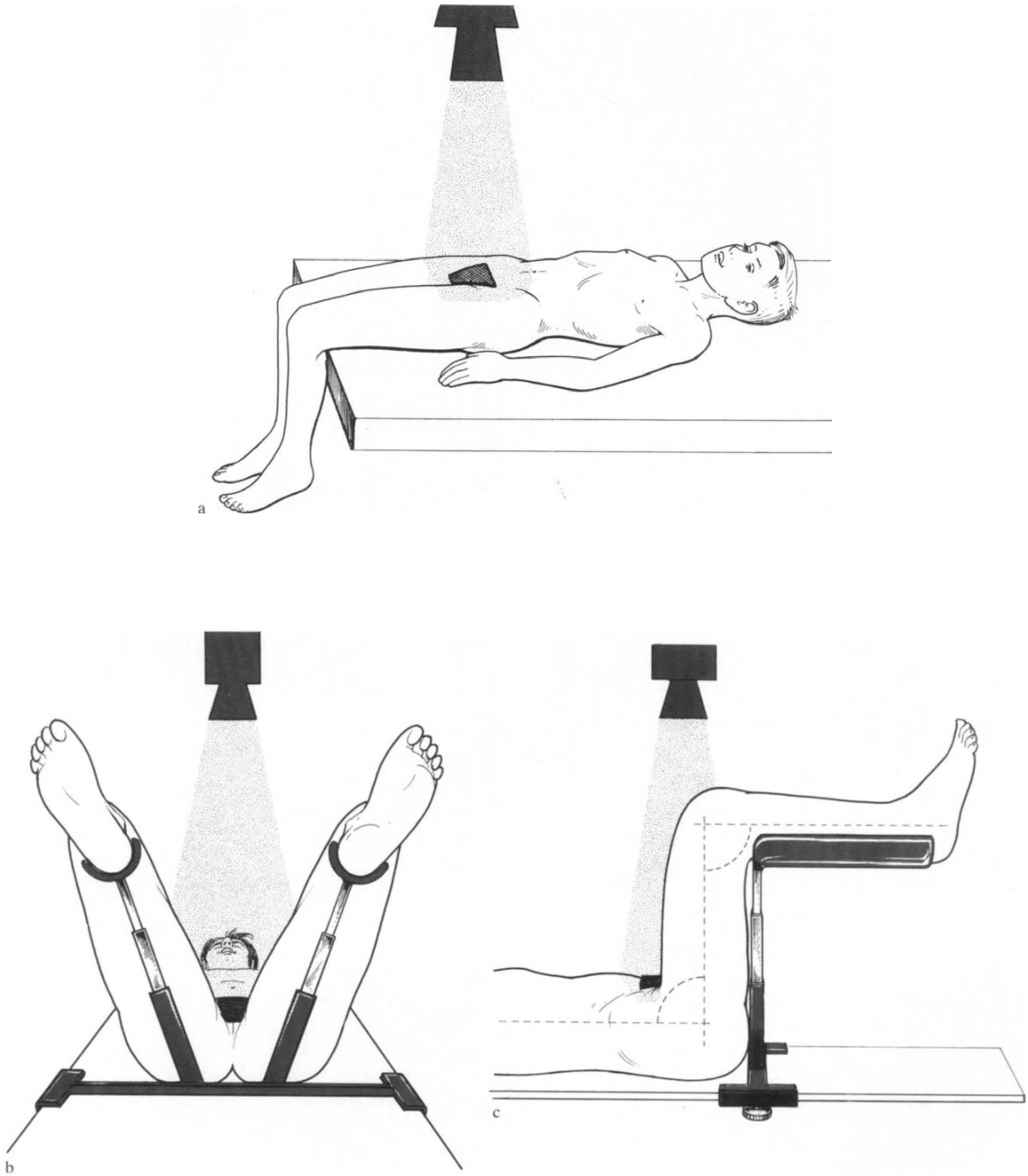
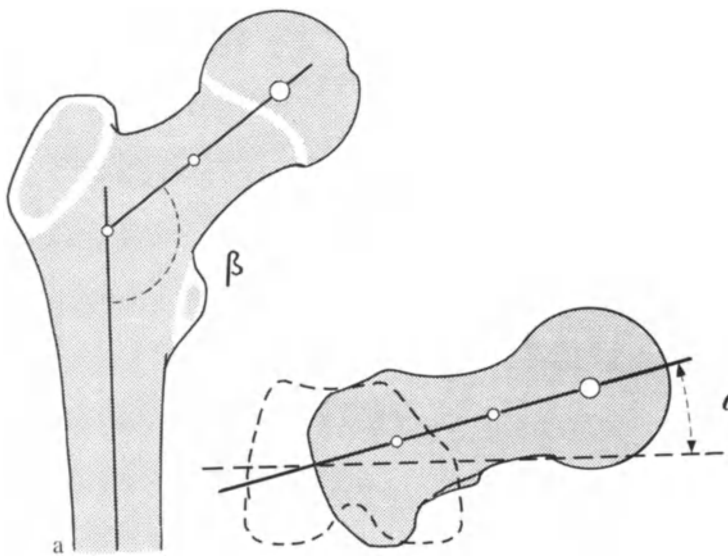


Fig. 30 a–c. *Positioning of the patient for radiography.*
a) Standard a-p view with the legs hanging down vertically and the hip joints extended so as to ensure symmetrical neutral rotation of the femora.
b, c) Anteversion films. A special positioning frame keeps the hip and knee joints in 90° flexion and both sides in 20° abduction. The lower legs are parallel to each other and the femora are in the neutral rotation position. The telescopic construction of the thigh struts allows adjustment of their length. The offset at the base can also be adjusted. In this manner, the frame can be adapted to allow correct positioning of the patient



PROJECTED ANGLE OF ANTEVERSION = PROJ. AV ∢

PROJECTED NECK-SHAFT ANGLE = PROJ. CCD ∢	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°
100°	4 101	9 100	15 100	20 100	25 100	30 99	35 99	40 98	45 97	50 96	55 95	60 94	65 94	70 93	75 92	80 91
105°	5 105	9 105	15 104	20 104	25 103	31 103	35 102	41 100	46 100	51 99	56 98	60 97	65 96	70 95	75 94	80 92
110°	5 110	10 110	16 109	21 108	27 108	32 106	36 106	42 105	47 104	52 103	56 101	61 99	66 98	71 97	76 95	80 93
115°	5 115	10 115	16 114	21 112	27 112	32 111	37 110	43 109	48 107	52 105	57 104	62 102	67 101	71 99	76 96	81 94
120°	6 120	11 119	16 118	22 117	28 116	33 115	38 114	44 112	49 110	53 108	58 106	63 104	68 103	72 101	77 98	81 95
125°	6 125	11 124	17 123	23 121	28 120	34 119	39 118	44 116	50 114	54 112	58 109	63 107	68 105	72 103	77 100	81 95
130°	6 130	12 129	18 127	24 126	29 125	35 124	40 122	46 120	51 117	55 116	60 112	64 109	69 107	73 104	78 101	82 96
135°	7 135	13 133	19 132	25 131	31 130	36 129	42 126	47 124	52 120	56 118	61 114	65 112	70 109	74 105	78 102	82 96
140°	7 139	13 138	20 137	27 135	32 134	38 132	44 130	49 127	53 124	58 120	63 117	67 114	71 111	75 107	79 103	83 97
145°	8 144	14 142	21 141	28 139	34 138	40 136	45 134	50 131	55 128	59 124	64 120	68 117	72 114	75 110	79 104	83 98
150°	8 149	15 147	22 146	29 144	35 143	42 141	47 138	52 136	56 134	61 129	65 124	69 120	73 116	76 112	80 105	84 100
155°	9 154	17 152	24 151	32 149	38 148	44 145	50 142	54 139	58 137	63 132	67 128	71 124	74 119	77 115	81 108	84 102
160°	10 159	18 158	27 157	34 155	44 153	46 151	52 147	57 144	61 141	65 134	69 132	73 128	76 122	79 116	82 111	85 103
165°	13 164	23 162	33 161	40 159	47 158	53 156	57 153	62 148	67 144	69 140	73 135	76 130	78 122	81 119	83 113	86 106
170°	15 169	27 167	37 166	46 164	53 162	58 159	63 157	67 154	70 150	73 145	76 142	78 134	80 130	83 122	84 118	87 113

UPPER NUMBER = TRUE ∢ OF AV LOWER NUMBER = TRUE ∢ OF CCD

b

Fig. 31 a, b. *Projected angle of the femoral neck.*
a) *Left:* the projected neck-shaft angle (β). *Right:* the anteversion angle between the vertical projection of the long axis of the femoral neck and that of the transverse axis of the condyles of the knee (α).
b) The conversion table (*Rippstein*) which is used to determine the true anteversion and neck-shaft angles

lowing fracture of the middle third of the shaft. Obstruction of the medullary cavity by callus or metal implants stimulates the collateral blood supply from the neighboring epiphyseal vessels and thus causes hyperemia in the epiphyseal plate. During the 2 years, which the fracture callus requires for its complete resorption, the longitudinal growth of the injured leg is accelerated. Upon completion of fracture healing, the vascular stimulus ceases and the growth rate returns to normal (Fig. 32).

The acceleration of longitudinal growth is particularly noticeable following internal fixation, especially after medullary nailing (*Goff*). Thus, internal fixation of a diaphyseal fracture of the femur should be avoided whenever possible if the epiphyses are still open.

The individual epiphyseal plates of the femur differ in their contributions to longitudinal growth. Seventy percent of the length of an adult femur is derived from growth in the *distal* epiphyseal plate, and one might therefore expect the latter plate to embody the greater part of the compensatory growth potential of the bone. However, growth in the other epiphyseal plates in the injured leg is also accelerated; thus, the activity of the proximal epiphysis of the tibia is stimulated by a fracture of the femur on the same side. Similarly, compensatory growth in the proximal femoral epiphysis may have important biomechanical effects on the hip joint.

Following a femoral fracture in childhood, the axes of the femoral necks may develop assymetrically, resulting in differences in the biomechanics of the two hip joints.

The acceleration of longitudinal growth is directly proportional to the intensity and duration of the hyperemia in and around the fracture. In order to ensure equal leg length following cessation of growth, diaphyseal fractures of the femur in young children should be allowed to unite with a moderate degree of shortening. Conversely, in older children in whom cessation of growth is imminent, shortening should be avoided since the fracture may cause premature closure of an epiphysis, particularly if the two are situated near to each other.

5 Results

5.1 Methods of Treatment

Our series includes 182 diaphyseal fractures of the femur (1961–1973). One hundred sixty-four were treated nonoperatively; the methods included vertical traction on the *Weber* traction table (149), a hip spica or push-and-pull traction (8), or other traction techniques (7) (Table 3).

Operative treatment (18 cases) was preferred for children over 13 years of age. Only two small children were operated on immediately: the first was a $2^1/_2$-year old patient with a severely dislocated subtrochan-

Fig. 32a, b. *Increased longitudinal growth following fracture healing*. S.W., ♂, aged 5 years, No. 113808.
a) The fresh fracture. Healing occurred with end-to-end contact of the fragments.
b) 4 years and 7 months after the accident. The moderate valgus deformity has persisted and longitudinal growth has increased by 2 cm

a b

Table 3. Treatment of diaphyseal femoral fractures in children (182 cases)

	Ages of the patients in years					
	1–4	4–7	7–10	10–13	13–16	Totals
Hip spica, push-and-pull cast	4	1	2	–	1	8
Vertical traction by *Weber* method	43	57	23	22	4	149
Russell traction	2	4	–	1	–	7
Internal fixation	1	1	–	2	14	18
						182

teric fracture of the right femur, a trochanteric fracture of the left femur, multiple fractures of the pelvis, and extensive injuries to the soft tissues of both sides: the second case was that of an 8-year old boy with an irreducible subtrochanteric fracture of the femur (Fig. 25).

Nonoperative treatment had been attempted in 3 of the 18 cases which were operated on. In two of these cases, which involved children of 14 and 15 years of age, open reduction and internal fixation were carried out following failure to achieve satisfactory alignment of the fragments by traction (Fig. 26); the third case was that of an 11-year old patient with bilateral open fractures of the femoral diaphyses.

5.2 Complications

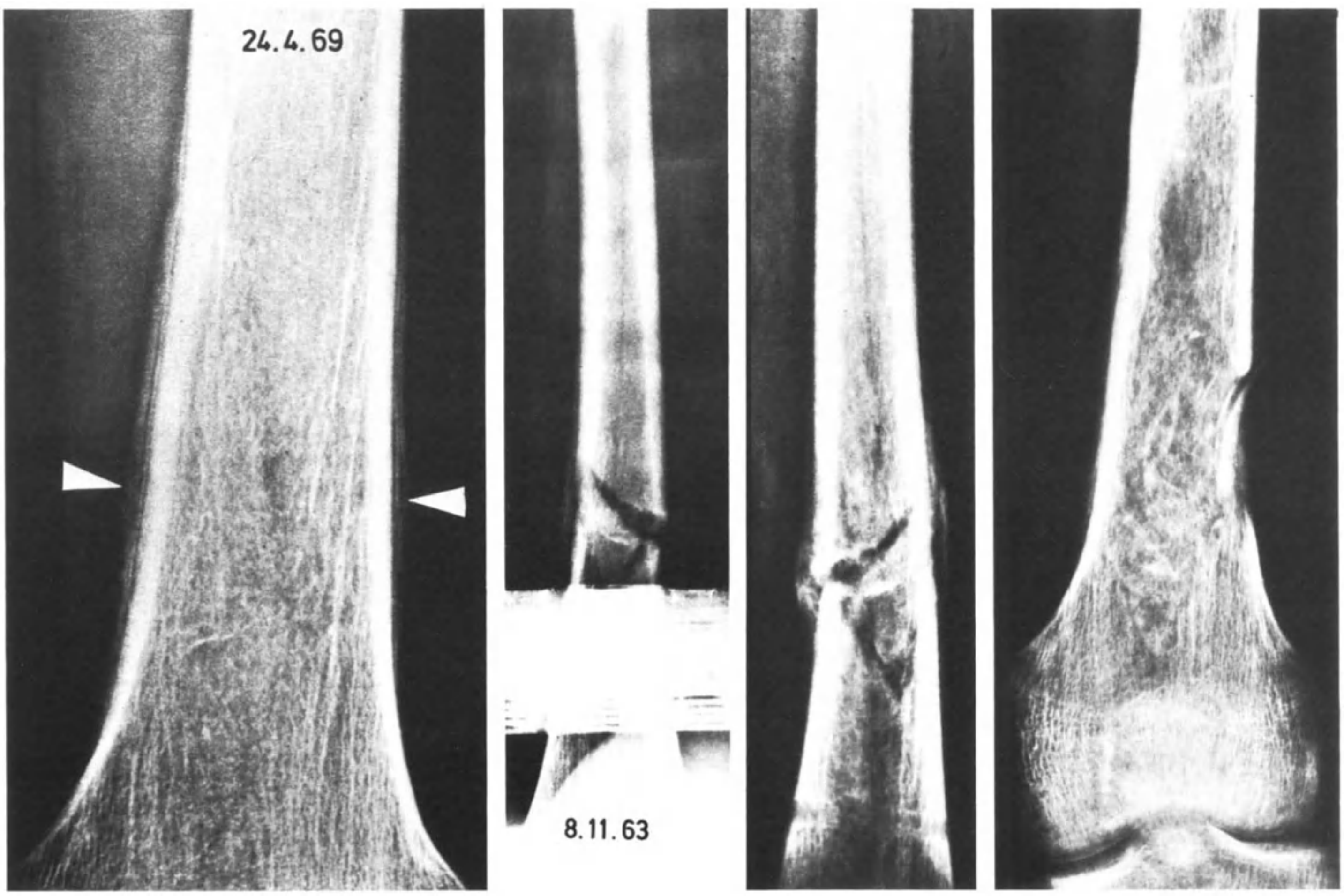
Three patients died within a few days of their accidents as a result of their extensive injuries. Mishaps during anesthesia and other severe systemic complications did not occur. Fourteen patients suffered severe *intercurrent infection* during treatment (pyocyanic sepsis following rupture of the kidney, urinary tract infections, enterocolitis, tonsillitis, varicella infections).

Table 4. Complications

	Vertical traction	Others
Intercurrent disease	13	1
Infection around pin	8	5
Delayed healing	1	–
Refractures	3	–
Amputations	–	1
Early infection	5	–
Late infection	1	–

The complications directly associated with the fracture treatment are shown in Table 4. In two cases, attempts to treat the fracture by vertical traction had to be followed by open reduction and internal fixation. The lower leg of one patient had to be amputated because of wound infection following extensive injury to the soft tissues of the fractured leg with rupture of the popliteal artery.

Delayed fracture healing or pseudarthrosis did not occur. Three fractures which were treated by traction fractured again within 2–3 months. Two of these three fractures united successfully after further nonoperative treatment, and the third healed following open reduction and fixation with a plate. The most frequent complication was *infection of the wound around the Steinmann pin,* which was most frequently due to staphylococcal infection. Thus, in 13 patients, a slight discharge was seen around the point of entry of the pin and healing could be induced in eight of these cases by removing the traction. Disturbances of healing of this type are most probably caused by excessive movement between the skin and the pin. We disapprove of the use of *Kirschner* wires for traction, since they tend to move relative to the bone and soft tissues. In five cases, surgical exploration and sequesterotomy had to be carried out in the distal femur; uneventful healing resulted in each case. In one patient, infection occurred along the pin track 6 years after treatment of the fracture; here too, satisfactory healing was brought about by extirpation of the circumscribed osteomyelitis followed by cancellous bone plasty (Fig. 33).



a b c d

Fig. 33a–d. *Late osteomyelitis following traction applied with a Kirschner wire.* B.M., ♂, aged 17 years, No. 83478.
a) The patient was hospitalized in the department of Internal Medicine for the investigation of chronic knee symptoms. Osteosarcoma was suspected and the patient was referred to the orthopedic clinic for biopsy.
b) The history included a diaphyseal fracture of the femur 5 years previously (at the age of 11 years) which had been treated by traction applied to a supracondylar *Kirschner* wire.
c) The healing fracture 6 weeks after the accident.
d) At operation (the requested "biopsy"), a large quantity of pus was evacuated. The source was a chronic posttraumatic osteomyelitis which had resulted from latent infection of the *Kirschner* wire track. This chronic osteomyelitis had remained relatively inactive for $5^1/_2$ years before causing symptoms. Extirpation of the osteomyelitic tissue followed by cancellous bone plasty resulted in successful healing

5.3 Follow-Up Examination of Our Own Cases

5.3.1 Parameters Measured

On discharge from hospital, the lengths of the children's legs were measured and radiological investigations were carried out to detect and document any axial misalignment or shortening. At the follow-up examination, the gait, the ranges of movement of the vertebral column, hip joints, and knee joints, and the lengths and circumferences of the thighs were recorded. The investigations also included a-p and lateral roentgenograms of the femur to assess the axial alignment, and standardized *Dunn, Rippstein* films of the pelvis to detect malrotation.

5.3.2 Results

We assessed the results of fracture treatment by examining data derived from follow-up examination of two groups of children. The first group comprised 28 children with fractures of the femur which had occurred in 1962 or 1963 and which had been treated nonoperatively. These cases were followed-up systematically 5–7 years after the accident. In the second series of cases, 87 of a group of 103 children whose fractures were treated nonoperatively between 1967 and 1973 were followed-up 3–9 years after their accidents. The clinical and radiological examinations showed mean malrotation of only 5° in both series; the maximum deformity was a 14° increase in antetorsion, which occurred in only one case. This deformity, which is not particularly severe, was found in the series of cases treated between 1961 and 1963 and is probably attributable to unfamiliarity with the new techniques being introduced at that time. In no case in the second series did rotational deformity of more than 10° occur.

The varus deformities seen at hospital discharge underwent spontaneous correction and amounted to only a few degrees at the subsequent follow-up examination. On the other hand, little or no spontaneous correction of valgus deformity was seen. Valgus malunion of more than 5° was found to persist, and in four patients, there was even an increase in the valgus angulation found on discharge from hospital.

Antecurvature also tended to persist, but these deformities were usually limited to a few degrees with an extreme value of 22° in one case. Retrocurvature of 5° was found in only one case.

A particularly interesting finding in the second series of cases was that a reduction in the antetorsion angle of the femoral neck at the time of bone union persisted during subsequent growth until physiological derotation on the nonfractured side had reached a point at which the antetorsion angles of the femoral necks were equal. Having thus become resynchronized, the physiological rotation of the femoral necks continued in a symmetrical fashion. In those patients who could be followed-up after reaching adulthood, the antetorsion angles on the two sides were always equal if the true angle on the fractured side had amounted to at least 20° at the time of hospital discharge.

Differences in leg length were found in almost all cases at the time of follow-up. Shortening of 3 cm was found in one child, but this was of idiopathic origin. In seven children, shortening of 0.5 cm was found on the fractured side. In all the other patients, disproportionate lengthening of the fractured leg had occurred and was quite considerable in some cases. In two cases, growth subsequent to bone union was found to have been accelerated by 3 cm. However, in the majority of cases, the increase in growth lay between 0.5 and 1.5 cm.

Table 5. Mean increase in growth following femoral fracture treated by traction on the *Weber* table

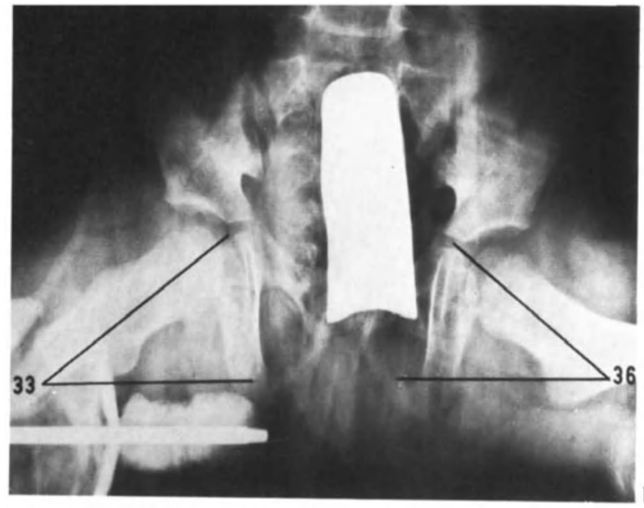
Age of child at accident	Increase in growth
Up to 4 years of age	0.5–1.0 cm
4–6 years old	1.0–1.5 cm
6–8 years old	1.5–2 cm
Over 8 years of age	0.5–1.0 cm

Table 5 shows the relationship between increase in leg length and age of the child. The mean acceleration of growth following comminuted fractures was 0.5 cm greater than that resulting from simple transverse fractures.

6 Summary

Femoral shaft fractures in children are caused by severe degrees of violence and are therefore usually accompanied by serious injuries to other parts of the body. The fractures are treated nonoperatively whenever possible; the type of treatment being determined by the age of the child. Malrotation is the only deformity which has to be completely eliminated at the time of reduction; this is best achieved by vertical traction on the *Weber* table. Open reduction and fixation is limited to exceptional cases. The longitudinal growth of a long bone in a child is always accelerated by a fracture, and the nonoperative treatment of a femoral fracture should therefore allow bone union with slight shortening (Fig. 34).

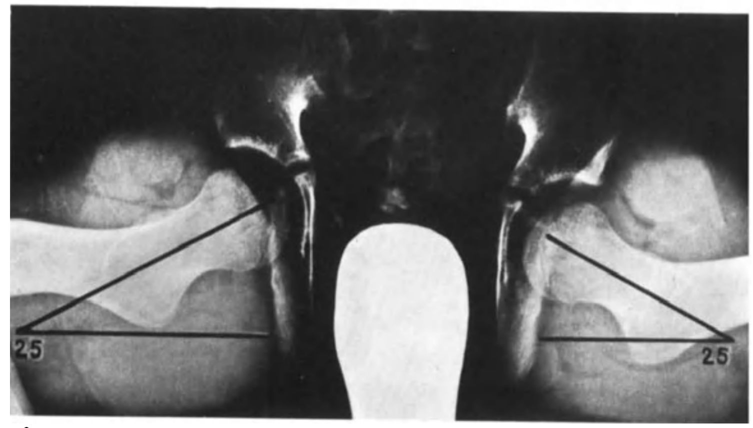
a



b

c

d



f

Fig. 34a–f. *Normal progress of a diaphyseal fracture of the femur in a child.* G.R., ♂, aged 3 years, No. 97217.
a) Spiral fracture of the femoral diaphysis. Nonoperative treatment by traction on the *Weber* traction table.
b) Checking of anteversion with the child on the extension table. The projected anteversion is reduced by 3°.
c) Radiological check with the child on the traction table 5 weeks after the accident. The fragments are joined by callus. The projected anteversion on the fractured side is 3° less than that on the intact side.
d) 8 months after the accident. Rapid remodelling and resorption of the excess callus have occurred.
e, f) Follow-up 5 years and 5 months after the accident. The leg length on the right is very slightly increased, the axes are symmetrical, there is symmetrical femoral rotation, and the anteversion angles are identical. A perfect result

7 References

Blount, W. P: Knochenbrüche bei Kindern. Stuttgart: Thieme 1957.

Dunn, J. M.: Anteversion of the neck of the femur. J. Bone Surg. **34** B, 181–186 (1952)

Freuler, F., Wiedmer, U., Bianchini, D.: Cast manual for adults and children. Berlin-Heidelberg-New York: Springer, 1979.

Le Mesurier, A. B.: The treatment of fractures of the shaft of the femur in children. Amer. J. Surg. **49**, 140 (1940).

Müller, M.E., Allgöwer, M., Schneider, R., Willenegger, H.: Manual of Internal Fixation, 2nd edition. Berlin-Heidelberg-New York: Springer 1979.

Neer, C. S., II, Cadmann, E. F.: Treatment of fractures of the femoral shaft in children. J. Amer. med. Ass. **163**, 634 (1957).

Rippstein, J.: Zur Bestimmung der Antetorsion des Schenkelhalses mittels zweier Röntgenaufnahmen. Zschr. Orthop. **86**, 345–360 (1955).

Russell, R. H.: Fractures of the femur. Brit. J. Surg. **11**, 491 (1924).

Staheli, L. T.: Femoral and tibial growth following femoral shaft fractures in childhood. Clin. Orthop. **55**, 159 (1967).

Tachdjian, M. O.: Pediatric Orthopedics. Philadelphia-London-Toronto: Saunders 1972.

Vontobel, V., Genton, N., Schmid, R.: Die Spätergebnisse der kindlichen dislozierten Femurschaftfraktur. Helv. chir. Acta **28**, 655 (1961).

Weber, B. G.: Zur Behandlung kindlicher Femurschaftbrüche. Arch. orthop. Unfall-Chir. **54**, 713 (1963).

Weber, B. G.: Prophylaxe der Achsenfehlstellungen bei der Behandlung kindlicher Frakturen. Unfallmed. Berufskr. **1**, 80–95 (1966).

Weber, B. G.: Indikationen zur operativen Frakturenbehandlung bei Kindern. Chirurg **10**, 441 (1967).

Fractures In and Around the Knee Joint

CH. BRUNNER

CONTENTS

Distal Femoral Fractures

Patella Fractures

Fractures of the Proximal Tibia

Distal Femoral Fractures

1 Introduction

Fractures of the femur in children are usually situated in the diaphysis and seldom occur in the metaphysis or epiphysis. Unusually severe violence is required to fracture the femur in the vicinity of the knee joint. Road traffic accidents are the most frequent cause, and there are often concomitant injuries with severe damage to the soft tissues surrounding the fracture. *Direct* violence usually leads to metaphyseal fracture of the supracondylar femur without involvement of the epiphyseal plate. *Indirect* violence, such as hyperextension of the knee joint generates *shear forces* in the distal femur which cause simple separation of the epiphysis. If there is an additional bending component, separation of the epiphysis occurs with the inclusion of a metaphyseal fragment (*Aitken I*). During forcible abduction or adduction of the knee joint with simultaneous axial compression, the pressure of the medial or lateral tibial plateau on the corresponding femoral condyle causes the latter to break away. The resulting fracture transects the growth cartilage of the epiphyseal plate and abnormal growth frequently results. The same trauma mechanism may lead to avulsion of a collateral ligament; since the insertion of the latter is adjacent to the epiphyseal plate, an injury of this type may also be followed by abnormal growth.

2 Fracture Types and Treatment

Fractures of the distal femur are classified according to their morphology and prognosis as follows:

a) Fractures which are limited to the metaphysis (supracondylar fractures of the femur);
b) Fractures which involve the epiphyseal plate; these are further classified into
   Fractures which do not cause abnormal growth.
   Fractures which cause abnormal growth.
c) Avulsion fractures of the insertion of a collateral ligament.

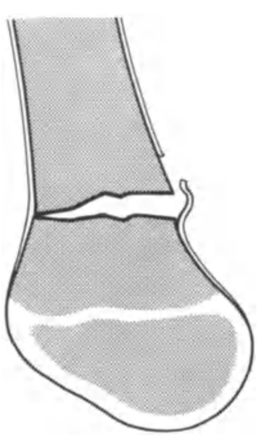


Fig. 1. *Greenstick fracture of the distal metaphysis of the femur*. Moderate dislocation. Tearing of the dorsal periosteum

2.1 Fractures Limited to the Metaphysis (Supracondylar Femoral Fractures)

2.1.1 Greenstick Fractures (Fig. 1)

2.1.1.1 Pathological Anatomy

These fractures occur in small children whose bones are very resilient and surrounded by a tough periosteum. The fracture is therefore restricted to the cortex on one side of the bone with tearing of the overlying periosteum. The cortex on the opposite side is only compressed or bent, and the overlying periosteum remains intact.

The latter intact structures exert unilateral tension on the bone and thus maintain the angulation of the fracture, even in a circular cast. Therefore, in order to treat the fracture effectively, the intact cortex must be broken or the angulation of the fracture must be over-corrected at the time of fixation. The direction and severity of the angulation are determined by the forces acting on the bone at the time of the accident.

2.1.1.2 Treatment

Fractures which are only slightly bent in small children do not necessarily need to be reduced. The axial misalignment corrects itself in the course of subsequent growth.

Fractures with severe angulation are reduced by breaking the intact cortex under general anesthesia. The reduction is then checked under the image intensifier.

Immobilization: A long, split, circular cast is applied for 2–3 weeks. The split cast is closed after 3–5 days. Following its removal, a full-leg walking cast is applied for a further 3 weeks.

Duration of fixation 5–6 weeks.

2.1.2 Dislocated Fractures

2.1.2.1 Pathological Anatomy

The cortex is completely broken and the periosteal cuff is disrupted. The distal condylar fragment is tilted by the pull of the gastrocnemius muscle (*Ehalt*), and the vessels and nerves at the back of the knee may be damaged by its sharp edge (Fig. 2). Awareness of

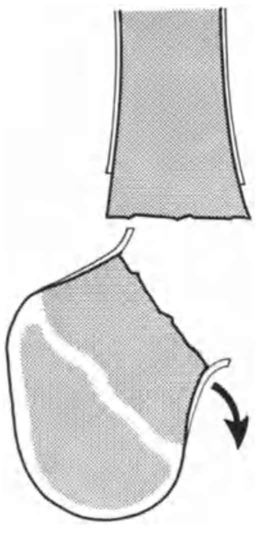


Fig. 2. *Dislocated supracondylar fracture*. The distal fragment is tilted in this characteristic manner by the pull of the gastrocnemius muscles

the tendency of the distal fragment to dislocate in this manner is of considerable practical importance.

2.1.2.2 Treatment

Nonoperative Treatment: Closed reduction is carried out under general anesthesia with the knee joint flexed in order to neutralize the muscle pull. The need for precise reduction increases with the age of the child, and any axial misalignment in an adolescent in whom growth has almost ceased should be completely eliminated since the residual growth potential is insufficient to correct the deformity.

Immobilization: a) Fractures which are fairly stable following reduction are immobilized with a long hip spica with the knee and hip joints slightly flexed.

b) Fractures which are unstable following reduction have to be immobilized in such a way as to neutralize the pull of the gastrocnemius muscle, which tends to tilt the distal fragment in the manner described above. The leg is therefore placed in a long, split circular cast with the knee joint flexed at 90°. After 2 weeks, bone union has advanced to the point at which the latter cast can be replaced by a long hip spica with the hip and knee joints slightly flexed.

Note: This treatment necessitates admission of the patient to hospital with careful surveillance of the circulation and motor and sensory innervation of the limb.

Duration of fixation: 6–8 weeks, depending on the age of the child.

Operative Treatment: Open reduction and internal fixation are indicated in the following situations:

a) Wide open fractures. Careful débridement necessarily involves exposure of the fracture. The soft tissue injuries heal more safely under stable conditions (*Weber*) (Fig. 3).
b) Irreducible fractures (Fig. 4).
c) Fractures which occur shortly before cessation of growth and which cannot be reduced with the required degree of precision by nonoperative methods. (Fig. 5).

Operative procedure: In a small child, the fracture is reduced and stabilized with crossed *Kirschner* wires. The latter are inserted above the epiphyseal plate or through the sides of the condyles and driven into the opposite cortices. *Kirschner* wires which pass through the epiphyseal plate should be aligned at as near to a right angle to the latter as possible (Fig. 6). In larger children and adolescents, the fracture is fixed with a plate which is kept proximal to the growth cartilage.

Postoperative treatment: A split, circular, well-padded full-leg cast is applied. Two weeks after the operation, the skin sutures are removed and the leg is placed in a full-leg walking cast for 4–6 weeks. *Kirschner* wires are removed after 8 weeks and plates after 4–6 months.

Duration of fixation: 6–8 weeks, depending upon the age of the child.

2.2 Fractures Involving the Epiphyseal Plate

This type of fracture leads to complete separation of the epiphyseal plate or may transect the germinative cartilage layers. In the latter case, severe progressive disturbance of growth may be expected. Injuries to the epiphyseal plate may therefore be divided into two categories on the basis of their prognosis, i.e.,

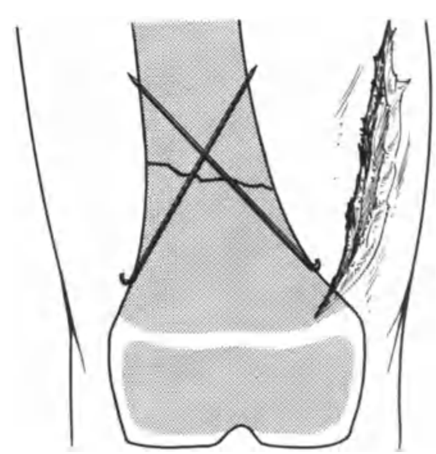
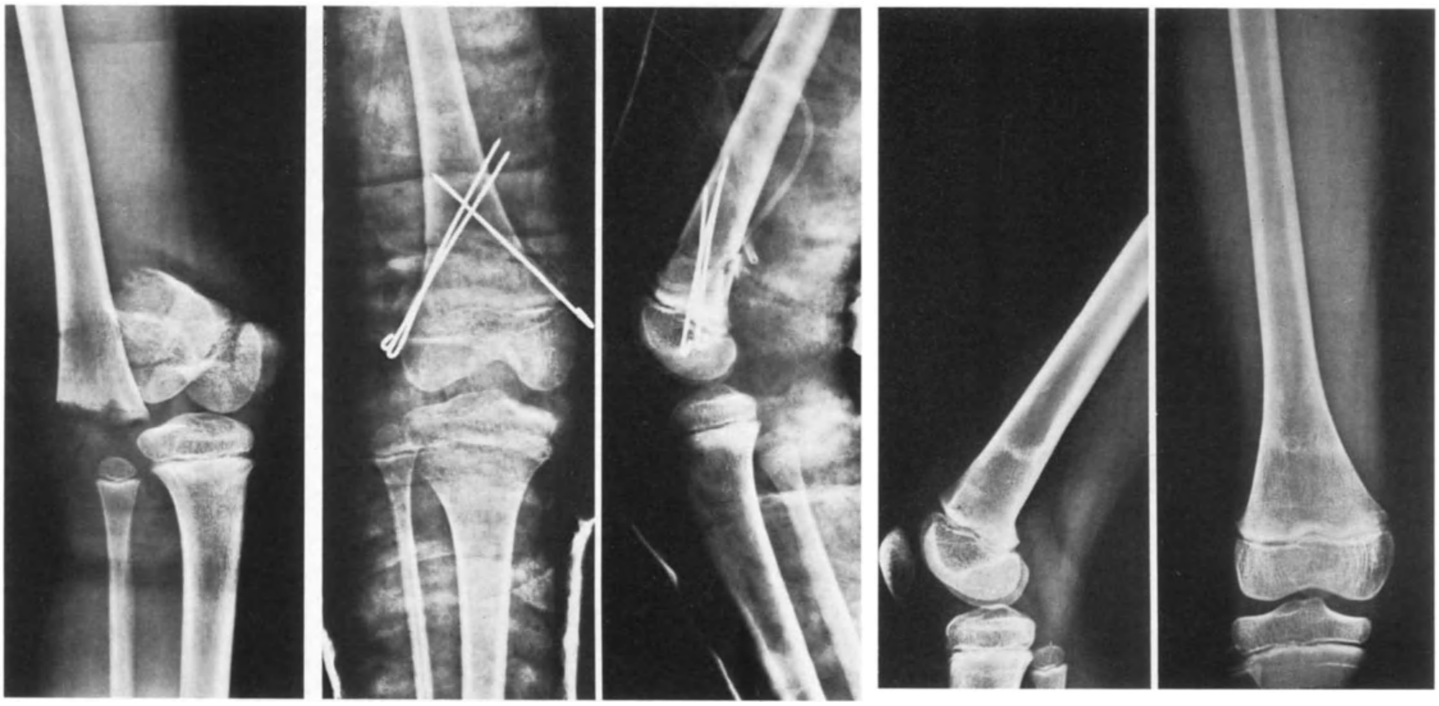
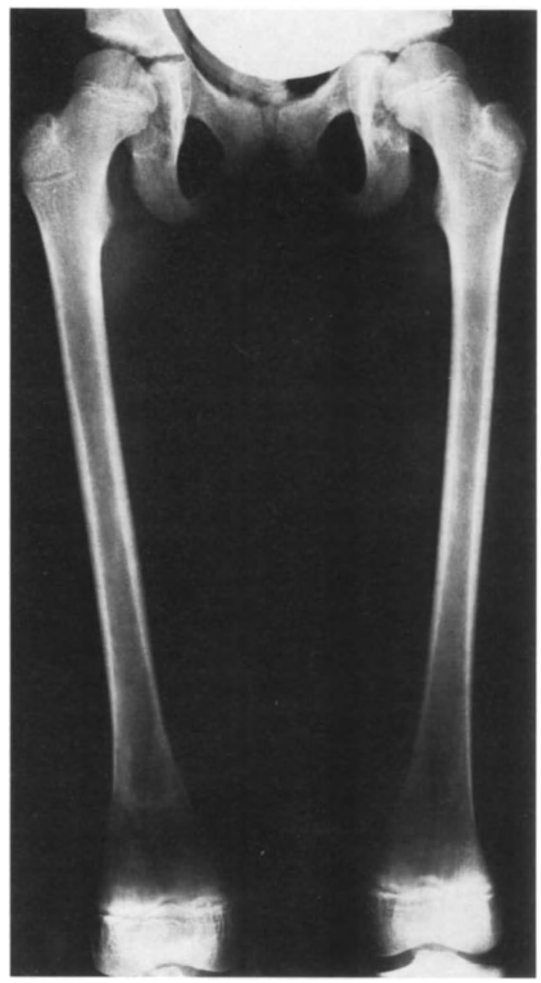


Fig. 3. *Indication for surgical exploration, exposure of the fracture, and internal fixation: severe soft tissue injury.* In order to promote soft tissue healing, open reduction of the fracture is followed by immobilization with crossed *Kirschner* wires



a b c

Fig. 4a–d. *Indication for open reduction: irreducibility of the fracture*. H.U., ♂, aged 9 years, No. 187473.
a) The fresh fracture. Attempted reduction under general anesthesia was unsuccessful.
b) Anatomically precise open reduction and *Kirschner* wire fixation.
c) 1 year after the accident. The fragments have united at the correct angle and growth has continued normally.
d) $1^1/_2$ years after the accident. There are no residual signs of the fracture



d

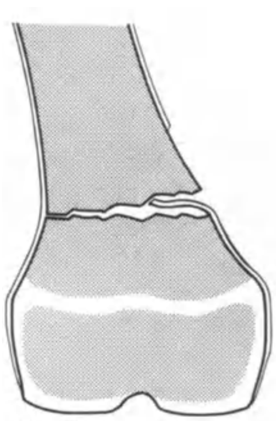


Fig. 5

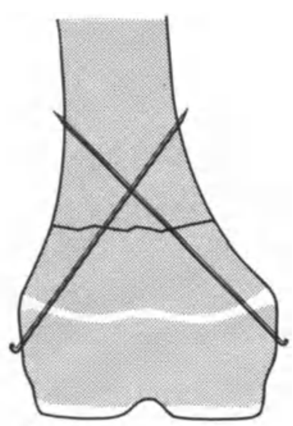


Fig. 6

Fig. 5. *Indication for surgical exposure of the fracture: a trapped periosteal flap in an adolescent*. The interposed tissue causes permanent axial misalignment

Fig. 6. *Technique of Kirschner wire fixation. Kirschner* wires should pierce the epiphyseal plate at as near to a right angle to it as possible

a) Fractures which do not cause progressive disturbance of growth;
b) Fractures which cause progressive disturbance of growth.

In effect, these groups are based on the *Aitken* classification.

2.2.1 Fractures Which do not Lead to Progressive Disturbance of Growth

a) Simple epiphyseal separation.
b) Epiphyseal separation with a metaphyseal fragment (*Aitken* I).

The prognoses and treatments of these two fracture types are identical. The fractures are caused by bending and shear forces.

2.2.1.1 Pathological Anatomy

Simple separation of the epiphysis. Violent hyperextension of the knee joint combined with contraction of the quadriceps muscle leads to forward dislocation of the femoral condyle. The periosteum is torn, and the femoral shaft is displaced backwards and may injure the adjacent vessels or nerves (Fig. 7).

Separation of the epiphysis with a metaphyseal fragment (Aitken I). This type of fracture is caused by the shear and bending forces generated by abduction or adduction or by hyperflexion of the knee joint. Since the tensile strength of the ligaments is greater than that of the junction between the epiphyseal plate and the metaphysis, separation tends to occur. The periosteum tears on the side of the separation and may fold on its distal attachment so as to become trapped between the fragments. The bending forces cause a metaphyseal fragment to break away. This fragment remains firmly attached to the epiphyseal plate (Fig. 8).

In both cases, the fracture line is situated between the layer of degenerating cartilage cells and that of primary bone formation. The germinative layer of the epiphyseal plate remains intact and the subsequent growth may therefore be expected to remain normal (*Süssenbach* and *Weber*).

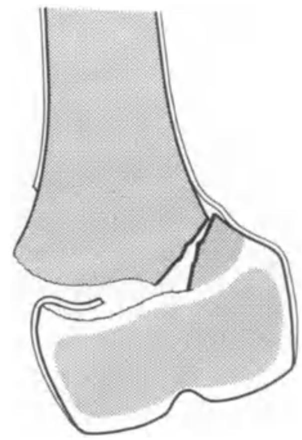


Fig. 8. *Aitken Type I fracture separation*. Here, a periosteal flap has slipped into the gap

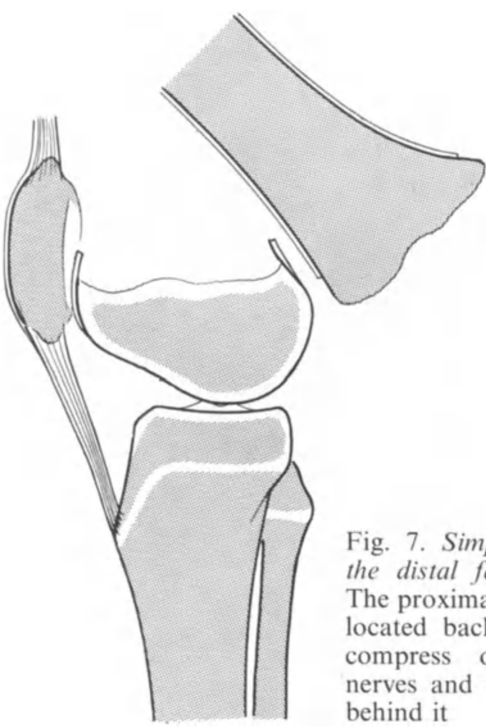


Fig. 7. *Simple separation of the distal femoral epiphysis*. The proximal fragment is dislocated backwards and may compress or damage the nerves and vessels which lie behind it

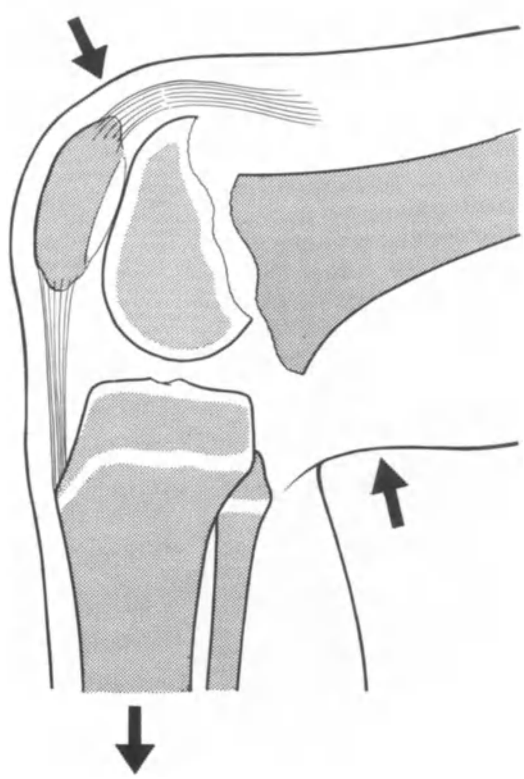


Fig. 9. *Reduction of a severely dislocated separation of the distal femoral epiphysis*. The epiphysis is first restored to its place on the end of the distal femoral metaphysis by traction and pressure. Reduction is then completed by flexing the knee joint

Fig. 10a–c. *Metaphyseal fracture separation of the distal femur*. M.J., ♂, aged 10 years, No. 162314.
a) Fresh fracture.
b) Closed reduction and fixation with a long hip spica.
c) $4^1/_2$ years after the accident. The limbs are symmetrical and complete recovery has taken place

2.2.1.2 Treatment

These fractures are usually treated nonoperatively, but the age of the patient is an important determinant. Residual angular misalignment following reduction is largely corrected by the subsequent growth of the epiphyseal plate. The magnitude of this growth potential decreases, and the need for precise reduction of the fracture therefore increases with the age of the child. In adolescents in whom growth has almost ceased, open reduction may be necessary to ensure precise alignment of the fragments (*Weber*).

Nonoperative Treatment: Reduction is carried out under general anesthesia.

Simple epiphyseal separation (Fig. 9): The hip and knee joints are flexed in order to neutralize the dislocating actions of the quadriceps and gastrocnemius muscles. Reduction is then brought about by exerting powerful pressure on the epiphysis and the femoral shaft with simultaneous traction on the lower leg.

Aitken Type I fractures (Fig. 10): Since the majority are abduction injuries, reduction by forced adduction of the fragments may be possible. Care should be taken to ensure correct rotation alignment, since malrotation does not undergo spontaneous correction in the course of subsequent growth. If correct axial alignment of the fragments cannot be obtained, a periosteal flap may be trapped between the fragments. In small children, the resulting initial malunion is unimportant since it undergoes correction during subsequent growth.

Immobilization: Simple separations: Frequently the fragments are stablest with the knee flexed at 90°. A split full-leg cast is therefore applied with the knee in this position. If the knee joint is insufficiently flexed, forward dislocation may recur (*Aitken* and *Magill*). After 2 weeks, the fracture is more or less stable, and the above cast is replaced with a long hip spica for 4–6 weeks with the hip and knee joints slightly flexed.

Aitken Type I fractures: Long hip spica.

Duration of fixation: 6–8 weeks, depending on the age of the child.

Operative Treatment: Open reduction and fixation are indicated in the following situations:

a) Open fractures. Internal fixation promotes soft tissue healing (*Weber*).

b) Adolescents shortly before cessation of growth. If anatomically precise reduction is not possible because of interposition of periosteum or for some other reason, open reduction is necessary.

c) Fractures which cannot be satisfactorily reduced.

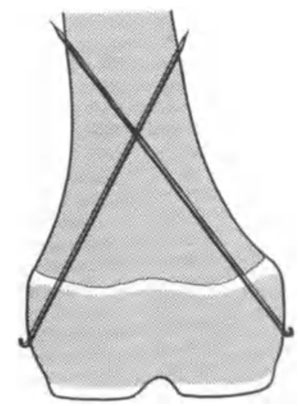


Fig. 11. *Technique of internal fixation of simple separation of the distal femoral epiphysis.* Reduction is followed by fixation with *Kirschner* wires which pierce the epiphyseal plate at as near to a right angle to it as possible

Operative procedure: Following the extraction of interposed soft tissue, the fracture is carefully reduced and stabilized by adaptation osteosynthesis. Simple epiphyseal separations are stabilized with crossed *Kirschner* wires which pass through the epiphyseal plate at as near to a right angle to it as possible (Fig. 11).

Aitken Type I fractures with a sufficiently large metaphyseal wedge are fixed with a screw which is placed parallel to the epiphyseal plate (Fig. 12). If this is not possible, *Kirschner* wires are used (Fig. 13).

A screw should never pass through the epiphyseal plate since this would induce epiphyseal fusion with correspondingly abnormal growth.

Postoperative treatment: A split, circular, well-padded, full-leg cast is applied. After 2 weeks, the skin sutures are removed and a full-leg walking cast is applied for 4–6 weeks. The metal is removed after 6–8 weeks.

Duration of fixation: 6–8 weeks, depending on the age of the child.

2.2.2 Fractures Which Cause Progressive Disturbance of Growth

a) Fracture separation with an epiphyseal fragment (*Aitken* Type II).
b) Fracture separation with an epimetaphyseal fragment (*Aitken* Type III).

Both types of fracture are caused by bending and compression forces. They transect the growth cartilage zone and result in discontinuity of the joint surface. These fractures are rare, but may have serious consequences.

a b c

d

Fig. 12a–d. *Irreducible fracture separation of an epiphysis. Screw fixation.*
a) Technique of screw fixation. The screw passes through the metaphysis and lies parallel to the epiphyseal plate.
b) R.T., ♂, aged 11 years, No. 157253. Irreducible supracondylar metaphyseal fracture separation.
c) Treatment by open reduction and fixation with screws which are restricted to the metaphysis.
d) 1 year after the operation. Full recovery has taken place and normal growth has continued

a b c

Fig. 13a–c. *Irreducible fracture separation. Kirschner wire fixation.* H.M., ♀, aged 10 years, No. 70882.
a) *Aitken* Type I fracture of a distal femur with a very small metaphyseal fragment.
b) Treatment by surgical exposure of the fracture, extraction of the periosteum which had impeded closed reduction, and internal fixation of the reduced fracture with two *Kirschner* wires.
c) 8 years later. Complete anatomical and functional recovery

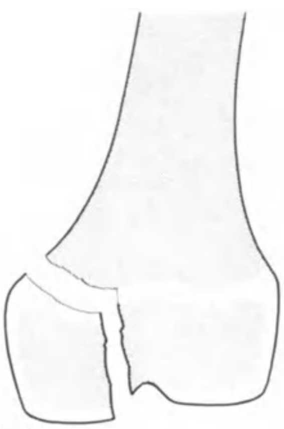


Fig. 14

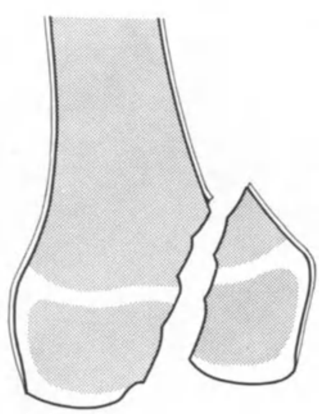
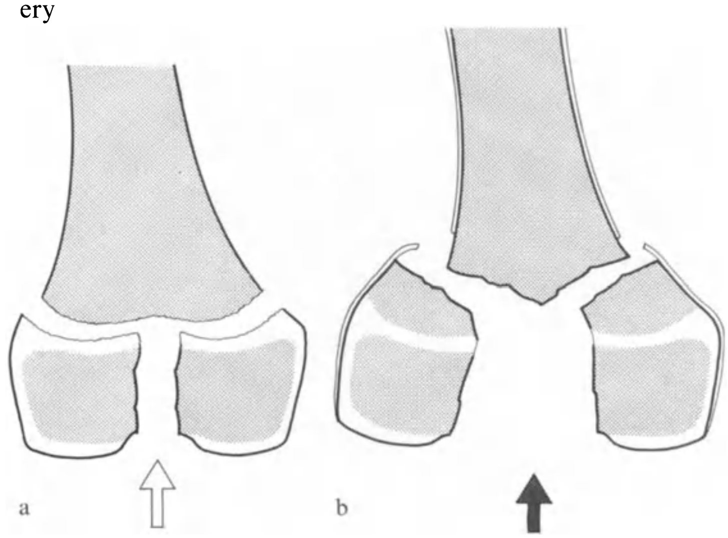


Fig. 15

Fig. 14. *Aitken Type II intraarticular fracture.* The fracture line crosses the epiphyseal plate

Fig. 15. *Aitken Type III intraarticular fracture.* The fracture line crosses the epiphyseal plate



a b

Fig. 16a, b. *T- and Y-fractures (Aitken Types II and III).*
a) T-shaped fragmentation (*Aitken* II).
b) Y-shaped fragmentation (*Aitken* III)

Fig. 17a–d. *Aitken Type III fracture of the distal femur. Screw fixation*. S.P., ♂, aged $9^{1}/_{2}$ years, No. 174518.
a) The fresh fracture.
b) Treatment by open reduction and fixation with screws placed parallel to the epiphyseal plate.
c, d) 1 year after the accident. Normal growth has taken place

2.2.2.1 Pathological Anatomy

Fracture separation with an epiphyseal fragment (Aitken Type II). Forced abduction or adduction of the knee joint combined with an axially directed impact causes the tibial plateau to exert pressure on the femoral condyle, and the latter breaks away. The fracture line completely transects the epiphyseal plate and then runs laterally between the zone of degenerating cartilage cells and that of primary ossification (Fig. 14).

Fracture separation with an epimetaphyseal fragment (Aitken III). The only difference between this fracture type and the *Aitken* Type II lesion lies in the course of the fracture line, which starts in the epiphysis, transects the epiphyseal plate, and continues on through the metaphysis (Fig. 15).

A purely axial impact causes a T-shaped fracture by driving the intercondylar eminence of the tibia between the femoral condyles, thus forcing them apart. An *Aitken* Type II or III fracture results (Fig. 16).

2.2.2.2 Treatment

These fractures always involve damage to the sensitive layer of germinative cells and the subsequent growth is therefore likely to be abnormal. Nonoperative treatment allows the formation of a callus bridge in the fracture gap which transects the epiphyseal plate. This is equivalent to partial epiphyseal fusion and results in disturbance of growth. However, observations of healing in the vicinity of the ankle joint (*Süssenbach* and *Weber*) have shown that this abnormal growth is not inevitable. Precise reduction of the fracture with restoration of perfect contiguity and firm fixation of the fragments provide excellent conditions for uneventful healing without the formation of a callus bridge between the epiphysis and metaphysis. Furthermore, lack of relative movement between the fragments promotes revascularization of the germinative cartilage layer. For these reasons, *Aitken* Type II and III lesions should always be treated by open reduction and internal fixation.

Operative Treatment: Operative procedure: Following gentle and anatomically precise reduction of the fracture, the fragments are fixed firmly together with a lag screw placed parallel to the epiphyseal plate (Fig. 17). This renders the fracture "watertight."

Postoperative treatment: A well-padded, circular, split, full-leg cast is applied. After 2 weeks, this is removed, the skin sutures are removed, and a full-leg walking cast is applied for 4–6 weeks.

Duration of fixation: 6–8 weeks, depending on the age of the child.

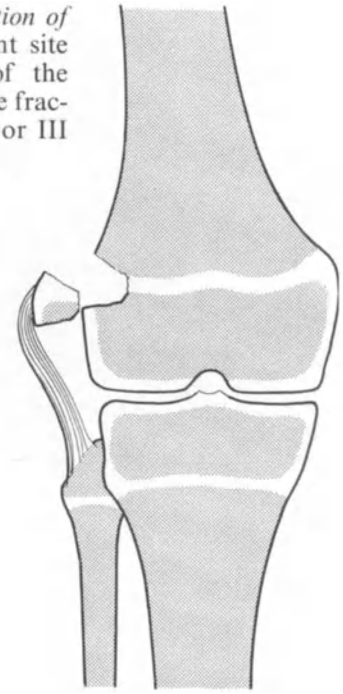


Fig. 18. *Avulsion of the insertion of a ligament.* The most frequent site is the proximal insertion of the lateral collateral ligament. The fracture belongs to the *Aitken* II or III category

2.3 Ligamentary Avulsion Fractures (*Weber*)

2.3.1 Pathological Anatomy

Injuries involving the ligaments alone rarely occur in children; avulsion at the site of insertion of the ligament in the femoral condyle is more usual. Since the insertions of the collateral ligaments are adjacent to the epiphyseal plate, avulsion may result in abnormal growth. The perichondrium is torn or the ligament rips away a disc of bone from the condyle. The resulting fracture line transects the germinative cartilage layer and the fracture therefore belongs to categories II or III of the *Aitken* classification (Fig. 18). Both types of injury may lead to formation of a bone bridge across the epiphyseal plate or partial ossification of the growth cartilage; in each case, progressively abnormal growth results (Fig. 19). In order to diagnose a fresh avulsion fracture, oblique roentgenograms or films with the limb held in forced adduction or abduction are sometimes required.

2.3.2 Treatment

Operative Treatment: In accordance with the guidelines for the treatment of *Aitken* Type II and III fractures, ligamentary avulsion fractures are always treated operatively. This is the only way of preventing the formation of a callus bridge between the epiphysis and metaphysis.

Operative procedure: Gentle reduction of the fragments and fixation with a small lag screw (Fig. 20). The latter should never cross the epiphyseal plate.

Fig. 19a–e. *Skew growth following nonoperative treatment of avulsion of the insertion of a ligament.* B.R., ♂, aged $12^1/_2$ years, No. 42701.
a) This avulsion fracture of the insertion of the lateral collateral ligament was not taken sufficiently seriously, and treatment was limited to a circular cast around the knee for 6 weeks.
b) 8 weeks later, epiphyseal fusion has already occurred on the lateral side.
c) $1^1/_2$ years later. Severe valgus deformity with shortening.
d) $2^1/_2$ years after the accident. Corrective osteotomy.
e) 2 months later. The corrective osteotomy has united and the valgus deformity has been eliminated. Leg shortening of 1.5 cm

Fig. 20a–c. *Internal fixation of an avulsion fracture of the insertion of the lateral collateral ligament (Aitken Type II).* H.M., ♀, aged 12 years, No. 118778.
a) The fresh fracture.
b) "Watertight" reinsertion of the avulsed fragment and fixation with a lag screw which is restricted to the epiphysis.
c) $1^3/_4$ years after the operation. No disturbance of growth has occurred, and the axes of the leg are normal

Postoperative treatment: Full-leg plaster splint for 2 weeks. On discharge from hospital, the skin sutures are removed and a full-leg plaster cast is applied for 4–6 weeks. The metal is removed after 6–8 weeks.

Duration of fixation: 6–8 weeks, depending on the age of the child.

3 Prognosis

3.1 Longitudinal Growth and Initial Angular Deformity

Hyperemia in and around the fracture stimulates activity in the epiphyseal plate and may cause *accelerated longitudinal growth* in some cases. Transient slowing of growth occurs much more frequently and is documented by the *Harris*-line on a roentgenogram. The increase or decrease in the growth rate is usually limited to a few millimeters and is not usually noticed by the child.

Slight degrees of initial angular misalignment are usually straightened by corrective assymetrical growth in the epiphyseal plate. However, this does not apply to malreduced fractures which have occurred shortly before the cessation of skeletal growth; the remaining growth potential is insufficient to correct the misalignment, and permanent deformity may result with all its consequences.

3.2 Progressive Angular Deformity

Aitken Type II and III fractures which are treated nonoperatively result in discontinuity of the joint surface and, in the great majority of cases, severely abnormal growth. Forced abduction of the knee joint coupled with an axially directed impact results in fracture of the germinative cartilage layer together with crushing of the lateral part of the epiphyseal plate. The latter cartilage ossifies in the course of healing, forming a callus bridge between the epiphysis and metaphysis. This is equivalent to partial epiphyseal fusion, and since normal growth continues on the medial side a *valgus knee* results. The same deformity occurs following avulsion of the lateral collateral ligament from the epiphysis if the nature of the injury to the epiphysis is not recognized. If the injury occurs on the medial side, it results in *varus deformity of the knee*. In both cases, the deformity is progressive and is accompanied by shortening of the femur. If the damage caused by crushing of the epiphyseal plate is reversible, prompt operative treatment can prevent abnormal growth.

4 Results

We treated a total of 13 epiphyseal and metaphyseal fractures of the distal femur between 1961 and 1969. With the following two exceptions, the fractures healed uneventfully.

Case 1: For reasons unknown to us, separation of an epiphysis was treated by immediate fusion using the *Phemister* technique. This resulted in 2.5 cm leg shortening.

Case 2: Avulsion of the lateral collateral ligament from the epiphysis was treated nonoperatively owing to failure of the surgeon to recognize the true nature of the injury. Partial epiphyseal fusion occurred and inevitably resulted in valgus deformity with shortening of the leg.

5 Summary

Fractures of the distal femur are usually treated nonoperatively. *Aitken* Type II and III epiphyseal fractures and fractures due to avulsion of the collateral ligaments are exceptions. The line of an epiphyseal fracture starts at the joint surface and transects the germinative layer of the epiphyseal plate; discontinuity of the joint surface always results. Open reduction and fixation are essential prerequisites to uneventful healing without sequelae.

Patella Fractures

1 Introduction

The patella of a child is surrounded by a thick layer of cartilage and is therefore well protected against injury. Fractures of the patella are therefore very rare in young children, but seem to occur somewhat more frequently in older children. If the patella is forced against the femoral condyle by a direct blow or a fall on to the knee, a *transverse or comminuted fracture* of the body of the patella or a *subchondral fracture* of its posterior surface results. Sudden contraction of the quadriceps muscle with the knee joint flexed

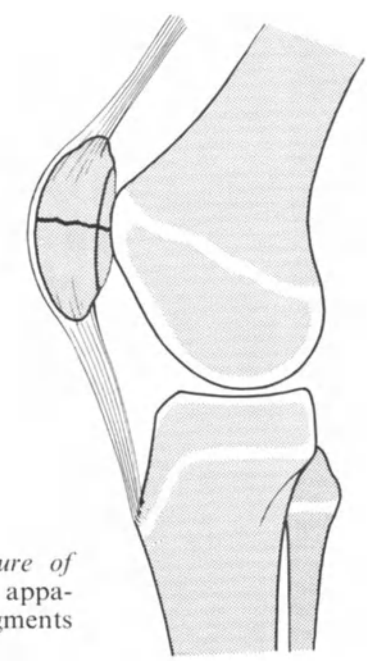


Fig. 21. *Nondislocated fracture of the patella.* If the extensor apparatus remains intact, the fragments are not drawn apart

Fig. 22a–c. *A nondislocated fracture of the patella.* B.M., ♀, aged 9 years, No. 122386.
a) Because the extensor apparatus was intact, the fracture was treated nonoperatively by immobilization of the knee with a plaster cylinder.
b) 1 month after the accident. The fragment has united.
c) $1^1/_2$ years after the accident. The fracture has healed. The patellae appear slightly different in the roentgenograms. The range of knee joint motion is normal

may cause avulsion of the upper or lower pole or a simple transverse fracture.

2 Fracture Types and Treatment

There is usually only one center of ossification in the patella. Occasionally, however, a second center which is completely separate from the main one arises in the upper lateral quadrant. This gives rise to a bipartite patella, which may simulate a fracture on a roentgenogram. The anomaly is usually present on both sides

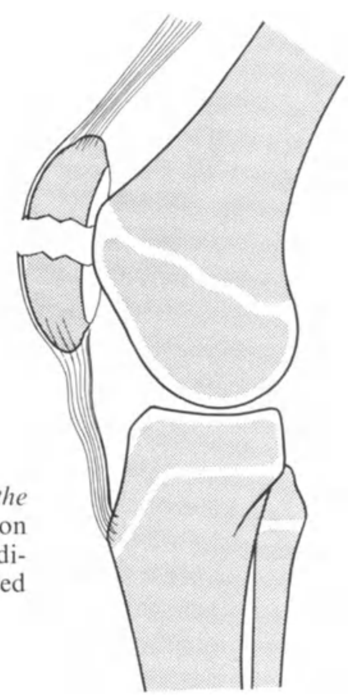
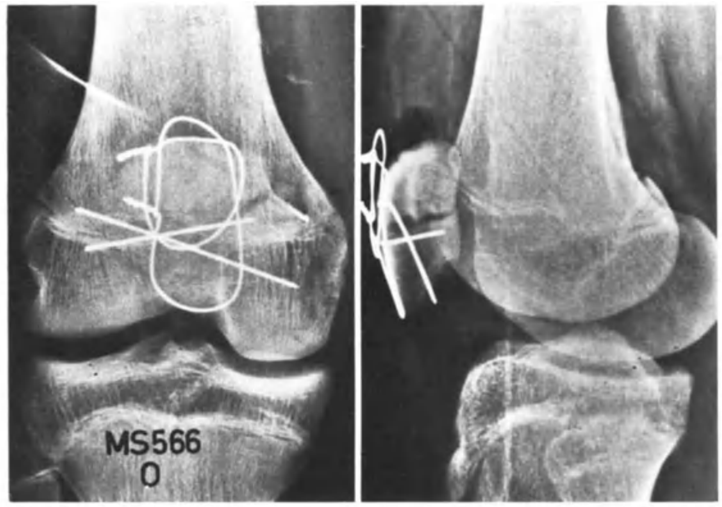


Fig. 23. *Dislocated fracture of the patella.* There is marked dislocation of the fragments and the fibrotendinous extensor apparatus is ruptured

a



b

c

Fig. 24a–c. *Dislocated fracture of the patella.* F.F., ♂, aged 14 years, No. 75460.
a) The fresh comminuted fracture which resulted from a fall on to the knee.
b) Intraoperative roentgenogram (*Kirschner* wire transfixation and tension-band osteosynthesis).
c) $7^1/_2$ years after the accident. Healing complete with no sequelae

and one is advised to X-ray the opposite side in cases of doubt.

Injuries to the patella are classified as follows:

a) Fractures of the body of the patella.
b) Avulsion of the upper or lower pole.
c) Flake fractures.

2.1 Fractures of the Body of the Patella

The treatment depends on the degree of damage to the extensor apparatus. There are two possibilities.

2.1.1 Fractures Without Failure of the Extensor Apparatus

2.1.1.1 Pathological Anatomy

The patellar retinaculi and the fibers derived from the quadriceps tendon which extend down over the patella remain intact. The child can still extend the knee joint and any dislocation of the fragments is only slight (Fig. 21).

2.1.1.2 Treatment

Fractures of the patella which are not accompanied by failure of the extensor apparatus are treated non-operatively, irrespective of the type of fracture (Fig. 22).

Immobilization: Circular full-leg cast with 25° knee joint flexion; the latter assures congruence of the posterior articular surface of the patella. If there is marked swelling, the cast is split and is then closed after 3–5 days.

Duration of fixation: 4–6 weeks

2.1.2 Fractures with Failure of the Extensor Apparatus

2.1.2.1 Pathological Anatomy

The fibrous extensor apparatus is completely torn and the fragments may be drawn widely apart by the pull of the attached muscle. The patient is no longer able to extend the knee (Fig. 23).

2.1.2.2 Treatment

Open reduction and fixation are the only means of restoring congruence to the articular surface of the patella.

Operative procedure: A transverse skin incision is made, the fragments are exposed, and the fracture is reduced. As in the adult, stabilization is by tension band wiring (Fig. 24). Immediate patellectomy is not indicated in children since even severe cartilage injuries may heal in the course of subsequent growth.

Postoperative treatment: Full-leg plaster splint for 5 days. Mobilization of the joint is then begun under supervision and continues until the wound has healed satisfactorily. A full-leg, circular cast is then applied for 4 weeks.

Duration of fixation: 6 weeks

2.2 Avulsion of the Upper or Lower Pole of the Patella

2.2.1 Pathological Anatomy

Sudden contraction of the quadriceps muscle against resistance (e.g., during sport) may cause tearing of the patellar ligament or, in rare cases, avulsion fracture of the point of attachment of the quadriceps tendon to the patella (Fig. 25). Part of the extensor apparatus remains attached to the small fragment and the patella is thus partially stripped off. If the lesion is limited to the deep layers of the extensor apparatus, active extension of the knee joint is still possible and a roentgenogram shows only slight dislocation of the polar fragment.

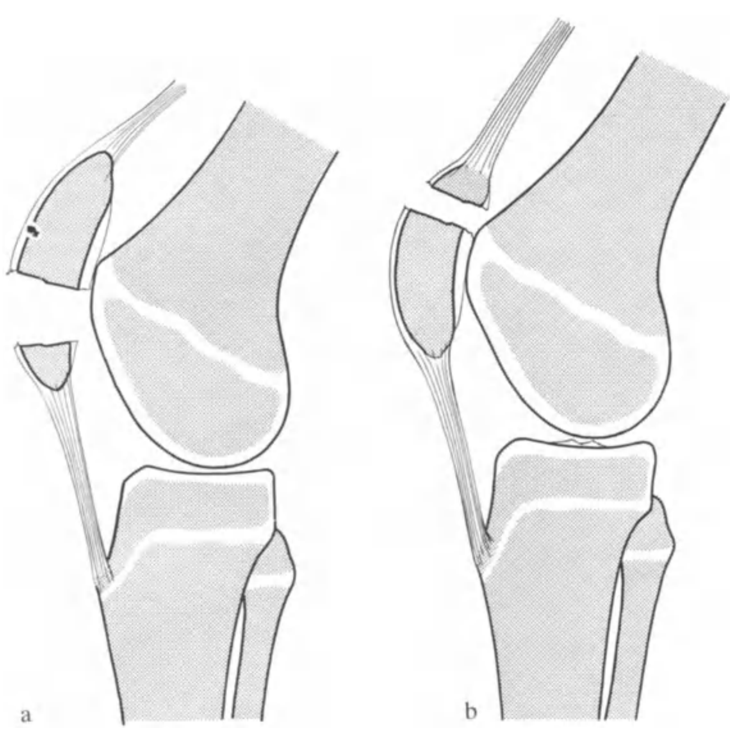


Fig. 25a, b. *Avulsion fractures of the patella.*
a) Avulsion of the lower pole.
b) Avulsion of the upper pole

2.2.2 Treatment

Nonoperative Treatment: Fractures without failure of the extensor apparatus and only slight dislocation of the fragments are treated nonoperatively (Fig. 26).

Immobilization: A circular, full-leg cast is applied. If there is marked swelling, it is split and is then closed after 3–5 days.

Duration of fixation: 4–6 weeks.

Operative Treatment: Open reduction and stabilization are indicated if failure of the extensor apparatus has occurred and there is considerable dislocation of the fragments.

Operative procedure: Frequently, it is sufficient to suture the extensor apparatus with strong material. If there is a large polar fragment, particularly in an adolescent, it is refixed with a small screw (Fig. 27).

Postoperative treatment: Full-leg plaster splint until satisfactory wound healing has occurred, followed by a full-leg, circular cast for 4 weeks.

Duration of fixation: 6 weeks.

2.3 Flake Fractures

2.3.1 Pathological Anatomy

A direct blow on the patella with the knee joint flexed may cause a cartilage fragment to break away from the posterior surface. This usually bears a subchondral layer of bone and is seen on a roentgenogram as a discreet shadow (Fig. 28). The differential diagnosis includes osteochondrosis dissecans of the femoral condyles, which can be excluded by tunnel view roentgenograms.

2.3.2 Treatment

Operative Treatment: The fragment is frequently larger than might be expected from its radiological appear-

Fig. 27a–d. *Pseudarthrosis of a large lower-pole fragment.* L.P., ♂, aged 14 years, No. 137373.
a) Pseudarthrosis of a dislocated fracture of the lower pole of the patella which had occurred 4 months previously. The patient is an athlete.
b) Treatment by stab incision and insertion of a small cortical lag screw.
c) 2 months after the operation. The fracture has become almost invisible.
d) 4 years and 3 months after the accident. Symmetrical knee joints

a

b

Fig. 26a, b. *Avulsion of the lower patellar pole*. N.M., ♂, aged 12 years, No. 130012.
a) The fresh fracture. The fragment is only slightly dislocated, i.e., the extensor apparatus is intact.
b) 9 months following nonoperative treatment by immobilization of the knee with a plaster cylinder. The knee joint is normal

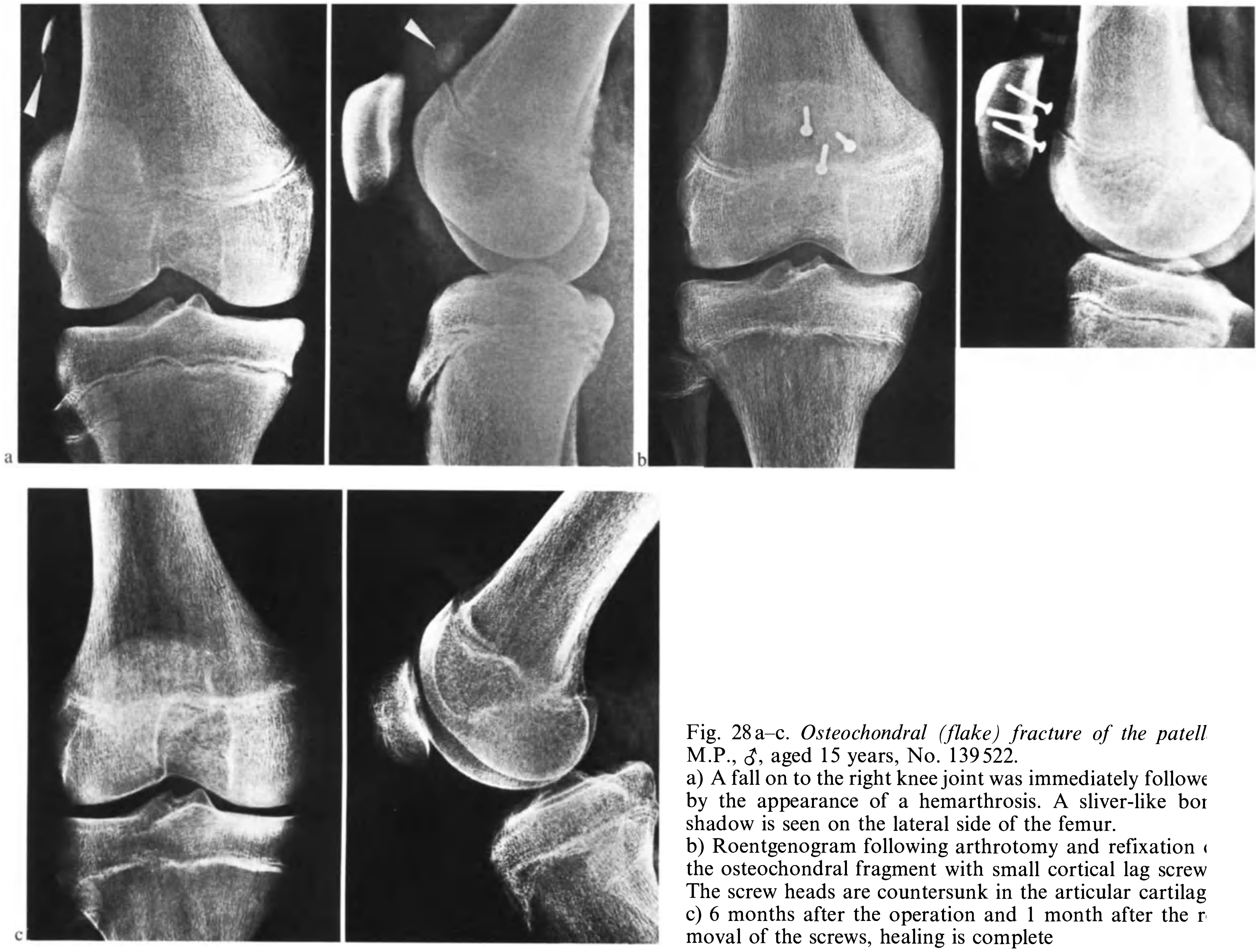


Fig. 28a–c. *Osteochondral (flake) fracture of the patell*
M.P., ♂, aged 15 years, No. 139522.
a) A fall on to the right knee joint was immediately followe
by the appearance of a hemarthrosis. A sliver-like boı
shadow is seen on the lateral side of the femur.
b) Roentgenogram following arthrotomy and refixation ‹
the osteochondral fragment with small cortical lag screw
The screw heads are countersunk in the articular cartilag
c) 6 months after the operation and 1 month after the r
moval of the screws, healing is complete

ance, and for this reason it is sometimes possible to fix it with a small countersunk screw (Fig. 28). Smaller fragments are removed, since the cartilage defect is repaired in the course of subsequent growth.

Postoperative treatment: A simple dressing is applied and early active movement is encouraged with partial weight bearing for 4–6 weeks. The implant is removed after 8 weeks.

3 Results

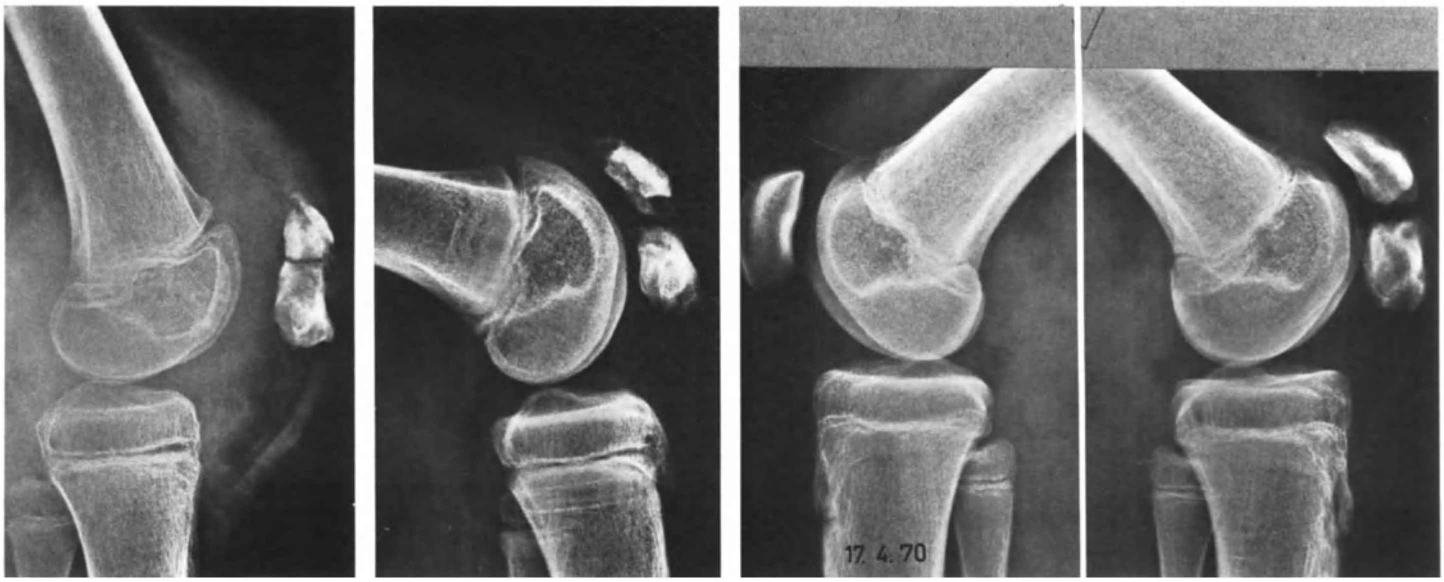
Seven fractures of the patella in children were treated at the cantonal hospital in St. Gall between 1961 and 1969. Complications occurred in two cases, i.e.

Reoperation of an inadequate internal fixation was followed by infection which, however, did not affect the subsequent function of the limb.

A transverse fracture of the patella was treated by simply suturing the fibrous extensor apparatus. This was followed by pseudarthrosis, which was not noticed by the child since it did not affect the function of the limb (Fig. 29).

4 Summary

Fractures of the patella are very rare in children. The choice of treatment is determined by the extent of the damage to the extensor apparatus. If the latter



a b c

d

Fig. 29a–d. *Pseudarthrosis following unsuitable osteosynthesis*. Z.C., ♀, aged 9 years, No. 102343.
a) 2 months after the accident, the transverse fracture, which was sutured together with chromic catgut, is still visible.
b) 14 months after the accident. Pseudarthrosis of the patella.
c) 4 years after the accident. Pseudarthrosis, with marked improvement in the shape of the patella.
d) 6 years after the accident. Pseudarthrosis, resulting in a bipartite patella. The knee joint functions normally and is symptom-free

is functionally intact, nonoperative treatment by immobilization in a cast suffices. If the extensor apparatus has failed or flake fracture has occurred, operative treatment is necessary.

Fractures of the Proximal Tibia

1 Introduction

Injuries to the proximal tibia occur relatively rarely in children, a fact which is due in part to the shape and structure of the bone at this site. Simple separation of the distal femoral epiphysis is seen relatively frequently, but the same lesion hardly ever occurs in the head of the tibia. A possible explanation is that the distal epiphyseal plate of the femur is bowl-shaped, whereas the contours of that of the proximal tibia are more complex and interlocking. Thus, the distal femoral epiphysis offers much less resistance to *shear forces* than that of the proximal tibia, and separation of the latter is therefore much less likely to occur. The collateral ligaments of the knee are mainly attached to the metaphysis on the medial side and insert into the head of the fibula on the lateral side. *Bending forces,* i.e., abduction and adduction forces, are therefore more likely to act on the distal femur; here, the proximal attachments of the ligaments lie in the immediate vicinity of the epiphyseal plate (*Tachdjian*). Similarly, *pressure forces* result more frequently in damage to the condyles of the femur. Fractures of the tibial plateau rarely occur while skeletal growth is in progress. The impression fractures of one or both tibial plateaus which occur in adults are hardly ever seen in children. Shortly before skeletal maturity is reached, the mechanical strength of the epiphyseal plate decreases. Sites which are subjected to severe stresses may therefore undergo separation during this phase. *Avulsion fracture* of the tibial tuberosity is a typical example and is said to be caused by landing on the feet with a severe jolt; the resulting pull on the patellar ligament tears it out at its insertion.

Injuries involving the ligaments alone are frequently seen in adults, but are extremely rare in children. The ligaments are extremely tough in children, and a fall on to the flexed knee is more likely to cause an avulsion fracture at the site of insertion of the cruciate ligaments, i.e., a fracture of the intercondylar eminence.

2 Fracture Types and Treatment

Injuries to the proximal tibia are classified as follows:

a) Fractures of the proximal tibial epiphysis.
b) Avulsion of the intercondylar eminence.
c) Avulsion of the tibial tuberosity.
d) Metaphyseal fractures of the proximal tibia.

2.1 Fractures of the Proximal Tibial Epiphysis

Fractures involving the epiphyseal plate may cause abnormal growth, the type of abnormality being determined by the site and shape of the fracture. We therefore differentiate between two types of injury which are based on the *Aitken* classification, i.e.,

Fractures which do not result in progressively abnormal growth.
Fractures which result in progressively abnormal growth.

2.1.1 Fractures Which are Followed by Normal Growth

These are:
Simple epiphyseal separation;
Separation of the epiphysis with a metaphyseal fragment (*Aitken* Type I).

2.1.1.1 Pathological Anatomy

Simple epiphyseal separation. The shape of the epiphyseal plate is such that sliding displacement is hardly possible and this type of injury is therefore extremely rare. Theoretically, forced hyperextension or flexion could cause ventral or dorsal dislocation, respectively (Fig. 30).

Separation of the epiphysis with a metaphyseal fragment (Aitken I). For the above reasons, this type of fracture can only occur under exceptional circumstances. The accident mechanism involves forced angulation of the lower leg in relation to the femur. A metaphyseal wedge which is firmly attached to the epiphyseal plate is broken away by the bending moment.

In both cases, the germinative cartilage layer remains uninjured and subsequent growth is therefore likely to be normal (Fig. 31).

2.1.1.2 Treatment

Nonoperative Treatment: Since these fractures only occur in adolescents shortly before cessation of skeletal growth, reduction should be anatomically precise and may therefore require operation. At this age, the epiphyseal plate no longer has sufficient growth reserve for the correction of the deformity which remains following imprecise reduction. Any axial misalignment is likely to be permanent and will adversely affect the function of the knee joint.

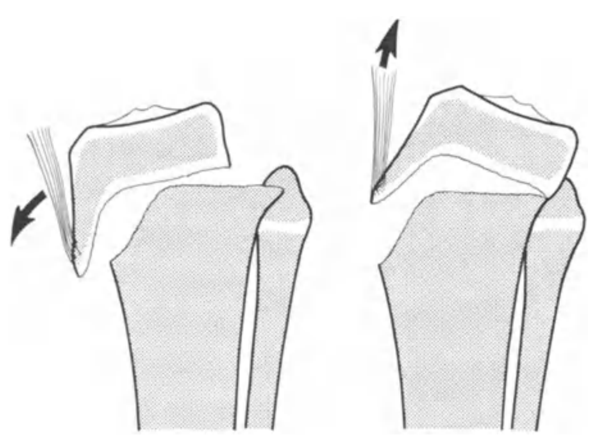


Fig. 30. *Simple separations of the proximal tibial epiphysis*

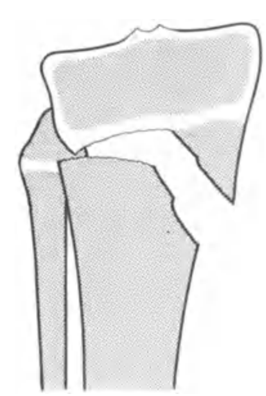


Fig. 31. *Aitken Type I fracture separation of the proximal tibial epiphysis*

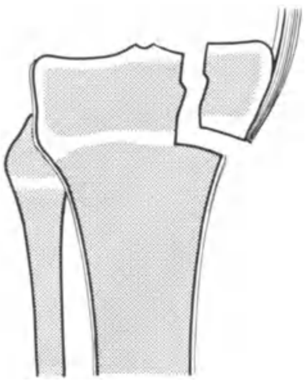


Fig. 32. *Aitken Type II fracture separation of the proximal tibial epiphysis*

Immobilization: Split, circular, full-leg cast which is closed after 3–5 days. Two weeks later, it is replaced by a full-leg walking cast.

Duration of fixation: 6–8 weeks.

2.1.2 Fractures Which are Followed by Abnormal Growth

These are:
a) Fracture separation with an epiphyseal fragment (*Aitken* II).
b) Fracture separation with an epimetaphyseal fragment (*Aitken* III).

2.1.2.1 Pathological Anatomy

Fracture separation with an epiphyseal fragment (Aitken II). The fracture line starts at the joint surface, transects the epiphyseal plate completely and then runs laterally between the layer of degenerating cartilage cells and that of primary ossification (Fig. 32).

Fracture separation with an epimetaphyseal fragment (Aitken III). The fracture line runs more or less parasagittally and extends from the joint surface into the metaphysis. It, thus, corresponds to splitting of the head of the tibia in an adult (Fig. 33).

In both cases, the germinative cartilage layer is damaged by the compression and bending forces, and subsequent growth is likely to be abnormal.

2.1.2.2 Treatment

Operative Treatment: These *Aitken* Type II and III injuries are very rare, but prognostically serious. They require anatomically perfect reduction and fixation, which can only be achieved operatively. Our experience with the treatment of fractures of the epiphyseal plate (*Süssenbach* and *Weber*) has shown that progressive disturbance of growth may thus be avoided.

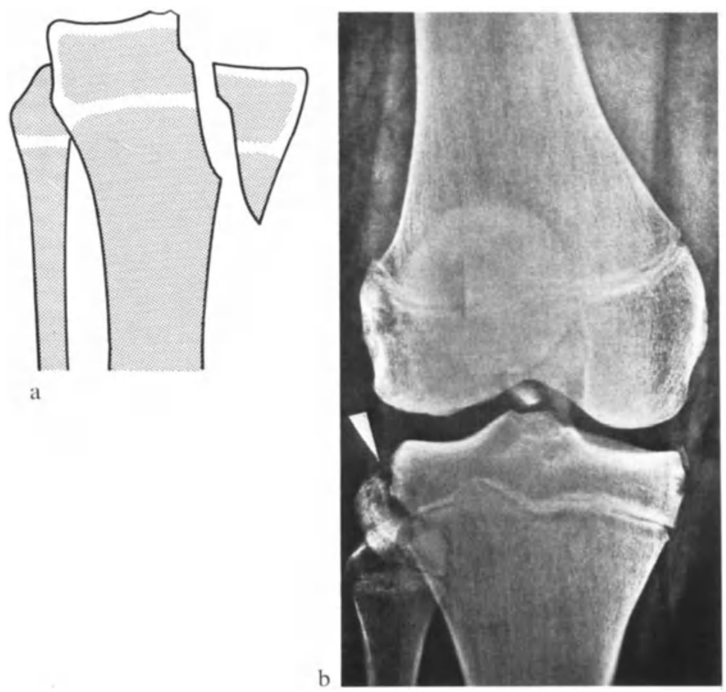


Fig. 33 a, b. *Aitken Type III epimetaphyseal fracture*.
a) This fracture corresponds to the splitting of the head of the tibia which occurs in adults.
b) Z.B., ♀, aged 14 years, No. AK 48513. Roentgenogram taken immediately following the accident, showing an *Aitken* Type III fracture on the lateral side with avulsion fracture of the cruciate ligaments and avulsion of the medial collateral ligament. The true nature and severity of this injury was not recognized on initial examination and the treatment was nonoperative

Operative procedure: Gentle, precise reduction of the fracture followed by fixation with a screw placed parallel to the epiphyseal plate (Fig. 34).

Postoperative treatment: A full-leg plaster splint is applied until satisfactory wound healing has taken place. It is then replaced by a full-leg, circular cast for 4–6 weeks. The metal is removed after 8 weeks.

Duration of fixation: 6–8 weeks.

2.2 Avulsion of the Intercondylar Eminence

2.2.1 Pathological Anatomy

Avulsion of the bony insertion of the cruciate ligaments is brought about by a fall on to the flexed knee or by torsion with simultaneous hyperextension

a b c

Fig. 34a–c. *Aitken Type II fracture of the head of the tibia.* V.A., ♂, aged 16 years, No. 79824.
a) The anterior surface of the tibia has been torn away.
b) Appearance following open reduction and internal fixation (screw fixation is permissible only in adolescents!).
c) 7 years after the accident. Symmetrical knees

(Fig. 35). The intercondylar eminence may only be slightly raised or may be completely dislocated. The former lesion is difficult to diagnose radiologically, and roentgenograms of the opposite, intact side may be required for comparison.

2.2.2 Treatment

The treatment is chosen according to the degree of dislocation of the fragment.

Nonoperative Treatment: An intercondylar eminence which is nondislocated or only slightly dislocated is treated nonoperatively (Fig. 36).

Immobilization: Split, circular, full-leg cast with the knee joint almost fully extended. The cast is closed after 3–5 days.

Duration of fixation: 6–8 weeks.

Operative Treatment: Malunion of an avulsion fracture of the intercondylar eminence causes incongruence of the joint and permanent limitation of knee joint extension. Open reduction and fixation are indicated if there is considerable dislocation.

Operative procedure: A medial parapatellar incision is made and the knee joint is opened. The fragment is replaced and is fixed with a wire loop or with a small lag screw which is inserted from below (Fig. 37).

Postoperative treatment: Immobilization with a full-leg plaster splint until satisfactory wound healing has occurred. The splint is then replaced by a full-leg, circular cast for 4–6 weeks. The metal is removed after 8 weeks.

Duration of fixation: 6–8 weeks.

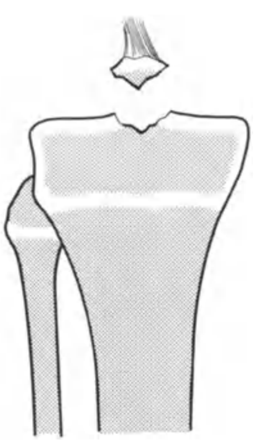
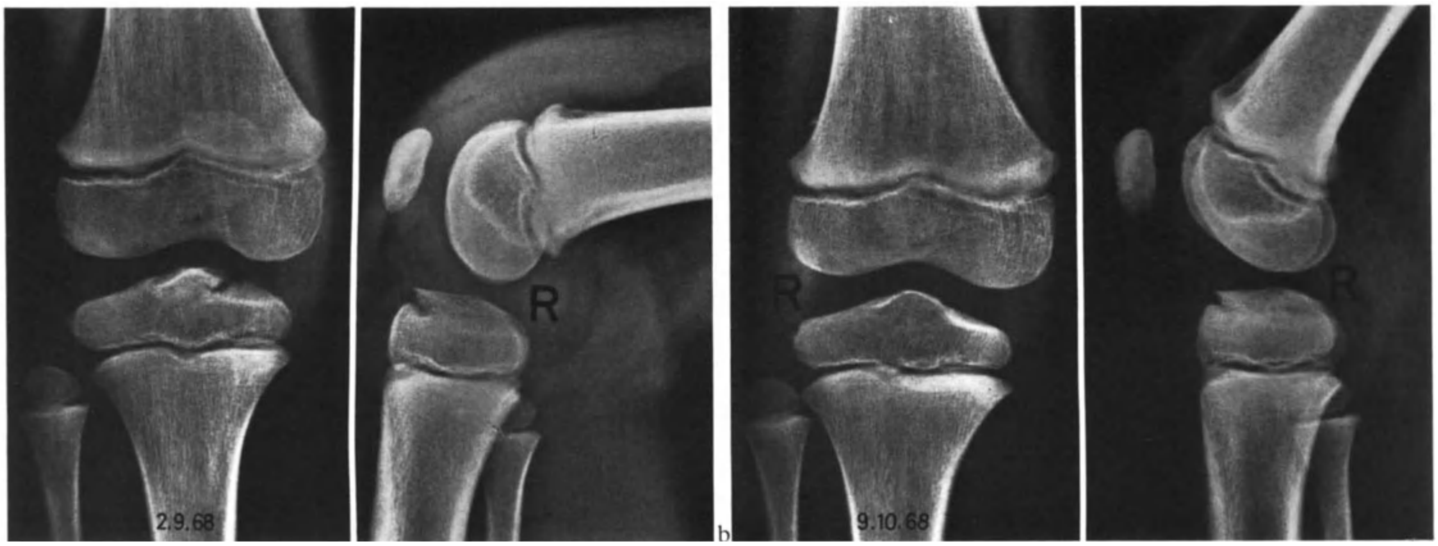


Fig. 35. *Avulsion fracture of the intercondylar eminence (site of insertion of the cruciate ligament)*

2.3 Avulsion of the Tibial Tuberosity

2.3.1 Pathological Anatomy

Forced flexion of the knee joint with simultaneous powerful contraction of the quadriceps muscle may lead to avulsion of the tibial tuberosity. This injury usually occurs during sport and is seen particularly frequently in adolescents whose skeletal growth is almost complete. The fragment may be small and extraarticular, or large and involve the joint. The frac-



a

b

c

Fig. 36a–c. *Avulsion fracture of the insertion of the anterior cruciate ligament with slight dislocation.* D.G., ♂, aged 5 years, No. 125372.
a) The fresh fracture, which was put in plaster.
b) 5 weeks after immobilization of the knee with a plaster cylinder, the fracture has healed.
c) 1 year and 3 months after the accident. The knees are clinically and functionally symmetrical

Fig. 37a–d. *Avulsion fracture of the insertions of both cruciate ligaments with severe dislocation.* F.G., ♂, aged 14 years, No. 103863.
a) The fresh fractures.
b) Treatment by exposure of the fracture (arthrotomy), reduction, and fixation with a lag screw which pierces the epiphyseal plate of the proximal tibia.
c) 3 months after the operation. The fracture has healed. The metal is about to be removed.
d) 4 years after the accident. Anatomically and functionally symmetrical knees

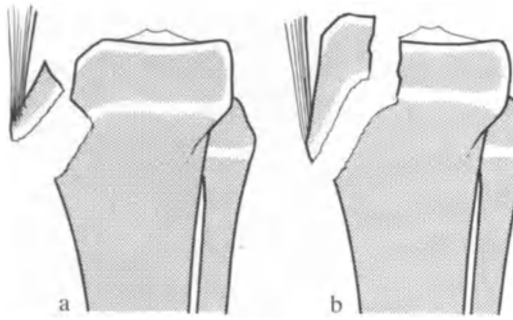


Fig. 38a, b. *Two types of avulsion fracture of the tibial tuberosity.*
a) Fracture of the tuberosity without involvement of the joint.
b) Fracture which includes the anterior part of the joint

ture belongs to the *Aitken* II category in both cases (Fig. 38).

2.3.2 Treatment

Operative Treatment: A fracture of the tibial tuberosity which is not completely reduced causes partial epiphyseal fusion which, in turn, results in retrocurvature deformity of the knee. On the other hand, precise and complete reduction of the same fracture allows growth to continue normally. If the fragment is large, the joint surface will be incongruent. For these reasons, operative treatment is indicated.

Operative procedure: Gentle reduction of the fragment, followed by tension band fixation (Fig. 39).

Postoperative treatment: Full-leg plaster splint until wound healing is sufficiently advanced. On discharge from hospital, a full-leg, circular cast is applied for 4–6 weeks. The metal is removed after 6–8 weeks.

Duration of fixation: 6–8 weeks.

a b

Fig. 39a, b. *Tension-band fixation of the tibial tuberosity.* W.R., ♂, aged 14 years, No. 136477.
a) Avulsion fracture of the tuberosity (accident during gymnastics).
b) Treatment by open reduction, *Kirschner* wire transfixation, and tension-band wiring

2.4 Metaphyseal Fractures of the Proximal Tibia

2.4.1 Pathological Anatomy

The fracture very frequently transects the epiphyseal plate of the tibial tuberosity (Fig. 40). Healing is accompanied by localized fusion of the epiphysis; the ossification occurs in the ventral part of the epiphyseal plate, which runs downwards and forwards, and thus leads to retrocurvature of the knee (Fig. 41).

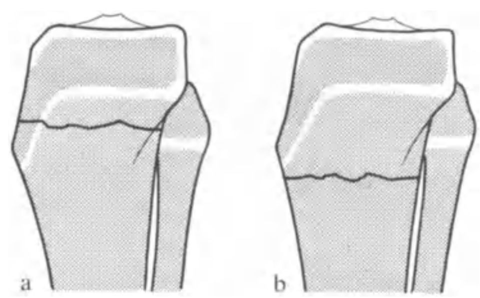


Fig. 40a, b. *High transverse fracture of the head of the tibia.*
a) This high transverse fracture of the head of the tibia lies distal to the proximal epiphyseal plate, but transects the downward-sloping tongue of the tibial tuberosity and the underlying epiphyseal plate. It is therefore likely to have serious consequences.
b) This more distal fracture does not involve the epiphyseal plate. The prognosis is therefore good

2.4.2 Treatment

Nonoperative Treatment: If the growth cartilage is definitely intact, nonoperative treatment is indicated. The fracture is reduced under general anesthesia.

Immobilization: Split, circular, full-leg cast which is closed after 3–5 days and retained for 3 weeks. It is then replaced by a full-leg walking cast for 3–5 weeks.

Duration of fixation: 6–8 weeks.

d

Fig. 41 a–g. *Retrocurvature of the knee secondary to a high transverse fracture of the tibia.* F.F., ♂, aged 15 years, No. 112934.

a) Transverse fracture. The involvement of the tibial tuberosity cannot be assessed in the roentgenograms of the fresh fracture.

b) 3 weeks after the accident, during treatment with a cast. There are signs of incipient fusion of the epiphysis of the tibial tuberosity due to fracture callus.

c) 8 months after the accident. Fusion of the epiphysis of the tibial tuberosity is advanced and retrocurvature of the knee is already present.

d) 16 months after the accident, there is severe retrocurvature of the knee and corrective osteotomy is indicated.

e) Appearance following corrective osteotomy with insertion of a wedge graft.

f, g) 1 year and 3 months after corrective osteotomy. The leg has almost returned to normal

Fig. 41 e–g

e

f

g

Operative Treatment: Open reduction is indicated if the epiphyseal plate of the tibial tuberosity has been damaged.

Operative procedure: Anatomically precise reduction of the fragments, followed by fixation with crossed *Kirschner* wires.

Postoperative treatment: Split, circular, full-leg cast until wound healing is satisfactorily advanced. A full-leg walking cast is then applied for 4–6 weeks. The metal is removed after 8 weeks.

Duration of fixation: 6–8 weeks.

3 Results

We saw the following 17 fractures of the proximal tibia between 1961 and 1969:

a) Fracture of the proximal tibial epiphysis (one case). This was a true fracture of the proximal tibia which belonged to the *Aitken* III category. Open reduction was followed by satisfactory healing with no sequelae (Fig. 42).

b) Avulsion of the intercondylar eminence (eight cases). Five of the eight cases were treated operatively. The final result was excellent in almost all cases; only

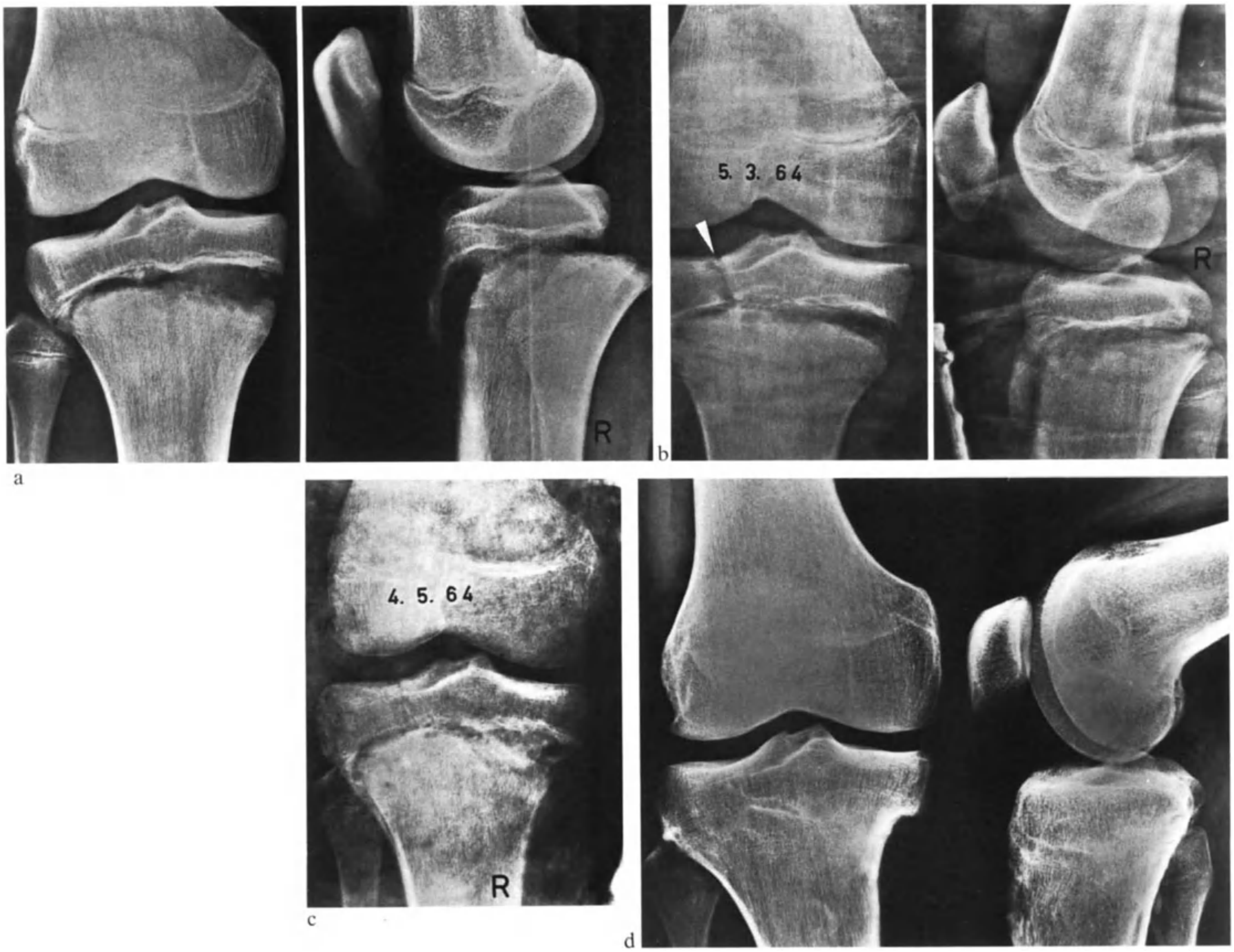


Fig. 42a–d. *A difficult epiphyseal fracture*. W.R., ♂, aged $15^1/_2$ years, AK.
a) Ventral dislocation of the tibial epiphysis with valgus angulation. Treatment was by closed reduction.
b) 4 days after the accident. An *Aitken* Type II and III fracture of the epiphysis is now apparent. The original reduction was insufficiently precise and open reduction was therefore carried out in order to ensure perfect contiguity of the fragments.
c) 2 months after the operation. The fracture has united and the fragments are correctly aligned.
d) $5^1/_2$ years after the accident. There is slight varus deformity of the knee as a result of asymmetrical epiphyseal fusion. The joint surfaces are congruent

one case, which had been treated nonoperatively, required subsequent surgery (extension osteotomy) because of a 30° loss of extension.

c) Avulsion of the tibial tuberosity (three cases). All three avulsion fractures were operated on and refixed, with a perfect result in each case.

d) Metaphyseal fracture of the proximal tibia (five cases). One meta-epiphyseal fracture of the proximal tibia was immediately immobilized in a circular cast because of failure to diagnose the injury to the epiphyseal plate of the tibial tuberosity. Retrocurvature of the proximal tibia inevitably occurred and required corrective osteotomy (Fig. 41). The remaining four metaphyseal fractures of the proximal tibia healed satisfactorily under nonoperative treatment.

4 Summary

Fractures of the proximal end of the tibia rarely occur in children. There are a number of different types, and the treatment varies according to the type. Immediate operative treatment of fractures involving the epiphyseal plate and of avulsion fractures of the intercondylar eminence has been shown to give satisfactory results. Other types of fracture should be treated nonoperatively.

5 References

Aitken, A. P.: The end results of the fractured distal tibial epiphysis. J. Bone Jt Surg. **18,** 3, 685 (1936).

Aitken, A. P., Magill, H. K.: Fractures involving the femoral epiphyseal cartilage. J. Bone Jt Surg. **38 A,** 1056 (1956).

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1960.

Harris, H. A.: Bone growth in health and disease; the biological principles underlying the clinical, radiological and histological diagnosis of perversions of growth and disease in the skeleton. London-Oxford: Univ. Press 1933.

Müller, M. E., Ganz, R.: Luxationen und Frakturen: Untere Gliedmaßen und Becken. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer, 1974.

Süssenbach, F., Weber, B. G.: Epiphysenfugenverletzungen am distalen Unterschenkel. Bern-Stuttgart-Wien: Hans Huber 1970.

Tachdjian, O.: Pediatric Orthopaedics. Philadelphia-London-Toronto: Saunders 1972.

Weber, B. G.: Epiphysenfugenverletzungen. Helv. chir. Acta **31,** 103 (1964).

Weber, B. G.: Indikationen zur operativen Frakturenbehandlung bei Kindern. Chirurg **10,** 441 (1967).

Fractures of the Proximal Tibial Metaphysis

B.G. Weber

CONTENTS

1 Introduction

Metaphyseal fractures of the long bones of children and adolescents heal uneventfully, even following only approximate reduction. Slight or moderate angular misalignment is corrected spontaneously by subsequent longitudinal and circumferential growth.

Exceptions to this rule occur in the case of fractures of the proximal tibial metaphysis which are caused by valgus bending.

2 Pathomorphology and Tentative Explanations of the Pathogenesis of Valgus Deformity

A high metaphyseal fracture of the tibia is almost always followed by progressive valgus deformity of the leg, irrespective of whether it is accompanied by a fibular fracture (Fig. 1).

Various explanations have been offered for this very unusual behavior of the bone. None of them has been supported by conclusive evidence, and none of them provide any ideas as to how the deformity could be prevented.

The following theories have been advanced:

Assymetrical stimulation of the epiphyseal plate (*Cozen*, 1954; *Blount*, 1954).

Tendency of the callus in the fracture gap to expand and drive the fragments apart, thus causing angulation of the fracture prior to consolidation (*Lehner* and *Dubas*, 1954).

Unilateral damage to the epiphyseal plate, causing slowing of growth on the fibular side (*Goff*, 1960).

Difference in the longitudinal growth rates of the tibia and fibula, causing the fibula to act as a lateral tension band or brake which tethers the tibia (*Taylor*, 1963).

Premature weight bearing with the leg in a cast, leading to secondary valgus deformity (*Pollen*, 1973).

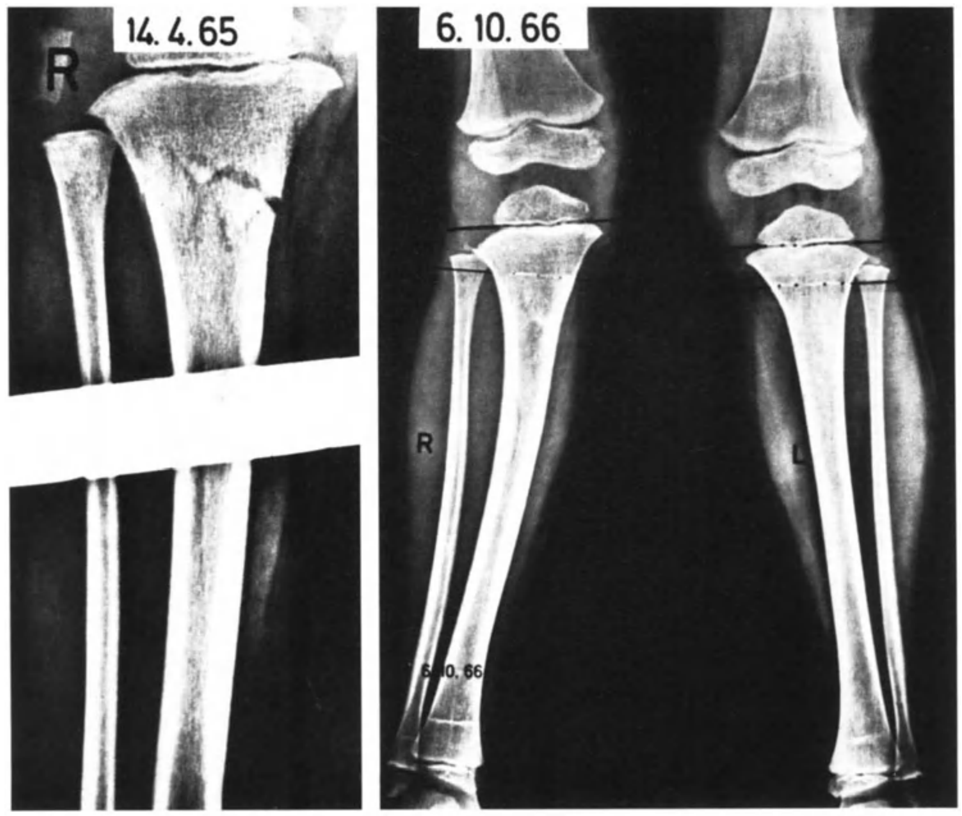
None of these pathogenetic theories explains the bending of the tibial diaphysis, which has no apparent connection with the growth cartilage or with the fracture itself.

Jackson and *Cozen* (1971) followed the progress of ten such cases and found that the correction of the deformity always presented serious problems.

3 Our Own Observations

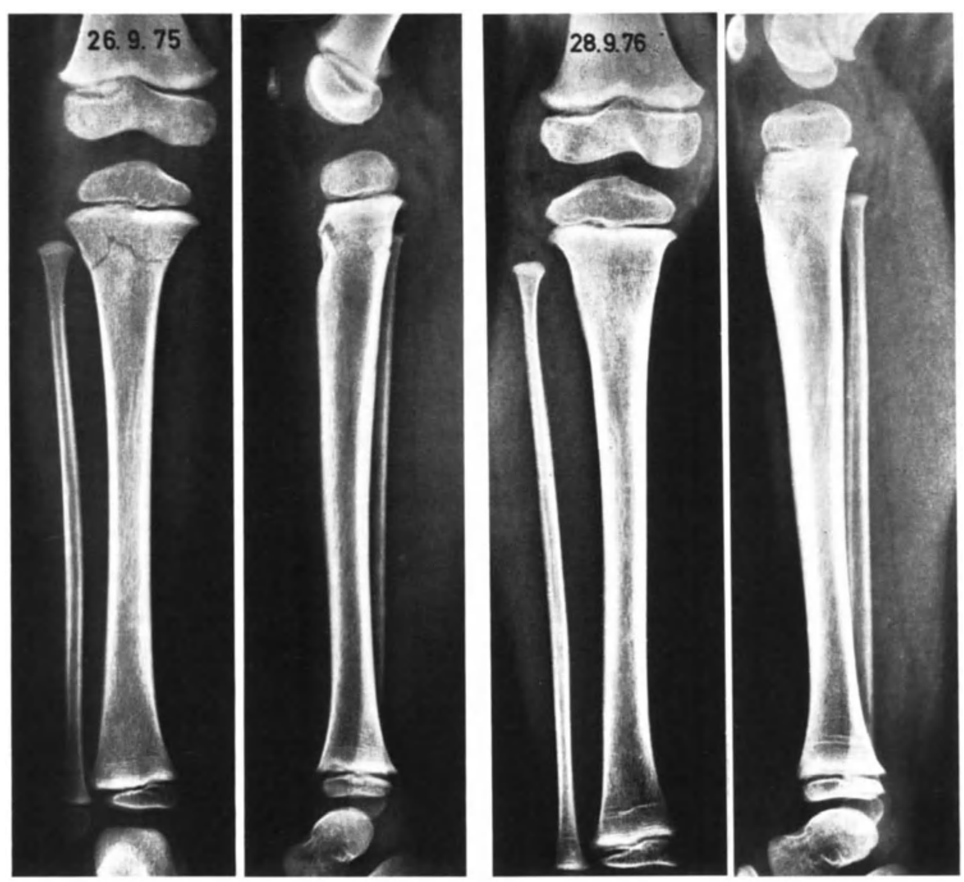
3.1 High Metaphyseal Fracture of the Tibia Without Secondary Deformity (Fig. 2)

Not every fracture of the proximal tibial metaphysis is followed by progressive deformity. Deformity does not result, for example, from acute subperiosteal fractures and fatigue fractures (i.e., fractures which leave the periosteum intact).



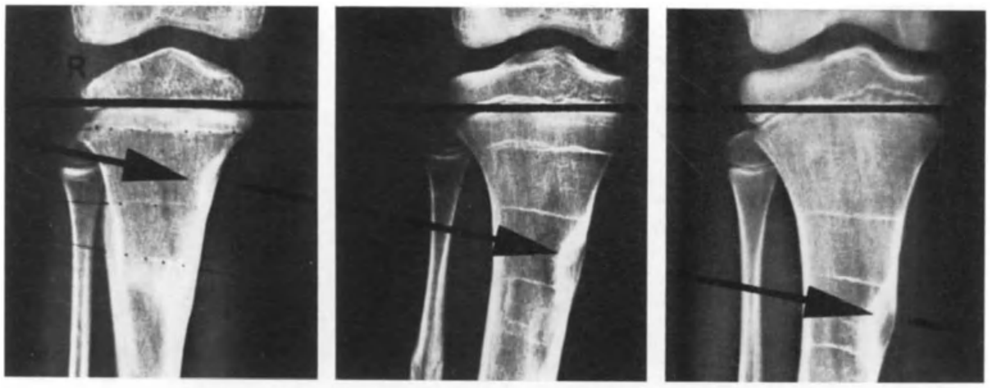
a b

Fig. 1a, b. *Valgus deformity secondary to a high metaphyseal fracture of the tibia.* A.R., ♂, aged 3 years, No. 100828.
a) The fresh fracture which was caused by a valgus bending moment. The fracture gapes somewhat on the medial side.
b) $1^1/_2$ years after the accident. There is S-shaped valgus deformity of the tibial diaphysis, wedge-shaped growth of the proximal tibial epiphysis, and slight signs of straightening growth in the distal epiphyseal plate. The length of the fractured tibia is greater than that of the opposite, intact leg



a b

Fig. 2a, b. *A high metaphyseal fracture of the tibia without secondary deformity.* P.A., ♀, aged 3 years, A.K., St. Hospital, Dr. G.
a) The fresh subperiosteal fracture, which shows no signs of dislocation or gaping.
b) 1 year later. The fracture has healed, leaving no sequelae, and the shape of the leg has remained normal



a b c

Fig. 3a–c. *Sclerosis of the medial tibial cortex*. Same patient as in Fig. 1.
a) New, 4 years after the accident, cortical sclerosis is visible.
b, c) In the course of longitudinal growth, the sclerosis moves distally and the newly formed bone proximal to it undergoes valgus deformation

3.2 High Metaphyseal Fracture of the Tibia with Secondary Deformity (Fig. 1)

We have dealt with four cases in which serious deformity has developed. The following features were common to all the cases:

At the site of the fracture, thickening of the cortex occurs which gradually moves distally in the course of longitudinal growth (Fig. 3).

Distal to the latter thickening, valgus angulation of the diaphysis takes place progressively in the course of circumferential growth.

Proximal to the cortical thickening, the growth lines show that asymmetrical longitudinal growth has occurred in the epiphyseal plate. The valgus deformity which results also extends to the head of the tibia.

The distal epiphyseal plate of the tibia attempts to correct the valgus deformity by compensatory longitudinal growth which tends to straighten the bone.

The affected tibia is longer than that on the opposite side, and S-shaped deformity of the lower leg occurs.

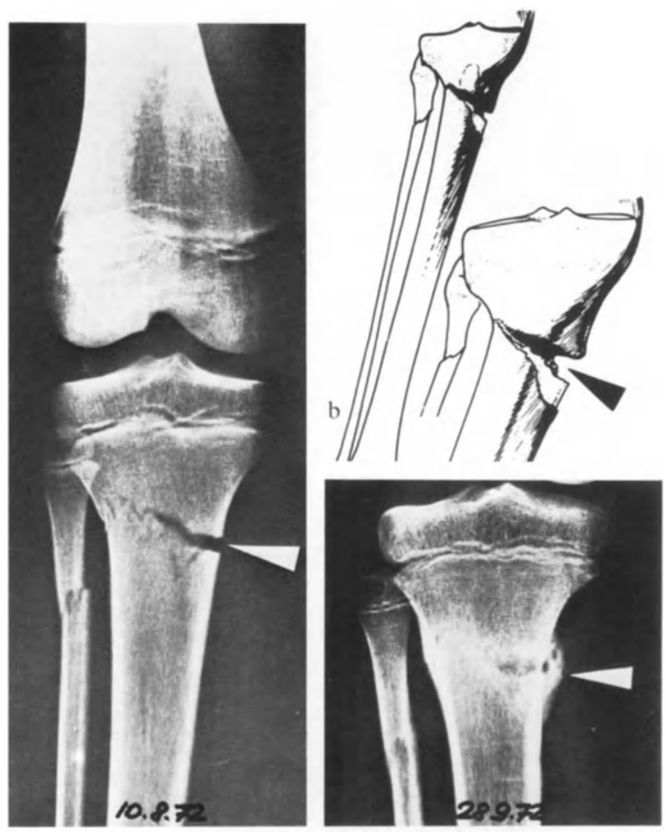
Corrective osteotomy is followed by a recurrence of the valgus deformity, and before cessation of skeletal growth, several osteotomies and procedures to correct the difference in leg length may be necessary.

3.3 High Metaphyseal Fracture of the Tibia Treated by Open Reduction

Starting in August 1972, we carried out surgical exposure of four typical fresh fractures and then immobilized them in circular casts. The findings in these cases can be summarized as follows (Fig. 4):

The periosteum and the insertion of the pes anserinus was stripped off the medial surface of the tibia distal to the transverse fracture. The periosteum and the pes anserinus had slipped into the fracture gap. These tissues had to be removed from the fracture in order to enable anatomically precise reduction (Fig. 5). The periosteum and pes anserinus were refixed to their original sites with simple sutures. The fracture was then immobilized in a circular cast.

Removal of the interposed tissue was followed by normal bone union in each case and valgus deformity did not occur (Fig. 6).



a b c

Fig. 4a–c. *A high metaphyseal fracture of the tibia with interposition of the pes anserinus in the fracture gap*. R.A., ♀, aged $8^1/_2$ years, No. 160802.
a) Fracture of the proximal tibia and fibula with valgus angulation and medial gaping of the tibial fracture.
b) At operation, the pes anserinus and the periosteum were found to be trapped in the fracture gap.
c) Anatomically normal healing of the fracture following extraction of the interposed tissue

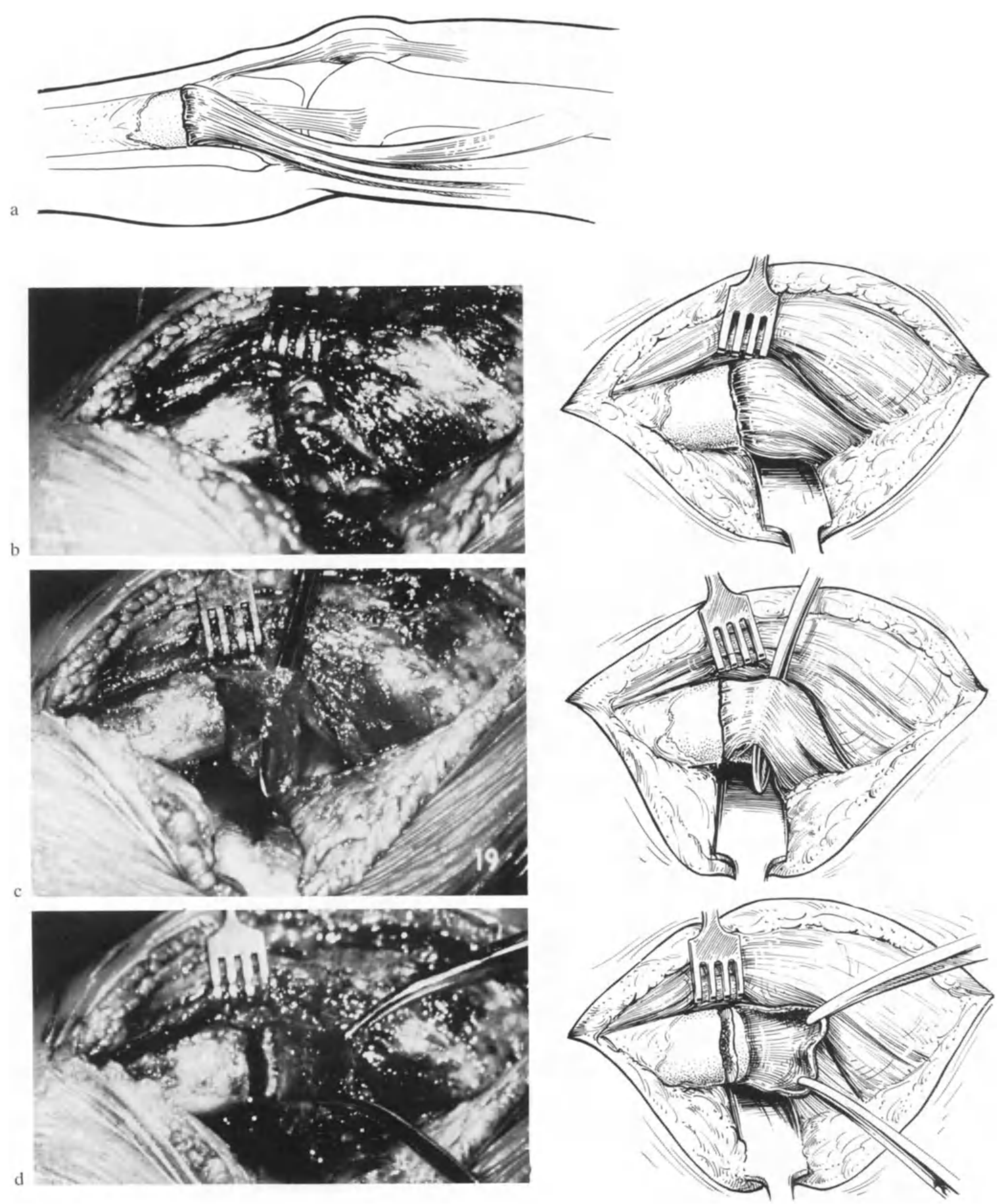


Fig. 5a–d. *Intraoperative appearance of a high metaphyseal fracture of the tibia with valgus angulation*. Same patient as in Fig. 4. Findings at operation on 16 August 1972. a) General appearance.
b) The periosteum is stripped away from the medial surface of the tibia and, together with the pes anserinus, is trapped in the transverse fracture gap.
c) An elevator is slid under the interposed tissues.
d) The interposed tissues are extracted from the fracture gap and the periosteum is held back with two forceps

Fig. 6. *Fracture healing with no sequelae following extraction of the periosteum and pes anserinus from the fracture gap.* Same patient as in Fig. 4. 4 years after the accident, the tibiae are anatomically symmetrical and the sclerosis of the medial tibial cortex at the original level of the fracture, which is a typical feature of this type of fracture, is absent

4 Pathogenesis of Valgus Deformity of the Lower Leg Secondary to High Metaphyseal Fracture of the Tibia (Fig. 7)

The difference in behaviour of subperiosteal fractures and fractures with interposition of periosteum and pes anserinus, and the occurrence of normal healing following the extraction of the interposed tissues from the latter type of fracture prove that the interposition of periosteum and pes anserinus is directly responsible for the subsequent deformity. It seems to me that the interposition results in loss of biomechanical equilibrium. The upward traction on the pes anserinus and periosteum on the medial side stops at the level of the fracture, whereas the upward traction on the lateral side through the biceps muscle and the fibula and down the fascia lata to the foot remains unchanged. This places a bending moment on the tibia. In accordance with *Wolff's* transformation law, the tibia gradually bends its axis in such a way as to escape the bending moment. In response to this curvature of the axis, the distal epiphyseal plate attempts to straighten the bone by compensatory asymmetrical growth. The reasons why the proximal epiphyseal plate does not do the same, in accordance with *Pauwels* law, are not yet clear.

5 Conclusions

Every high metaphyseal fracture of the tibia in a child or adolescent should be carefully examined to see whether periosteum or pes anserinus tissue has become

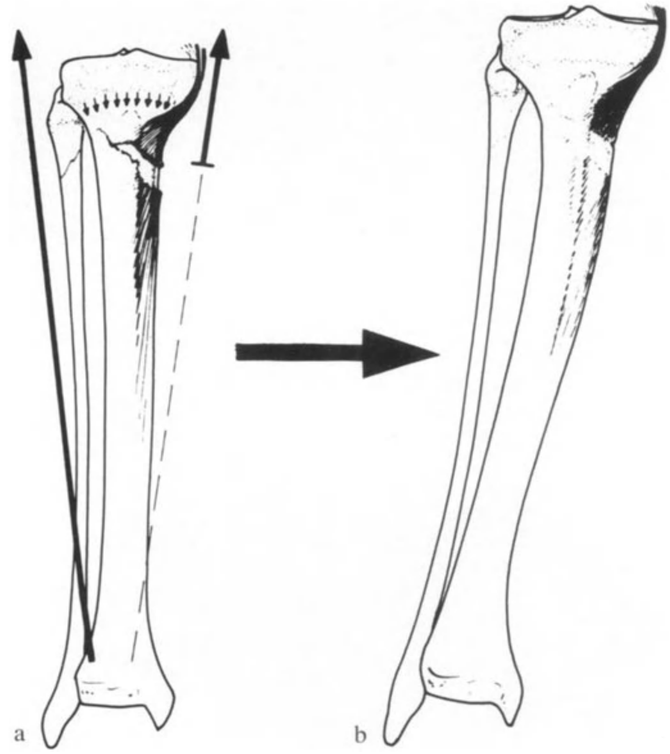


Fig. 7a, b. *A tentative explanation of the pathogenesis of valgus deformity secondary to a high metaphyseal fracture of the tibia.*
a) Trapping of the pes anserinus and periosteum on the medial side of the head of the tibia interrupts the normal transmission of forces.
b) The growing bone reacts to the abnormal distribution of forces by structural adaptation in accordance with *Wolff's* transformation law. The results are valgus deformation of the shaft (circumferential growth) and asymmetrical growth in the epiphyseal plate (longitudinal growth)

trapped in the fracture. Interposition of this kind does not occur following fatigue fracture. It is sure to have occurred if a fracture gapes on the medial side and valgus angulation is present. If in doubt, a roentgenogram should be made with the limb held in such a way as to reveal latent valgus deformity. If interposition is strongly suspected or confirmed, operative removal of the tissues from the fracture is necessary. Failure to do this is inevitably followed by severe valgus deformity of the knee and leg.

6 Summary

A high metaphyseal fracture of the tibia with interposition of periosteum or pes anserinus between the fragments always requires open reduction. Surgical removal of the interposed tissues is the only way of preventing secondary valgus deformity of the leg with all its serious consequences.

7 References

Blount, W. P.: Fractures in children. Baltimore: Williams and Wikins, 1954.

Cozen, L.: Fracture of the proximal portion of the tibia in children followed by valgus deformity. Surg. Gynec. Obstet. **72,** 183 (1953).

Cozen, L.: Knock knee deformity after fracture of the proximal tibia in children. Orthopaedics **1,** 230 (1959).

Goff, C. W.: Surgical treatment of unequal extremities. Springfield/Ill.: Ch. C. Thomas, 1960.

Harris, H. A.: The growth of the long bones in childhood with special reference to certain bony striations of the metaphysis and to the role of vitamins. Arch. intern. Med. **38,** 785 (1926).

Jackson, D. W., Cozen, L.: Genu valgum as a complication of proximal tibial, metaphyseal fractures in children. J. Bone Jt Surg. **53 A,** 1571 (1971)

Lehner, A., Dubas, J.: Sekundäre Deformierungen nach Epiphysenlösungen und epiphysenliniennahen Frakturen. Helv. chir. Acta **21,** 388 (1954).

Pauwels, F.: Grundriß einer Biomechanik der Frakturheilung. 34. Kongreß Verh. dtsch. Orthop. Ges. 1940.

Pollen, A. G.: Fractures and dislocations in children. Edinburgh, London: Churchill Livingstone, 1973.

Taylor, S. L.: Tibial overgrowth: A cause of genu valgum. J. Bone Jt Surg. **45 A,** 659 (1963).

Weber, B. G.: Fibrous interposition causing valgus deformity of the upper tibial metaphysis in children. J. Bone Joint Surgery **59 B,** 290–292 (1977).

Wolff, J.: Das Gesetz der Transformation der Knochen. Berlin: Hirschwald, 1892.

Fractures of the Lower Leg

R. Marti

CONTENTS

1 Introduction

In our part of the world, the lower leg is the site at which fractures occur most frequently in children. The victim is often a skier and the accident mechanism usually involves torsion and causes a spiral fracture. Direct violence more often causes a transverse fracture with simultaneous injury to the soft tissues. Depending on the age of the child, the fracture may be subperiosteal, of the greenstick type, or dislocated.

The age distribution shows a steady increase in the frequency of the bone injuries up to the age at which skeletal growth ceases. This is probably ascribable to the decreased elasticity of the bones of older children and to the more frequent involvement of these children in high energy sports.

2 Fracture Types and Treatment

Fracture Site. A fracture of the lower leg may be located in

a) The diaphysis, or
b) The distal metaphysis.

Fracture Type. The fracture type is determined by the age of the child and by the degree of violence. The following fracture types may occur at each of the above sites:

Subperiosteal Fractures (Fig. 1): The torsional forces fracture the cortex around its full circumference, but the tough surrounding periosteal cuff remains intact. The fracture is therefore *stable,* i.e., dislocation cannot occur, and there is no tendency to shortening. This type of fracture characteristically occurs in children up to the sixth year of life and is usually located in the diaphysis (*Blount*).

Greenstick fractures (Fig. 2): Application of an excessive bending moment to the bone may lead to fracture of the cortex around half its circumference with tearing of the overlying periosteum. The opposite cortex is impacted or bent and its overlying periosteum remains intact. This type of fracture is also stable and dislocation of the fragments cannot occur. The commonest site is the distal metaphysis and, if the victim is a skier, the injury is frequently referred to as a boot-top fracture.

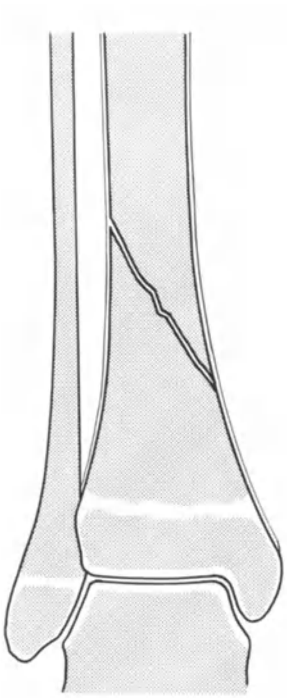


Fig. 1

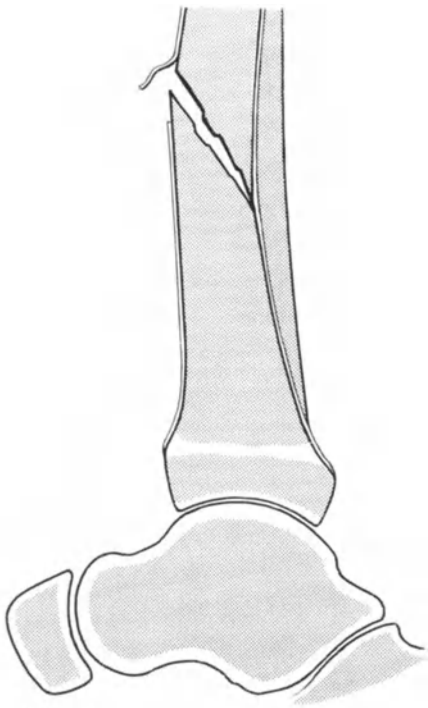


Fig. 2

Fig. 1. *Subperiosteal fracture*. Almost oblique fracture

Fig. 2. *Greenstick fracture*. The periosteum and bone are broken on one side and there is some degree of angulation

Dislocated fractures (Fig. 3): The cortex is completely fractured and the periosteal cuff is torn through. The tibia alone may be broken or there may be an accompanying fracture of the fibula. Dislocated fractures occur more frequently in older children; in a young child, the periosteal cuff, which protects and splints the bone, is very tough and the bone itself is relatively elastic.

2.1 Diaphyseal Fractures of the Lower Leg

2.1.1 Subperiosteal Fractures

2.1.1.1 Pathological Anatomy

These are very often isolated fractures of the tibia without dislocation of the fragments. The intact periosteal cuff prevents any angulation and, furthermore, malrotation cannot occur. Since the periosteal vessels remain undamaged, there is very little swelling and the fracture hematoma remains subperiosteal.

2.1.1.2 Treatment

Nonoperative Treatment: These fractures are always treated nonoperatively, and general or local anesthesia is unnecessary (Fig. 4).

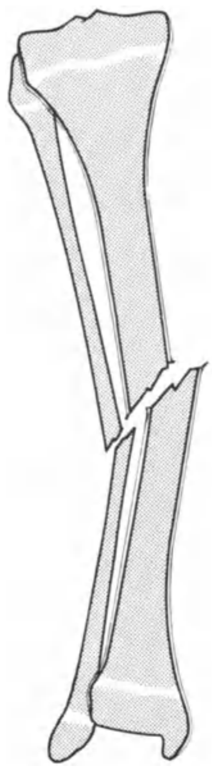


Fig. 3. *Dislocated fracture*. The discontinuity of the periosteum and bone extends around the whole circumference and there is a variable degree of dislocation

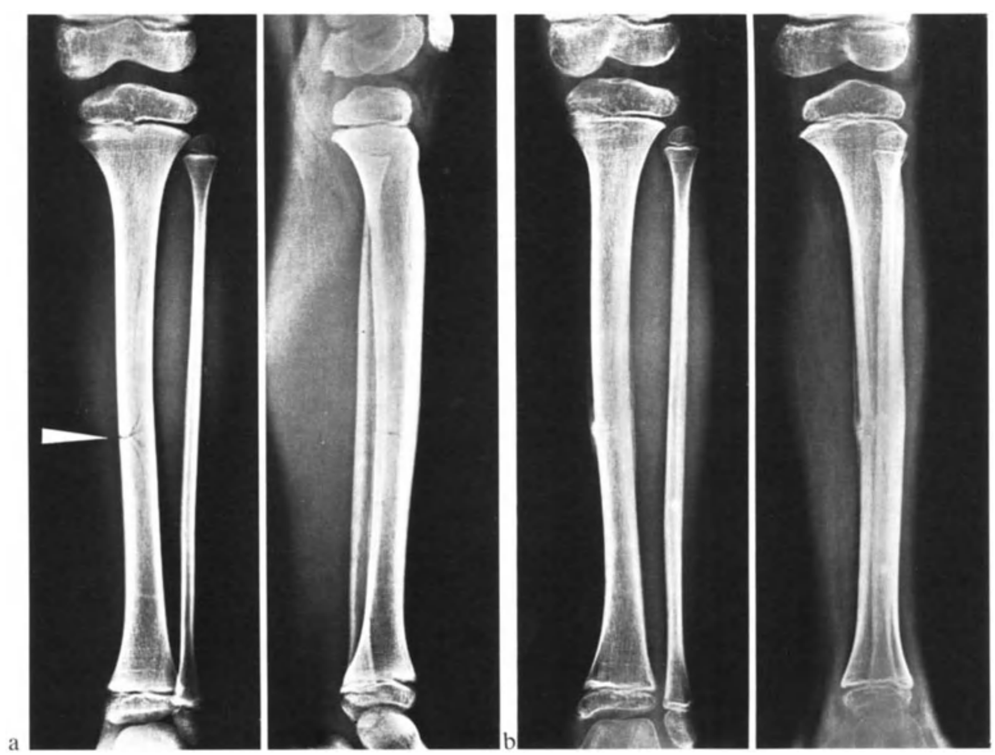


Fig. 4a, b. *A subperiosteal fracture*. Sch.M., ♂, aged 6 years, No. 197617.
a) Subperiosteal fracture without dislocation.
b) 7 weeks after treatment with a below-knee walking cast. The fracture has healed and the axes are correctly aligned

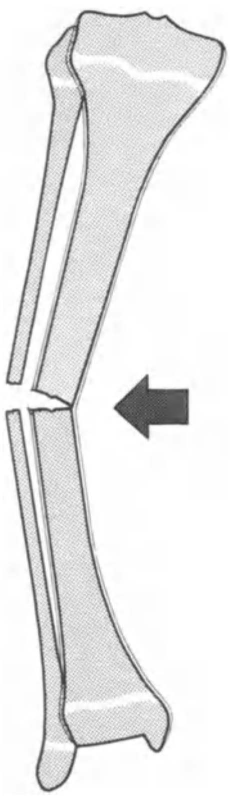


Fig. 5. *Greenstick fracture*. The angulation indicates the direction of the violence which caused the fracture

Immobilization: Circular, full-leg cast for 2–3 weeks, followed by a walking cast for a further 2–3 weeks.

In older children, a plaster boot of the *Sarmiento* type (*Freuler, Wiedmer,* and *Bianchini*) may be applied immediately. This allows functional treatment of the fracture.

Duration of fixation: 4–6 weeks, depending on the age of the child.

2.1.2 Greenstick Fractures

2.1.2.1 Pathological Anatomy (Fig. 5)

A greenstick fracture results if the diaphysis of a young child is subjected to direct violence. The angulation of the shaft corresponds to the direction of the force. The intact structures act as a unilateral tension band which tends to maintain or increase the angulation of the fracture, but also prevents shortening and malrotation, i.e., the lower leg is simply bent.

2.1.2.2 Treatment

Nonoperative Treatment: These fractures are stable, and immediate treatment with a cast is therefore possible (Fig. 5).

Reduction under general anesthesia: The "intact" cortex is broken without using excessive force. Success is frequently rewarded with a loud snapping sound. If the bone is not fractured in this manner, but is simply straightened, the final result is often unsatisfactory; the unilateral tension exerted on the fracture by the intact structures (periosteum and cortex) causes the angulation to recur, even if the limb is surrounded by a cast.

Immobilization: A split, circular, full-leg cast is applied and the patient is nursed with the leg raised. After 3–5 days, the fracture is checked radiologically and the cast is closed. Wedging is carried out if the position of the fracture is unsatisfactory. After 3 weeks, a full-leg walking cast is applied for 3–4 weeks.

Duration of fixation: 6–7 weeks.

2.1.3 Dislocated Fractures

2.1.3.1 Pathological Anatomy

This type of fracture results in complete discontinuity of the cortex and periosteum, and mainly occurs in older children. Severe dislocation is frequently accompanied by extensive damage to the surrounding soft tissues with a large hematoma and edema formation in the anterior tibial compartment. Therefore, if the fragments are markedly displaced, the circulation, sensibility, and movement of the toes should be carefully monitored. This is the only way of ensuring early diagnosis and treatment of an anterior or posterior compartment syndrome.

2.1.3.2 Treatment

Nonoperative Treatment: The treatment is determined by the *stability* of the fracture (Fig. 6).

Stable fractures are those which do not tend to shorten. Thus, isolated fractures of the tibia are stable, since shortening is prevented by the intact fibula. Transverse fractures of the lower leg may also be stable following reduction.

Unstable fractures are those which tend to shorten. Classical examples are dislocated oblique and spiral fractures of the tibia and fibula.

The following guide lines apply to the treatment of the two types of fracture:

Stable fractures→Immediate cast fixation
Unstable fractures→Traction→cast

The transverse axis of the ankle joint is rotated externally by 15° by 25° in relation to the axis of the knee joint. It should be remembered, however, that the rotation of the leg varies according to the age of the child (*Hutter* and *Scott, Le Damany, Miku-*

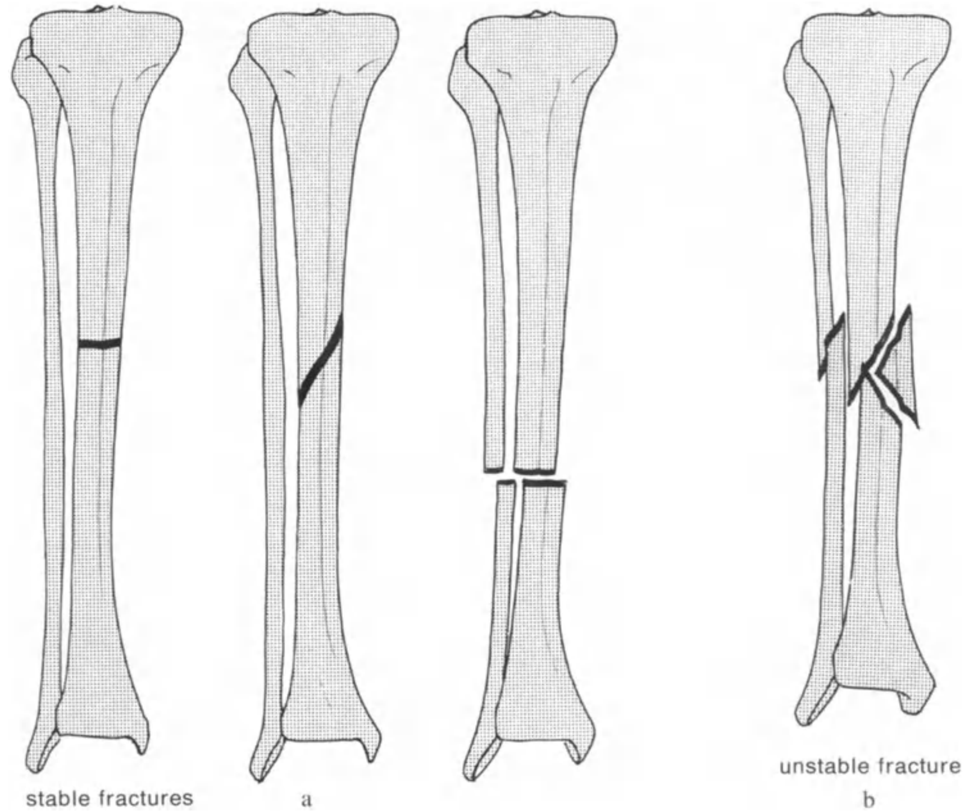


Fig. 6a, b. *Classification of the fractures.*
a) Fractures which are stable following reduction. If the fibula is intact or the fractures are transverse, there is no tendency to shortening.
b) Fractures which are unstable following reduction, i.e., oblique or spiral fractures of the tibia and fibula which tend to allow shortening

licz, Müller, Weber). The knees of a newborn child are in external rotation, but the feet are in internal rotation. This physiological deformity increases during the first 2 years of life. Similarly, the valgus angulation and retrocurvature of the knee of a 3-year old is only transient. In order to allow normal physiological development, the limbs should be aligned symmetrically when a cast or traction is applied. During these latter procedures, the two legs should always be carefully compared.

Stable fractures: Since shortening cannot occur, there is no sense in applying traction. The fracture is reduced under general anesthesia, care being taken to ensure symmetrical rotation alignment in the following manner: The legs are laid across a broad wooden block so as to equalize the flexion of the knee joints (Fig. 7). Differences in rotation can be detected by comparing the axes of the knee joints and ankle joints of both legs. If there is a difference between the two sides, the surgeon rotates the injured limb until mirror-image symmetry is obtained. During this procedure, the assistant keeps the knee joints fixed.

Note: Malrotation does not undergo spontaneous correction during subsequent growth.

Immobilization: A split, full-leg cast is applied in three stages for 3–4 weeks (*Freuler, Wiedmer,* and *Bianchini*) as follows:

First stage: Temporary stabilization of the fracture;
Second stage: Fixation of the foot and ankle joint;
Third stage: Completion of the cast surrounding the knee and thigh.

The leg is kept raised and the fracture is checked radiologically after 3–5 days. At the same time, the cast is closed, and wedges are inserted if the alignment of the fracture needs to be corrected. After 3–4 weeks, the fracture is X-rayed without the cast and a full-leg walking cast is applied for 3–6 weeks.

If the leg is very swollen, the patient is *kept in hospital* for a few days in order to ensure and facilitate *close surveillance* of the sensation, circulation, and toe movement of the injured limb.

A stable fracture of the lower leg in a child over 11 years of age can be treated by immediate active movement of the limb if the surgeon is skilled in the technique involved. Following reduction of the fracture, a closely contoured full-leg walking cast is applied with the leg extended and is replaced 1–2 weeks later by a *Sarmiento* plaster boot. This technique allows free movement of the knee and almost immediate mobilization of the patient (*Freuler, Wiedmer,* and *Bianchini*).

Duration of fixation: 6–10 weeks, depending on the age of the child.

Unstable fractures: By definition, these fractures tend to cause shortening of the limb and therefore have to be placed in traction for a short while to enable accurate reduction. The *Kirschner* wire is widely used, but we prefer the more rigid *Steinmann* pin.

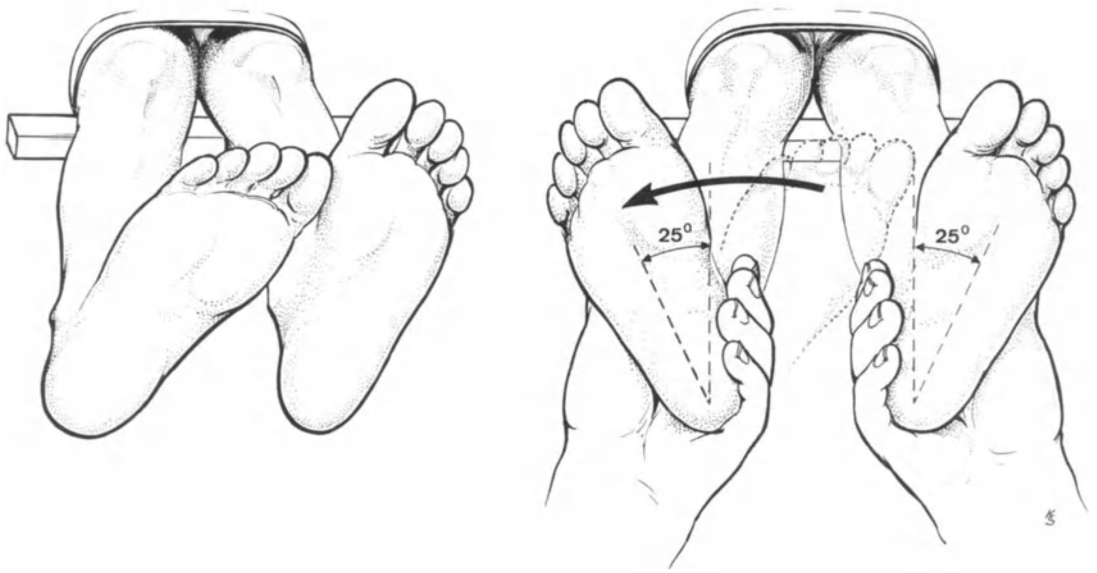


Fig. 7. *Correction of malrotation*. The knee joints are placed across a wooden block and rotational deformity is eliminated by comparing and equalizing the rotation position of the feet. Note that the long axis of the foot normally makes an external rotation angle of 25° with a line which is at right angles to the transverse axis of the knee joint

The latter exerts less pressure (force per unit area) on the bone and therefore lacks the cheese-wire effect of the *Kirschner* wire. Furthermore, it does not rotate if the traction is set up correctly, and this reduces the danger of infection.

Insertion of the *Steinmann* pin: A general anesthetic is administered and the foot is draped with sterile towels. A stab incision is made over the medial aspect of the calcaneus below the neurovascular bundle. After checking that the rotation positions of the two legs are mirror images of each other, a 4.0–4.5 mm *Steinmann* pin is inserted parallel to the baseboard with a hand chuck. Insertion of the pin with a power drill is dangerous and causes thermal damage to the bone with formation of an annular sequester. Traction is then applied with normal external rotation of the foot with respect to the transverse axis of the knee (Fig. 8). Vertical alignment of the foot, which is often seen, always causes internal malrotation (Fig. 9). The traction cord should rotate freely around the pin at its point of attachment; if the attachment is rigid, the pin rotates in the bone and widens the pin track, leading to loosening of the nail and infection. The fracture is reduced as accurately as possible under the same anesthetic so that 1–2 kg suffice to maintain the required position (the exact weight depends on the age of the child). Since a mean increase of 10 mm in the longitudinal growth of the bone may be

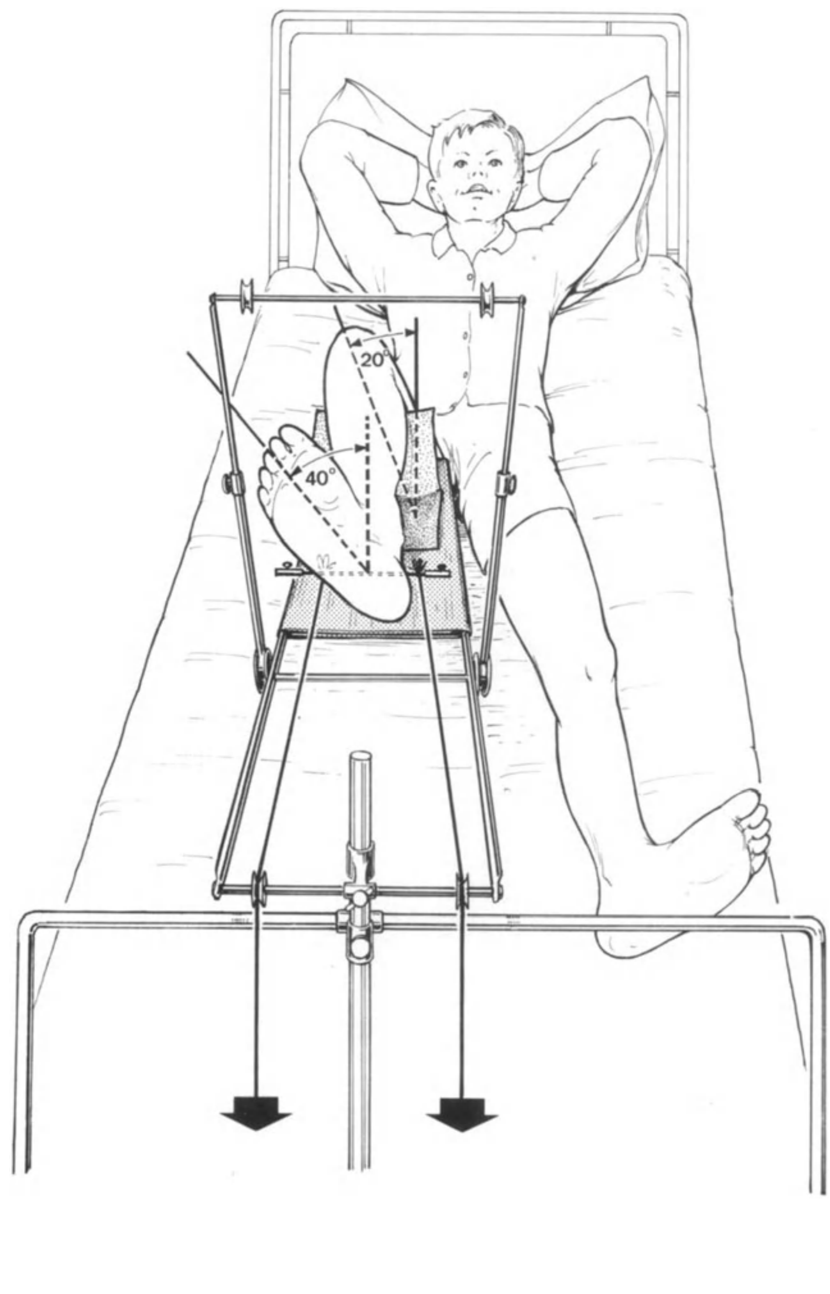


Fig. 8. *Adjustment of rotation on the traction frame*. With the thigh in 20° abduction, the foot should be rotated externally at an angle of 40°–50° to the sagittal plane in order to ensure normal external rotation of the lower leg. Traction is applied with two cords

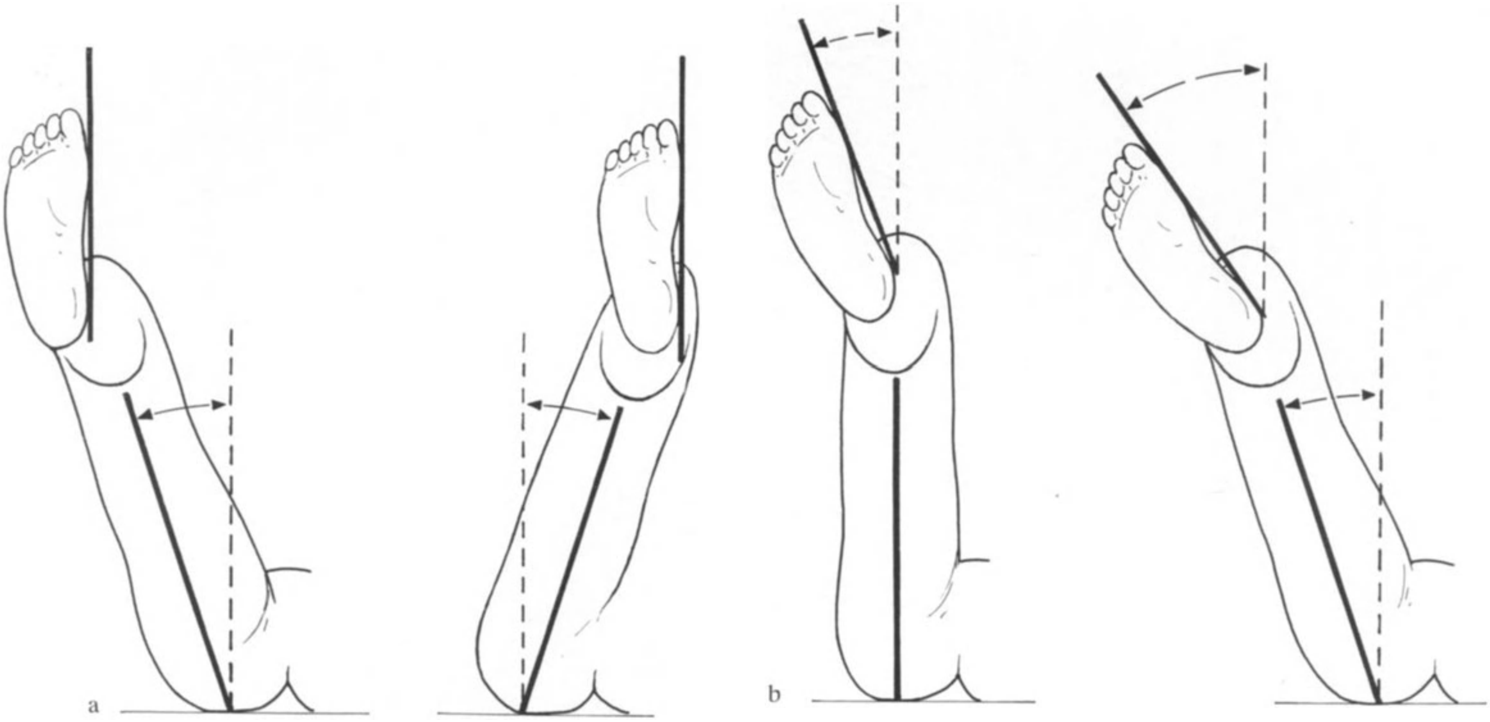


Fig. 9a, b. *Prevention of malrotation during treatment of a fracture by traction.*
a) With the foot vertical and the femur in the usual position of 20° abduction, a 40° internal rotation deformity would be expected. Vertical positioning of the foot would only be correct if the femur were in 20° adduction. However, this position is impracticable.
b) In practice, the foot should never be positioned with its long axis vertical

expected, slight shortening is permissible. The leg is then placed on a foam rubber traction splint which allows free movement and prevents pressure sores. The thigh is fixed, but the lower leg is left freely mobile so that it is always aligned with the direction of traction. The sensation, circulation, movement of the toes, and rotation angle of the injured limb should be checked daily, particularly if the child is restless. The longitudinal alignment of the fragments and especially the torsional alignment are always checked by comparison of the two sides (Fig. 7). Careful surveillance is necessary for the prevention or early detection of complications, such as paresis of the lateral popliteal nerve, or an anterior or posterior compartment syndrome.

Subsequent treatment: When bone union has reached the point at which, on removal of the traction weight, painless active movement of the limb is possible without bending at the fracture, a cast is applied. At this point, fracture healing has advanced sufficiently to prevent shortening in the absence of traction. This is usually the case after 10–14 days, with variation between individuals. A circular, full-leg cast is applied for 2–3 weeks. It is then removed, the fracture is checked radiologically, and a full-leg walking cast is applied for 3–4 weeks. It should be remembered when assessing the callus that a callus in a child is significantly weaker than one of identical radiological appearance in an adult. If a walking cast is applied too early, slight angular misalignment or shortening may result. It is therefore important that the stability of the fracture be checked clinically as well as radiologically.

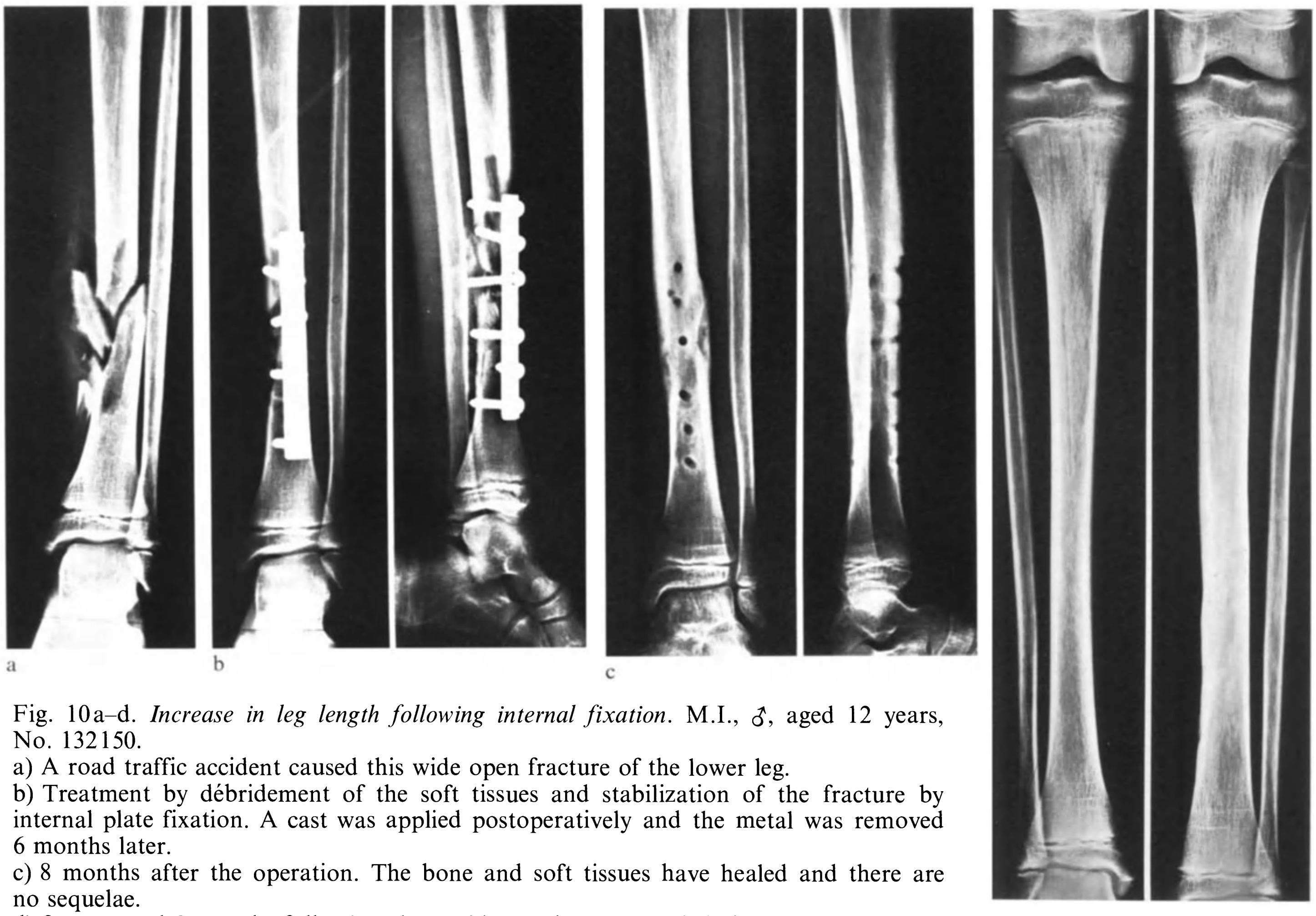
Duration of fixation: 7–10 weeks. The rate of healing varies considerably between patients, and the management of a fracture should therefore be determined by the radiological and clinical findings following removal of the first cast rather than by a standard protocol.

Operative Treatment: The methods of nonoperative treatment described are relatively safe, and the operative treatment of fractures of the lower leg in children is therefore restricted to a small range of indications, i.e.:

Wide open fractures; here, the internal fixation promotes soft tissue healing (*Weber*).

Fractures in patients with brain injury or cerebral paresis; internal fixation of these fractures facilitates nursing.

A fracture in an adolescent, in whom skeletal growth has almost ceased, has to be reduced accurately since little growth potential remains for the correction of axial misalignment or shortening; fractures of this



a b c d

Fig. 10a–d. *Increase in leg length following internal fixation.* M.I., ♂, aged 12 years, No. 132150.
a) A road traffic accident caused this wide open fracture of the lower leg.
b) Treatment by débridement of the soft tissues and stabilization of the fracture by internal plate fixation. A cast was applied postoperatively and the metal was removed 6 months later.
c) 8 months after the operation. The bone and soft tissues have healed and there are no sequelae.
d) 2 years and 9 months following the accident. The leg length is increased by 1.5 cm

type which cannot be accurately reduced by closed methods, therefore, require open reduction.

Anterior tibial compartment syndrome; splitting of the fascia is followed by reduction and fixation of the fracture.

Operative procedure: The few diaphyseal fractures of the lower leg which require operation are fixed under compression with a minimum amount of implant material (Fig. 10). Frequently, two lag screws suffice, since postoperative cast fixation in accordance with the guidelines for nonoperative treatment described above has no disadvantages. The implant is removed as soon as possible in order to diminish the risk of metal-induced acceleration of longitudinal growth.

2.2 Distal Metaphyseal Fractures of the Lower Leg (Boot-Top Fractures)

2.2.1 Pathological Anatomy (Fig. 11)

A fall forwards with the calcaneus fixed (a common accident during skiing) frequently causes a greenstick fracture just proximal to the distal tibial epiphysis. The ventral cortex becomes impacted, and comminution frequently occurs. The dorsal cortex is completely fractured and the overlying periosteum is torn. In accordance with the accident mechanism, there is visible retrocurvature deformity which is sometimes quite severe.

2.2.2 Treatment

Nonoperative Treatment: A general anesthetic is given. Using a padded, wooden block as a fulcrum, the leg is straightened and the impacted ventral cortex is restretched. Considerable force is required for this proce-

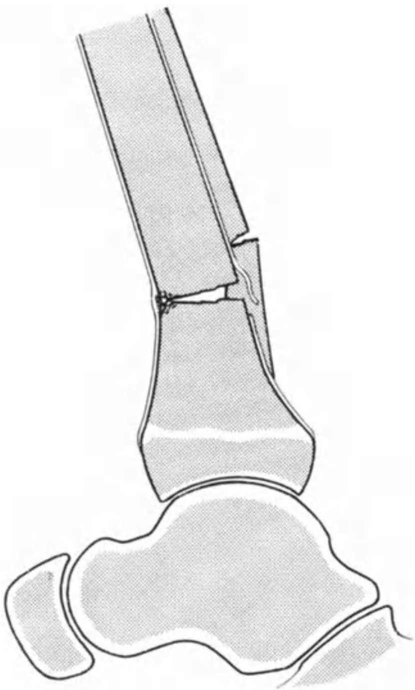


Fig. 11. *Boot-top fracture of the lower leg.* The anterior cortex is impacted and the overlying periosteum is intact. The posterior cortex gapes and the overlying periosteum is torn

Fig. 12a–c. *A boot-top fracture.* B.W., ♂, aged 15 years, No. AK BE 220557.
a) A-p roentgenogram.
b) Lateral view with the leg in a cast and the foot at a right angle. The retrocurvature deformity is clearly visible.
c) Only after reduction under general anesthesia with reverse bending of the fracture over a wooden block and application of a cast with the foot in plantar flexion has the anterior cortex regained its normal shape

dure; the intact ventral periosteum is placed under tension and stretched (Fig. 12).

Immobilization: In order to prevent the retrocurvature from recurring, the leg is first immobilized in a split, circular full-leg cast with the foot in plantar flexion for 3–4 weeks. This cast is then removed, the fracture is checked radiologically, and a full-leg walking cast is applied for 3–4 weeks with the foot in the neutral position. In a child, temporary immobilization of the foot in plantar flexion does not affect the joint function permanently (Fig. 13).

Duration of fixation: 6–8 weeks.

3 Prognosis

3.1 Acceleration of Growth

A fracture may be accompanied by stripping of the periosteum from the bone and be followed by extensive callus formation and displacement of the medullary cavity by bone fragments or metal; these and other experimentally determined factors increase the blood flow and thus stimulate activity in the epiphyseal plate (*Trueta, Weber*). The degree to which growth is accelerated is frequently exaggerated. As a rule, it just compensates for the shortening caused by the fracture.

However, one should not rely on this increase in growth rate, since it does not occur with the same regularity as that following a femoral fracture (*Weber*). Underestimation of the shortening caused by the fracture may result in permanent shortening which affects the function of the limb. Fracture-induced, premature

Fig. 13a–e. *Boot-top fracture*. W.C., ♂, aged 13 years, No. 88377.
a) The fresh fracture.
b) Roentgenograms following reduction and immobilization in plantar flexion with a cast.
c) Radiological check 5 days after the accident. The alignment of the fragments is unchanged.
d) 7 weeks after the accident. The fracture has healed.
e) 6 years after the accident. Symmetrical legs

d

Fig. 14a–d. *Underestimation of the initial shortening caused by a fracture*. H.E., ♂, aged 12 years, No. 137239.
a) Open (first degree) comminuted fracture of the lower leg.
b) Treatment by soft tissue débridement and closure of the wound, followed by traction applied to a *Steinmann* pin through the calcaneus.
c) The shortening was insufficiently corrected during the traction period. On applying the cast, 1.8 cm shortening was radiologically detectable (easily measurable at the fibula).
d) 3 years and 9 months after the accident. There is still 1.2 cm shortening. There was additional idiopathic shortening of the femur (0.8 cm), resulting in total shortening of 2.0 cm with corresponding compensatory scoliosis

epiphyseal closure occurs particularly frequently just before the end of the growth phase and may prevent the bone from compensating for shortening caused by a fracture. Therefore, the older the child, the greater should be the attention which is paid to the prevention of shortening (Fig. 14). The degrees of shortening which may be tolerated immediately following closed reduction of a fracture are:

1–15 years	10–15 mm
5–10 years	5–10 mm
10–15 years	0– 5 mm

These figures are intended as rough guidelines which do not necessarily apply to all types of fractures.

Internal fixation is followed by marked acceleration of growth. The increase in leg length results from the anatomically precise reduction and the stimulatory effect which metal is known to have on bone growth. The surgical procedure usually increases the area of stripped periosteum and the medullary cavity is partially occluded by the metal. If the occlusion lies within the area of the nutrient artery, a collateral circulation arises via the epiphyseal vessels, causing hyperemia in and around the epiphyseal plate (*Trueta*). The tips of the screws constitute additional foreign bodies which stimulate the periosteal circulation on the opposite side of the bone. The most important conclusion to be drawn from these theoretical considerations is that the implant material should be removed as soon as possible.

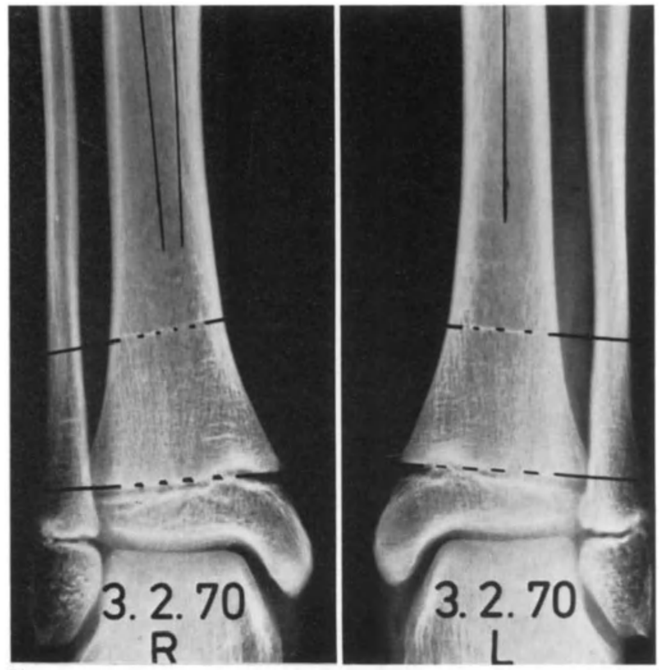
3.2 Initial Axial Misalignment

There has never been unanimity as to the degree of axial misalignment which may be tolerated following reduction of a fracture. One topic which is frequently discussed is the tendency of the most frequently occurring fracture type, the isolated fracture of the tibia, to result in *varus deformity*. The procedures recommended for the prevention of this almost unavoidable complication have even included osteotomy of the fibula (*Ehalt*). In fact, permanent valgus deformity is better than the same degree of varus angulation, since 30° of supination are available at the subtalar joint for functional adaptation, compared to only 5° pronation (*Müller*). The potential for compensation of varus malunion in an adult is very limited. Varus tilt of the talus therefore occurs, followed by compensatory valgus tilt of the calcaneus, and angulation of the hind foot results. These considerations are all valid in the adult. The bones of a child, however, possess two important properties which tend to reduce the deformity caused by a fracture. These are the compensatory growth potential of the epiphyseal plate and the apposition and resorption of diaphyseal bone in the late phases of fracture healing (Fig. 15). A roentgenogram may show curvature of the shaft of the bone, but also show signs of compensatory epiphyseal straightening in the form of wedge-shaped segments separating the *Harris* lines (Fig. 16). The only functionally significant deformity is that ascertained by comparison of the planes of the knee and ankle joints; curvature of the diaphysis itself is only of aesthetic importance. The diaphyseal curvature of the tibia might be such that corrective osteotomy would seem to be indicated. The latter procedure might well improve the appearance of the limb, but would have deleterious effects on the static function of the foot. Fortunately, residual diaphyseal angulation is largely masked by the surrounding soft tissues and is hardly noticed by the patient.

Fig. 15. *Spontaneous correction of axial misalignment in the course of subsequent growth*. The angulation of the shaft is corrected in the course of circumferential growth by apposition of bone on the concave side and resorption on the convex side (*Wolff*). The tilted joint surfaces are righted by asymmetrical longitudinal growth (*Pauwels*)

Fig. 17a–c. *Persistence of a valgus deformity*. K.E., ♂, aged 13 years, No. 79139.
a) Comminuted fracture of the lower leg (skiing accident) which was treated by traction and application of a cast.
b) $3^1/_2$ months after the accident. The fracture has healed with 7° valgus angulation.
c) 4 years after the accident. The diaphyseal angulation and the tilting of the joint surface are still present and there is no tendency to correction.
Note on the method of measurement: Tangents are drawn across the femoral condyles and the talus. By parallel displacement of these tangents, the angles between them can be measured and compared. In this example, valgus tilt of the left ankle joint is found on comparison with the right side

a b



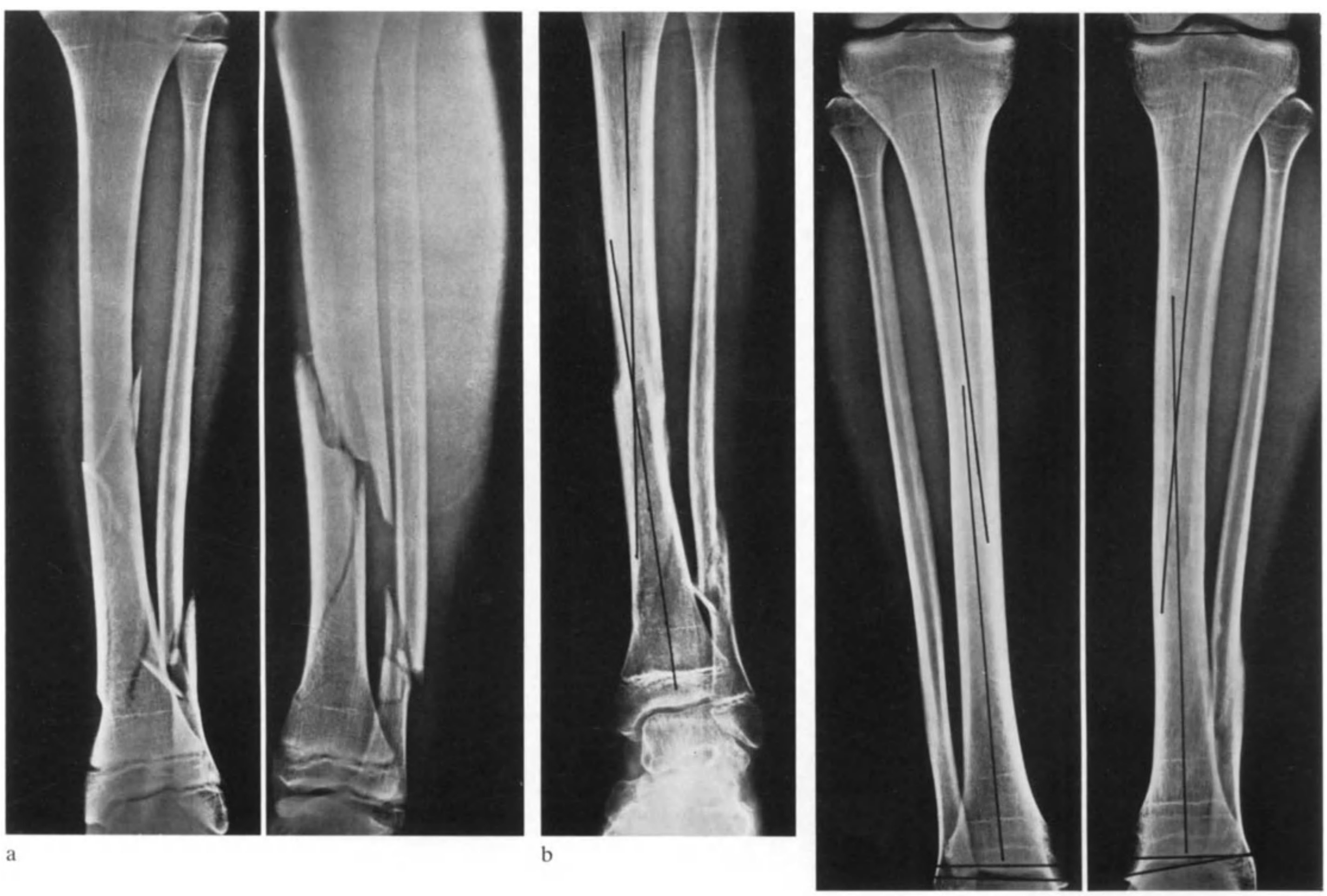
c

Fig. 16a–c. *Correction of a varus deformity by asymmetrical growth in the epiphyseal plate.* H.F., ♂, aged 9 years, No. 93101.

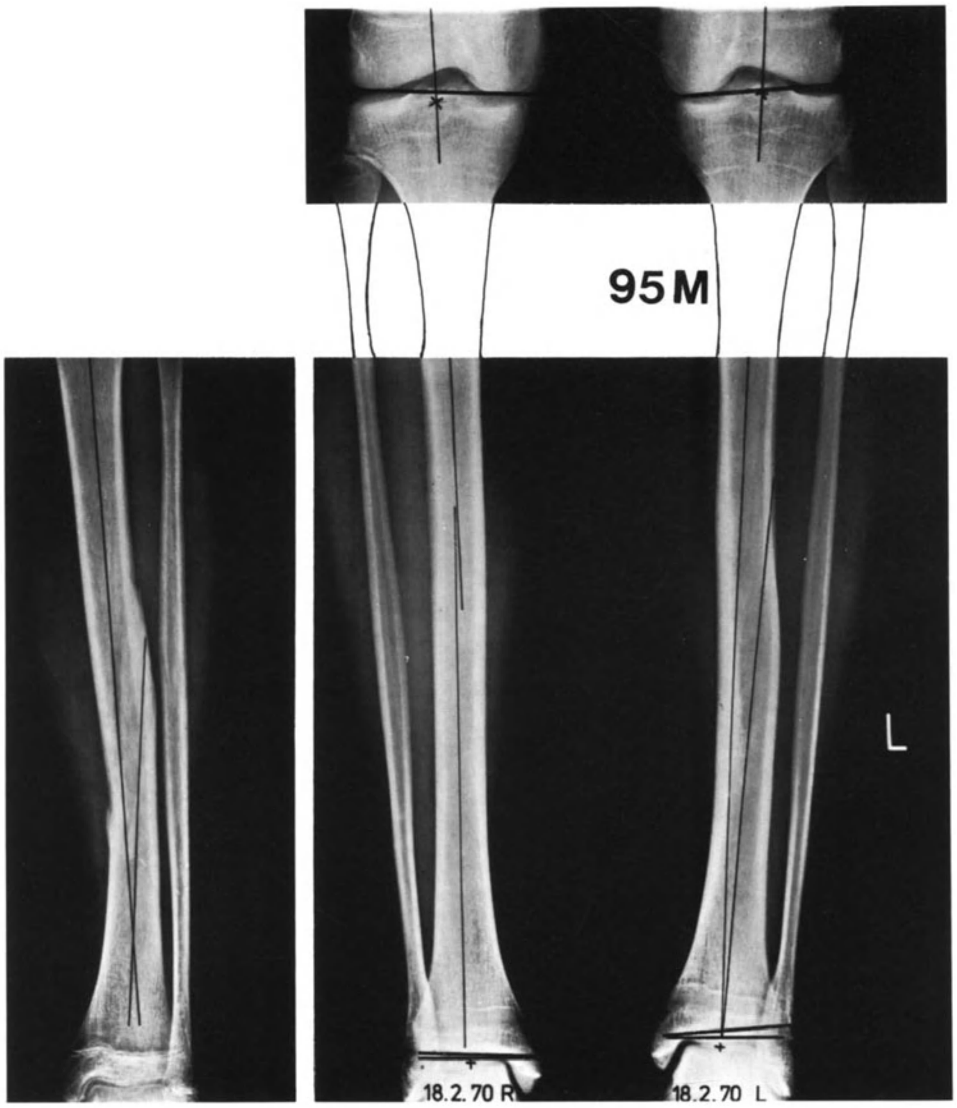
a) Fracture healing with 8° varus angulation.

b) 5 years after the accident. The deformity has been corrected at the articular level by asymmetrical growth in the epiphyseal plate.

c) 5 years after the accident. The *Harris* lines provide clear evidence of the accelerated growth on the medial side of the epiphyseal plate which corrected the deformity



a b c



a b

Fig. 18a, b. *Spontaneous correction of varus deformity*. H.H., ♂, aged 16 years, No. 72110.
a) The fracture has united with 7° varus deformity.
b) 95 months after the accident, the residual varus amounts to only 2°. The *Harris* lines are clearly asymmetrical

Fractures which heal with valgus deformity are rarer. In contrast to varus angulation, the spontaneous correction which valgus deformity undergoes is incomplete (Fig. 17) and increases are by no means rare. It is interesting to compare the spontaneous correction undergone by two fractures in boys of the same age, one of which united in varus and the other in valgus (Figs. 18 and 19). In the first case, the deformity, as measured by comparison of the joint planes, disappeared completely, but the valgus deformity in the second patient had, if anything, increased.

Retrocurvature and *antecurvature* deformities are only partially corrected at the diaphyseal and articular levels.

Malrotation is not corrected at all. External rotation causes overloading of the medial arch of the foot, but is nevertheless the less important of the two types of rotation deformities. Internal rotation on the other hand, leads to forced pronation of the foot during walking or to compensatory external rotation of the knee joint. These in turn cause osteoarthrosis in the subtalar joint or knee complaints (*Weber*). Even a few degrees of malrotation may have an adverse effect. At this point, it must once again be strongly emphasized that the rotation position of the leg on the traction frame can only be checked clinically. During this procedure, the abduction of the thigh should be taken account of when positioning the patient (Fig. 9).

The different methods for correction can be deduced from the following considerations. The weight of the body is transmitted by the lower limb along a line which joins the centers of the hip, knee, and talotibial joints. The position of this line in relation to the skeleton is not fixed, but moves in accordance with the displacement of the center of gravity during walking. Varus deformity causes transfer of weight to the medial part of the distal tibial epiphyseal plate during standing and walking. The cartilage plate responds to the changed pressure distribution by righting itself

Fig. 19a, b. *Absence of spontaneous correction of a valgus deformity*. G.H., ♂, aged 16 years, No. 72778 (a patient of the same age as that in Fig. 18).
a) The fracture has united with 4° valgus deformity.
b) 94 months after the accident, the valgus deformity has increased at the articular level and now amounts to 8° difference in valgus. The mid-diaphyseal angulation is still detectable

(*Pauwels*). It seems that valgus deformity does not give rise to an equivalent stimulus, and the changes in pressure distribution in the epiphyseal plate which result from retrocurvature and antecurvature are overshadowed by those which arise during walking. Malrotation never undergoes spontaneous correction since it does not give rise to the necessary biomechanical stimulus. Thus, the following guidelines apply to the prevention of permanent axial misalignment:

An isolated fracture of the tibia with a tendency to varus angulation is immobilized in a cast without prolonged or extensive attempts at correction.

All other types of deformity should be reduced to the best of one's ability.

Malrotation, however slight, must be completely eliminated.

Ad latus displacement is of no consequence, but the accelerated bone turnover associated with remodelling of this type of deformity sometimes causes excessive growth.

When this occurs, the leg length should be checked clinically and radiologically after 1 year so as to allow early planning of any corrective measures which may be necessary, e.g., use of a "sleeping bag" to warm the shorter leg during the night, or epiphyseal fusion on the longer side.

3.3 Pseudarthroses

Pseudarthroses of the bones of the lower leg hardly ever occur following correct nonoperative or operative treatment. The cause of a pseudarthrosis is very frequently internal fixation which is performed incorrectly and which results in postoperative infection. If osteosynthesis of a fracture of the lower leg is indicated, the fragments should be fixed stably with a minimum of metal (screw or plate fixation). Infection will not result if the usual principles of cleanliness, antisepsis, and sterility are rigidly adhered to.

4 Results

In the years 1961–1969, we treated 638 fresh fractures of the lower leg, 613 of them nonoperatively and 25 (4%) operatively.

4.1 Results of Nonoperative Treatment

Originally, we intended to follow-up all the patients in the order of their year of birth. After evaluating the data from the first 30 fractures, however, we decided to concentrate on the cases of malunion and the isolated fractures of the tibia, which tend to heal in varus. The patients were followed-up 5–9 years after their accidents and had ceased to grow or were reaching the end of their growth phase. Of these 62 fractures of the lower leg which were followed-up, 50 had been treated by immediate application of a circular cast and 12 had been placed in traction.

4.1.1 Acceleration of Growth

The analysis was limited to the data derived from 58 of the 62 cases; the remaining four patients had suffered bilateral or recurrent fractures and the resulting findings were difficult to interpret. Both lower legs of each child were measured clinically and radiologically. In addition, the lengths of the legs were measured indirectly with the patient in the standing position by placing shims under the feet until the pelvis was horizontal.

Irrespective of the initial shortening due to the fracture, leg length was increased in 22 cases (4–5 mm mean increase) and was decreased in 17 cases (9 mm mean shortening); the leg length was equal in 19 patients. By adding the initial shortening due to the fracture, the true change in growth rate can be computed; the growth rate was found to have increased in 42 patients, decreased in 7 patients, and remained unchanged in 9 patients. The mean acceleration of growth resulting from the different types of fracture is shown diagrammatically in Fig. 20. The growth rate was not accelerated by a slightly dislocated transverse fracture which was perfectly reduced, and the maximum increase in growth rate observed (13 mm) resulted from a severe torsion fracture with 25 mm shortening.

The results of our follow-up examinations have shown that slowing of growth occurs more frequently than was previously assumed and that increases in growth of more than 5 mm are relatively rare, except following open reduction and fixation.

4.1.2 Malunion

We are well aware that, even under optimum conditions, absolutely symmetrical roentgenograms are impossible to prepare. Every method of measurement contains sources of error, but the uniformity of our findings supports the validity of our conclusions.

Eleven fractures which occurred in patients of all age groups and which had united at varus angles of 5°–13° all underwent complete correction of the deformity at the level of the epiphyseal plate; in none of these cases was the residual diaphyseal curvature no-

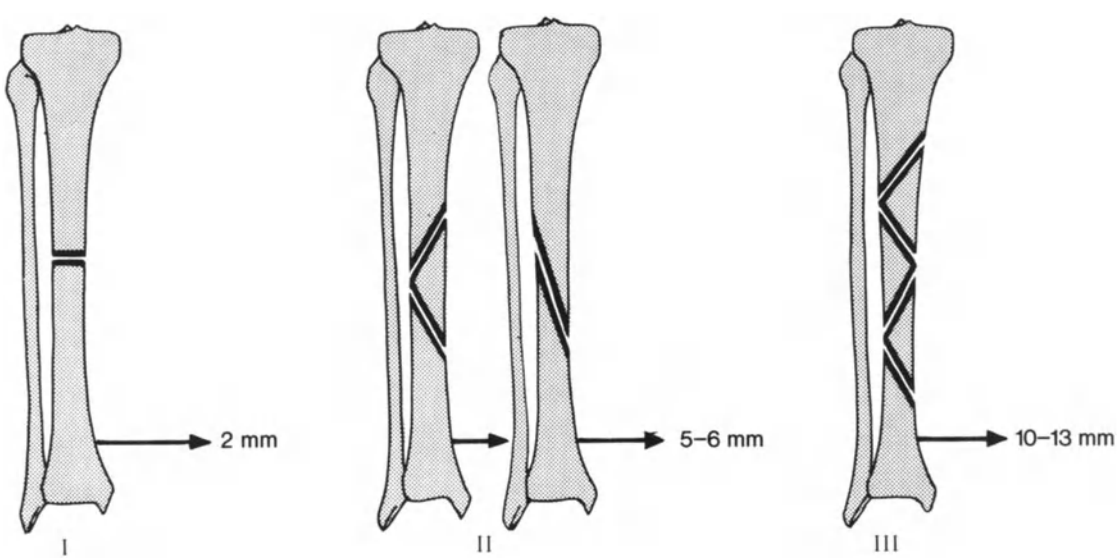
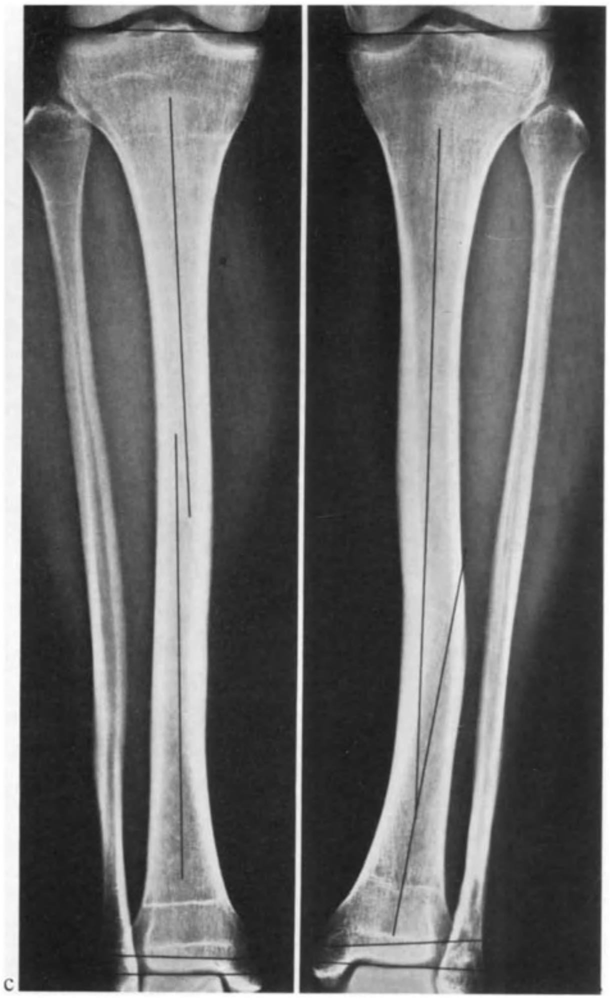


Fig. 20. *Mean increases in growth resulting from various types of fracture. I:* Transverse fracture; 2 mm mean increase. *II:* Oblique or butterfly fracture; 5–6 mm mean increase. *III:* Comminuted fracture; 10–13 mm mean increase



a b c

Fig. 21 a–c. *Incomplete correction of diaphyseal angulation with total elimination of epiphyseal tilt.* Sch.H., ♂, aged 14 years, No. 106381.
a) The fracture has united with 13° varus deformity.
b) 4 months after the accident. Remodelling of the shaft and righting of the epiphysis by asymmetrical growth in the epiphyseal plate have both begun.
c) $4^1/_2$ years after the accident. The varus angulation between the joint surfaces is almost completely compensated for; the residual varus amounts to 2°. There is still marked varus deformity of the diaphysis

a b

Fig. 22a, b. *Exceptional correction of a valgus deformity.* Z.V., ♀, aged 6 years, No. 101945.
a) The fracture has healed with 10° valgus deformity.
b) 10 years after the accident. The abnormal valgus angle between the planes of the joints has been almost completely corrected by asymmetrical epiphyseal growth. There is marked leg lengthening. The mid-diaphyseal angulation is still present

a b

Fig. 23a, b. *Retrocurvature deformity which underwent incomplete correction.* Sch.R., ♀, aged 6 years, No. 87671.
a) Marked retrocurvature of the fracture in the cast.
b) 6 years after the accident. The retrocurvature of the shaft is still present and is partially compensated for at the articular level. Retrocurvature immediately following the accident = 12°; residual retrocurvature at follow-up = 5°

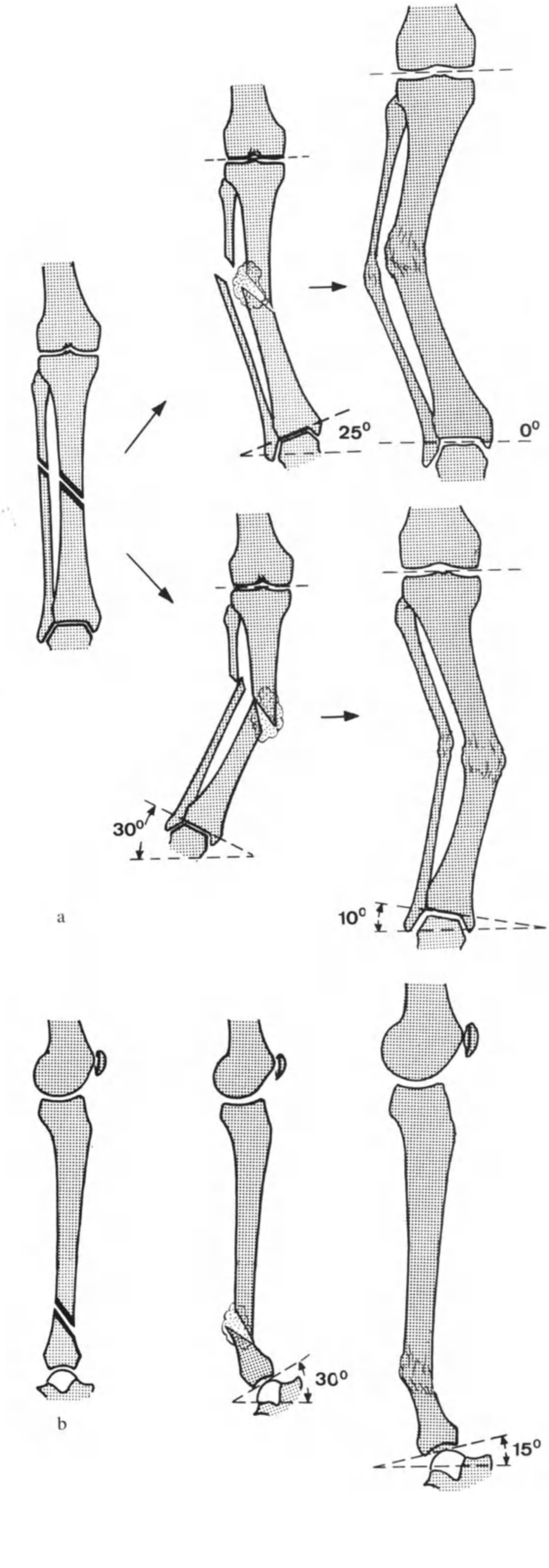


Fig. 24a, b. *Capacity for correction of different types of deformity.* The corrective potential diminishes very rapidly from the time of prepuberty onwards.
a) Valgus or varus deformity; the potential for correction of varus deformity ranges up to 25°. The maximum potential for correction of valgus deformity is 20°, but correction does not usually occur.
b) Retrocurvature: corrective potential approximately 15°

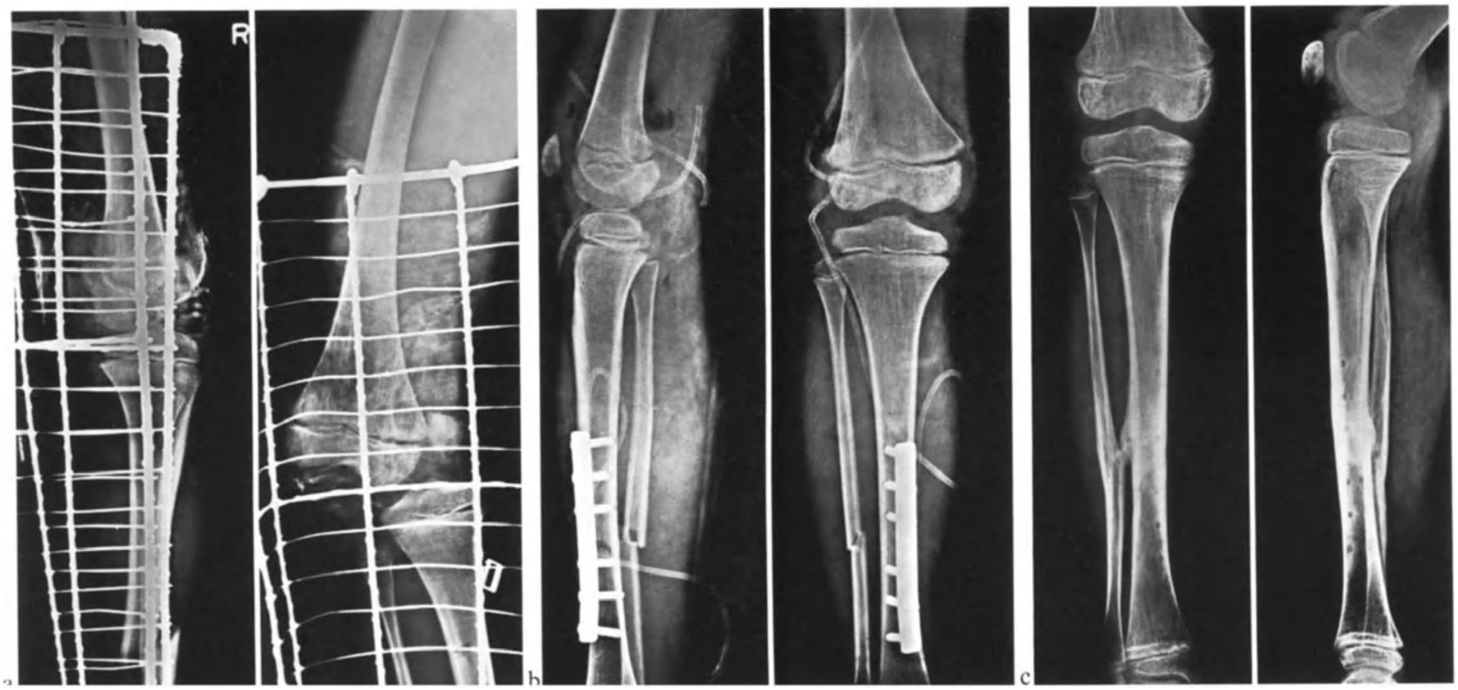


Fig. 25a–d. *Acceleration of longitudinal growth following internal fixation.* H.N., ♂, aged 8 years, No. 77130.
a) Open dislocation of the knee and open fracture of the lower leg caused by a road traffic accident.
b) Operation: débridement and suture of ligaments of the knee joint; débridement and internal plate fixation of the tibia.
c) 7 months after the accident. The fracture and all the soft tissue injuries have healed completely with no sequelae. Roentgenogram taken following removal of the metal.
d) 7 years and 4 months after the accident. This 2.5 cm increase in leg length at the site of the fracture was treated by fusion of the proximal tibial epiphysis

ticed by the patient (Fig. 21). The method by which axial alignment is checked is described in the legend to Fig. 17.

Follow-up examination of five fractures which had united with 5°–7° valgus showed full correction of the deformity at the level of the joint to have occurred in only one case (Fig. 22). In three patients, the axial misalignment was permanent, and in one case it had even increased somewhat.

Eight fractures healed with *retrocurvature* of 5°–15°. These were all transverse fractures of the distal metaphysis and the retrocurvature could have been prevented by the use of a circular cast with the foot in plantar flexion. At follow-up, a certain degree of realignment of the diaphysis had occurred, but comparison of the joint planes showed residual deformity to be present in every case.

In one case of *antecurvature,* bone resorption and apposition had resulted in slight correction of the diaphyseal angulation, but the straightening at the level of the epiphyseal plates was only partial (Fig. 23).

The diagrams in Fig. 24 show the different ways in which bone growth can bring about correction of the different types of deformity.

External rotation deformities of 5°–10° were found in eight cases, but had not been noticed by the patients themselves. Three cases of clinically obvious malrotation were found, severe internal rotation being present in each case.

Fig. 26a–d. *Unnecessary internal fixation*. B.R., ♂, aged 7 years.
a) Mid-diaphyseal fracture of the lower leg with shortening.
b) Treatment in another hospital by open reduction, subperiostal cerclage wiring, and immobilization with a cast.
c) 2 months later. Infection has occurred.
d) 5 months after the accident. Infected pseudarthrosis. Comment: There was no indication for internal fixation

4.2 Results of Operative Treatment

All the 25 fractures of the lower leg which underwent internal fixation were operated on for the reasons already described (see Indications for Operative Treatment). Almost all cases were followed-up 4 and 12 months after the operation and some of them were seen more frequently. No complications occurred. Twelve fractures which had occurred in patients under 14 years of age and which had been treated by lag screw or plate fixation were followed-up again several years after the accident. The remaining 13 patients were about to cease growing at the time of operation or died from other more severe injuries. In each case, anatomically precise reduction was carried out and the minimum amount of metal was used. As in the case of the nonoperatively treated fractures, the lower legs were measured clinically and radiologically, but clinical methods alone were used for the measurement of thigh length. The mean of the increases in length of the lower legs was 9.6 mm and that of the thighs was 5.3 mm; the maximum observed increase in leg length was 18 mm and that of the femur was 12 mm. The differences in the length of the lower limbs were less than 15 mm in eight patients; they exceeded 20 mm in four patients and were accompanied by corresponding symptoms which made blocking of the shoes or operative correction of leg length necessary (Fig. 25).

The interpretation of the above results is complicated by the absence of data concerning the initial leg lengths of the patients concerned. A difference in leg length of up to 1 cm may be regarded as physiological, but may summate with that which follows internal fixation. Conversely, a preexisting difference in leg length could, theoretically, disappear following internal fixation of a fracture of the shorter leg. Recently, we started measuring the lengths of both lower legs radiologically immediately following the operation, and we have found that the acceleration of growth following internal fixation is significantly greater than that following closed reduction of the same types of fracture. The results of our investigations show that the stimulatory effect of osteosynthesis lasts not longer than 1 year, if, as is the case in our clinic, the metal is removed within 4 months.

4.3 Pseudarthroses

No pseudarthroses were found on examination of the case records of the 638 fractures in our series. In the same period (1961–1969), however, seven pseudarthroses were referred to us for treatment. Five had been caused by incorrect internal fixation and one resulted from treatment of an isolated fracture of the tibia with 3–4 kg traction instead of immediate application of a circular cast. In the latter case, there was almost no bone contact between the fragments.

Analysis of the five cases in which internal fixation had resulted in pseudarthrosis revealed no indication for operative fracture treatment (Fig. 26).

Four fractures had been fixed in an unstable fashion (cerclage wiring, *Rush*-pin) and in one case a correctly performed internal fixation was followed by infection and pseudarthrosis.

5 Summary

Isolated fractures of the tibia and stable fractures of the lower leg are fixed immediately with a cast, but unstable fractures are first placed in traction. Varus deformities of up to 15° in growing children undergo spontaneous correction, but valgus deformity, antecurvature, and retrocurvature persist to some degree. Malrotation is permanent. The increase in leg length resulting from the acceleration of growth caused by a nonoperatively treated fracture is rarely significant and excessive degrees of shortening following reduction should therefore be avoided. Internal fixation should be reserved for exceptional cases since it always causes excessive lengthening of the leg.

6 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme, 1957.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1961.

Freuler, F., Wiedmer, U., Bianchini, D.: Gipsfibel 1. Berlin-Heidelberg-New York: Springer, 1975.

Freuler, F., Wiedmer, U., Bianchini, D.: Cast manual for adults and children. Berlin-Heidelberg-New York: Springer, 1979.

Harris, H. A.: Bone growth in health and disease; the biological principles underlying the clinical, radiological and histological diagnosis of perversions of growth and disease in the skeleton. London, Oxford: University Press, 1933.

Hutter, C. G., Scott, W.: Tibial torsions. J. Bone Jt Surg. **36A,** 511–520 (1954).

Le Damany, P.: La torsion du tibia, normale, pathologique, expérimentale. J. Anat. Paris **45,** 598–615 (1909).

Mikulicz, J.: Ueber individuelle Formdifferenzen am Femur und an der Tibia des Menschen. Arch. Anat. Physiol. **1,** 351–404 (1878).

Müller, M. E. (Hrsg.): Posttraumatische Achsenfehlstellungen an der unteren Extremität. Bern: Huber, 1967.

Pauwels, F.: Gesammelte Abhandlungen zur funktionellen Anatomie des Bewegungsapparates. Berlin-Heidelberg-New York: Springer, 1965.

Pauwels, F.: Contributions on the functional anatomy of the locomotor apparatus. Berlin-Heidelberg-New York: Springer 1980.

Pauwels, F.: Über die Bedeutung der Bauprinzipien des Stütz- und Bewegungsapparates für die Beanspruchung der Röhrenknochen. Acta anat. (Basel) **12,** 207–227 (1951).

Trueta, J.: The influence of the blood supply in controlling bone growth. Bull. Hosp. Jt Dis. (N.Y.), **14,** 147 (1953).

Weber, B. G.: Zur Behandlung kindlicher Femurschaftbrüche. Arch. orthop. Unfall-Chir. **54,** 713 (1963).

Weber, B. G.: Inwieweit sind isolierte extreme Torsionsvarianten der unteren Extremität als Deformitäten aufzufassen und welche klinische Bedeutung kommt ihnen zu? Z. Orthop. **94,** 287 (1961).

Weber, B. G.: Indikationen zur operativen Frakturbehandlung bei Kindern. Chirurg **10,** 441 (1967).

Malleolar Fractures

B.G. Weber and F. Süssenbach

CONTENTS

1 Introduction

Injuries to the ankle joint always involve the epiphyseal plate. The type of injury and its effects on the joint can be predicted from the magnitude and direction of the violence to which the epiphyseal plate is subjected.

The force which causes the injury is more often indirect than direct; in practice, the ratio between the two is 4:1, respectively. Forced *external rotation, abduction*, and *pronation* of the foot generates shear forces in the joint and in the vicinity of the epiphyseal plate which cause sliding fractures. These take the form of simple epiphyseal separations or, in cases where there is an additional bending component, separation of the epiphysis with a wedge-shaped metaphyseal fragment. If the foot is forced into *internal rotation, adduction,* and *supination*, the ankle joint is predominantly subjected to axial pressure and bending forces. These cause impacted fractures which have adverse effects on the subsequent function of the epiphyseal plate. In a child, the maturation and function of the joint may be endangered by pronation injury, which tends to be less harmful, or by supination injury, which is much more serious.

Bishop cited forced external rotation and abduction as the causes of injury in 32% of the cases in his series, and adduction and supination in 55%. On the other hand, *Carothers* and *Crenshaw* ascribed 57% of the injuries to excessive external rotation and abduction, and only 26% to adduction and supination. Bone injury in the vicinity of the ankle joint rarely occurs in children under 8 years of age. The violence usually causes simple separation; this type of injury is more likely to occur since the tough ligaments, which have a high tensile strength, are inserted below the epiphyseal plate. The epiphyseal plate is less resistant to tensile forces and is likely to fail before rupture of the ligament occurs. The distal epiphyses of the lower leg are among the commonest sites of separation (12%–25% of all separations), being second only to the distal radial epiphysis in this respect (*Ehlers* and *Eberlein*). Separations of the distal epiphysis and fractures of the lower leg occur in a ratio of 1:4 (*Bartl*), the injury occurring four times more frequently in boys. True malleolar fractures are uncommon in small children; those which do occur are impacted fractures of the medial malleolus caused by severe degrees of violence. They are brought about by an adduction/supination mechanism and their prognosis is very poor.

Around the *tenth year of life*, the union between the diaphysis and epiphysis strengthens and simple separation without involvement of the bone therefore becomes less common. From the *fifteenth year of life* onwards, the frequency of occurrence of epiphyseal separation drops rapidly and the fractures begin to resemble those which occur in adults.

Simple ligamentary injuries are rarely seen in children. The lateral subluxation of the talus which occurs frequently in adults as a result of injury to the deltoid ligament and the anterior syndesmosis (pronation injury) is never found in children. Simple subluxation of the supination type with injury to the anterior fibulotalar ligament and to the calcaneo-fibular ligament (supination injury) is occasionally sustained by a child.

2 Fracture Types and Treatment

The ankle is an articulation of the mortise type which unites the distal end of the tibia and fibula with the talus. The proximal part consists of the malleolar mortise, which is held together by the taut, but resilient anterior and posterior ligaments of the syndesmosis. The movement of the talus in the malleolar mortise is controlled precisely by the lateral ligaments (Fig. 1).

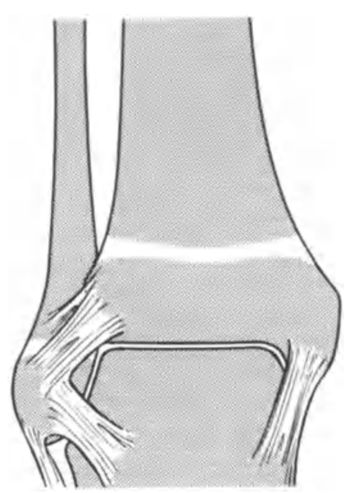


Fig. 1. *Anatomy of the ankle joint*. The movement of the talus in the malleolar mortise is controlled by strong ligaments, i.e., the medial malleolar ligament, the lateral malleolar ligaments and the ligaments of the syndesmosis

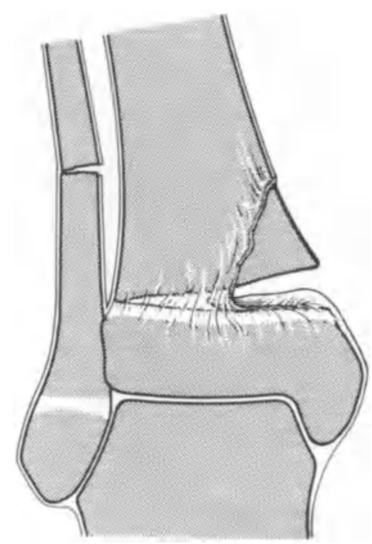


Fig. 2. *Separation of the distal tibial epiphysis*. The periosteum is frequently folded into the fracture gap and there is usually an angulation fracture of the distal fibular diaphysis

In this vulnerable part of the skeleton, the epiphyseal plates represent relatively weak structures, i.e., weaker than those adjacent to other joints. They are subjected to heavy loads, and epiphyseal fractures, which have a serious prognosis if incorrectly treated, occur much more frequently here than at other sites. Disturbances of healing, therefore, have serious effects on the ankle joint, and even slight degrees of misalignment of the epiphyseal plate cause displacement of the axis of the joint and articular incongruence. This results inevitably in osteoarthrosis, which occurs particularly frequently in the skeleton of the lower limbs. Injuries to the bones of the ankle joint are classified in three groups on the basis of their prognosis and treatment, i.e.:

a) *Harmless injuries* Simple epiphyseal separation and loosening of the epiphyseal plate, and separation of the epiphysis with a wedge-shaped metaphyseal fragment	No growth disturbance
b) *Serious injuries* Fracture separation with an epiphyseal fragment, and fracture separation with an epimetaphyseal fragment	Progressive disturbance of growth
c) Transition fractures, and Fractures of the tuberosity of *Tillaux-Chaput*	Osteoarthrosis secondary to joint incongruency

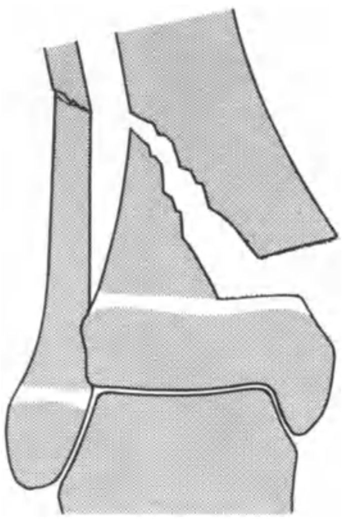


Fig. 3. *Aitken Type I separation with a metaphyseal wedge*. The valgus deformity is characteristic

This classification is based largely on the anatomical classification of *Aitken*. It takes into account the fact that the *Aitken* classification does not expressly include true crush injuries, which have a particularly poor prognosis if they occur in the vicinity of the ankle joint.

The treatment is determined by the type of injury, attention being paid to the degree of damage to the epiphyseal plate, to the skeletal age of the patient, and to the effect which these are likely to have on fracture healing and the subsequent growth and alignment of the bone.

2.1 Harmless Injuries

These are:

Simple epiphyseal separation or loosening of the epiphyseal plate.

Separation of the epiphysis with a metaphyseal fragment (*Aitken* I).

The prognoses and treatments of the two types of injury are identical and they are therefore discussed together. They are sliding fractures which are caused by shear forces and which mainly occur in young children.

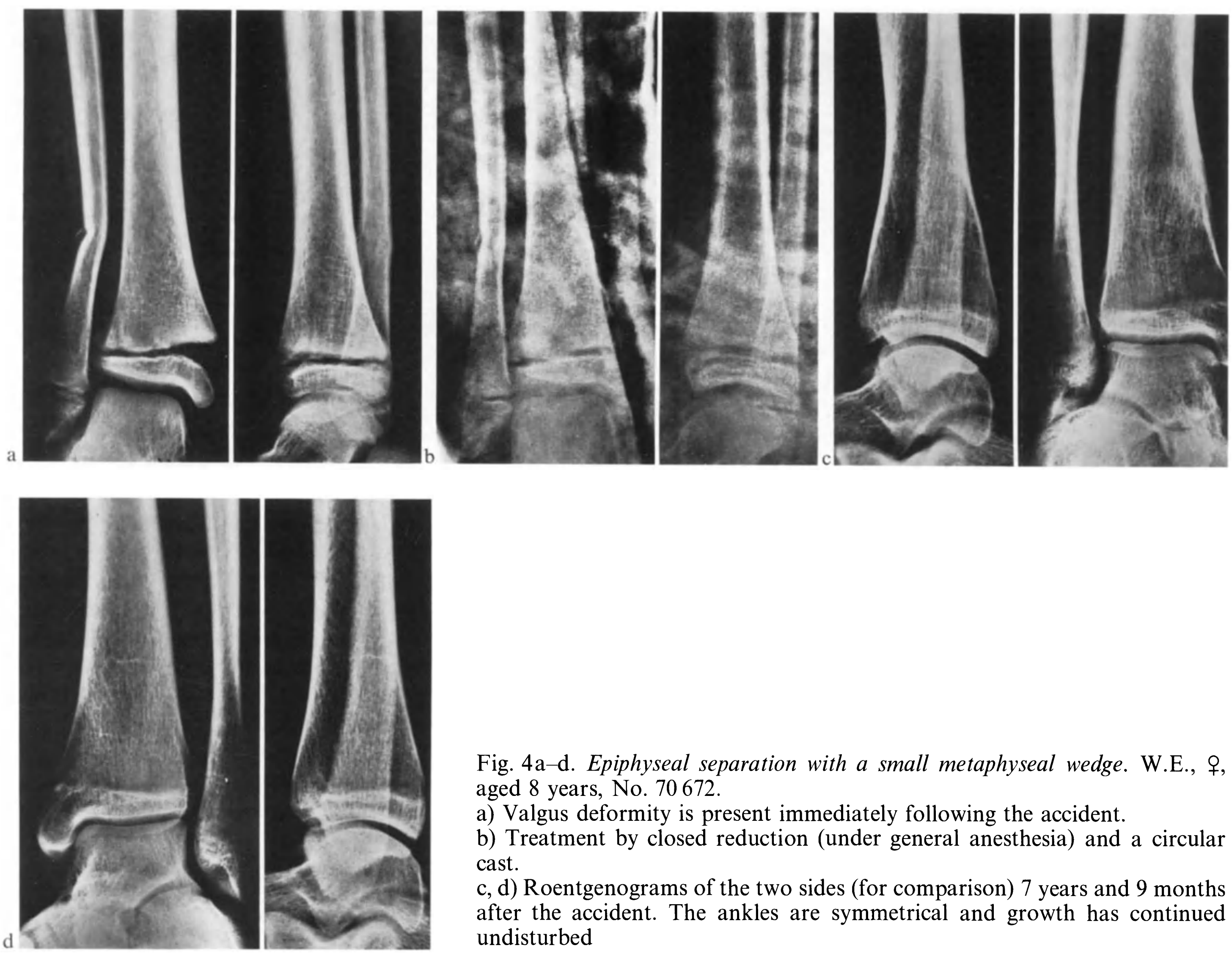


Fig. 4a–d. *Epiphyseal separation with a small metaphyseal wedge*. W.E., ♀, aged 8 years, No. 70 672.
a) Valgus deformity is present immediately following the accident.
b) Treatment by closed reduction (under general anesthesia) and a circular cast.
c, d) Roentgenograms of the two sides (for comparison) 7 years and 9 months after the accident. The ankles are symmetrical and growth has continued undisturbed

2.1.1 Pathological Anatomy

2.1.1.1 Simple Epiphyseal Separation or Loosening

These injuries may occur in the tibia, in the fibula, or in both bones. The epiphyseal plate itself is not damaged and the joint surface also remains intact. The line of separation runs through the layer of degenerating cartilage cells and that of primary endochondral ossification. The periosteum frequently becomes torn and forms a flap which remains attached at one end to the epiphysis. The free end then becomes trapped in the gap between the fragments (Fig. 2).

2.1.1.2 Separation of the Epiphysis with a Metaphyseal Wedge (Aitken I)

This lesion is a form of epiphyseal separation with the addition of a wedge-shaped metaphyseal fragment of variable size which remains attached to the epiphyseal plate. The dislocation may be quite severe, but the epiphyseal plate itself is undamaged and the vascular supply to the epiphysis remains intact (Fig. 3).

In neither case does the lesion involve the vulnerable layer of germinative cartilage and progressive disturbance of growth is therefore unlikely to occur. The usual effect is a slight increase in growth rate or, more frequently, transient slowing of growth (shown by the epiphyseal arrest lines of *Harris*).

2.1.2 Treatment

The treatment is determined by the age of the child and is usually nonoperative. In small children, angular misalignment is corrected to a certain degree by functional asymetrical longitudinal growth in the epiphyseal plate (*Pauwels*). Towards the end of the skeletal growth phase, little corrective growth potential remains in the epiphyseal plate and axial misalignment therefore persists. For this reason, the simplest of fractures in an adolescent requires anatomically precise realignment of the fragments, by open reduction if need be (*Weber*).

Nonoperative Treatment: If reduction is necessary, it is always carried out under general anesthesia (Fig. 4). If the dislocation is severe, it may be impossible to achieve satisfactory reduction immediately by gentle manipulation. In the majority of such cases, the fragments are separated by a *periosteal flap* (Fig. 5) which remains trapped between them despite repeated attempts at reduction. If the flap is small and the child young, the residual axial misalignment will undergo spontaneous correction in the course of subsequent growth. A larger amount of interposed tissue causes a partial "pseudarthrosis" which gradually moves in the direction of the diaphysis. This cortical scar may remain visible for several years (Fig. 24).

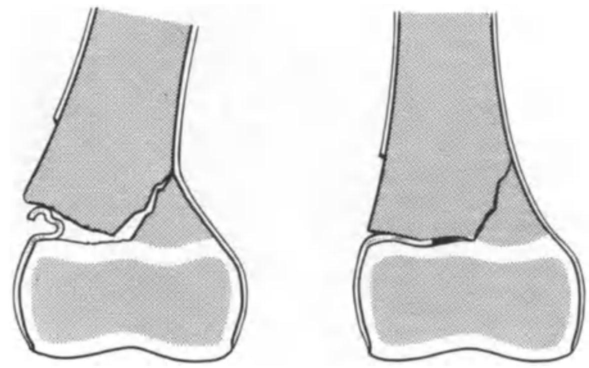


Fig. 5. *Entrapment of periosteum resulting in incomplete reduction.* Anatomically precise reduction is prevented by the periosteal flap which has been folded into the fracture gap

Immobilization: A padded cast is applied to the lower leg and is immediately split; it is closed as soon as the swelling has subsided. It is replaced 2 weeks later by a below-knee walking cast. If simple loosening of the epiphyseal plate has occurred, a below-knee walking cast is applied immediately and worn for 4 weeks.

Duration of fixation: 4–6 weeks, depending on the age of the child.

Operative Treatment: If the patient is an adolescent who has almost ceased growing, soft tissue which is interposed between the fragments and which cannot be extracted by manipulation will cause permanent malunion. In such a case, further attempts to reduce the fracture by closed manipulation should be abandoned and open reduction should be carried out immediately. Open fractures should also be exposed and reduced in the course of surgical exploration, débridement, and repair of the wound.

Note: Repeated attempts to reduce a fracture may cause additional damage to the epiphyseal plate.

Operative procedure: Following extraction of the interposed tissue (periosteum, cruciate crural ligament), the fracture can easily be reduced. If it is then sufficiently stable, fixation with a plaster cast suffices. If it is unstable, the fragments are stabilized by adaptation osteosynthesis as follows:

Simple epiphyseal separations: these are stabilized with *Kirschner* wires which pierce the epiphyseal plate at as near to a right angle to it as possible (Fig. 6). The surgeon should work gently and with precision in order to avoid unnecessary drilling of the epiphyseal plate.

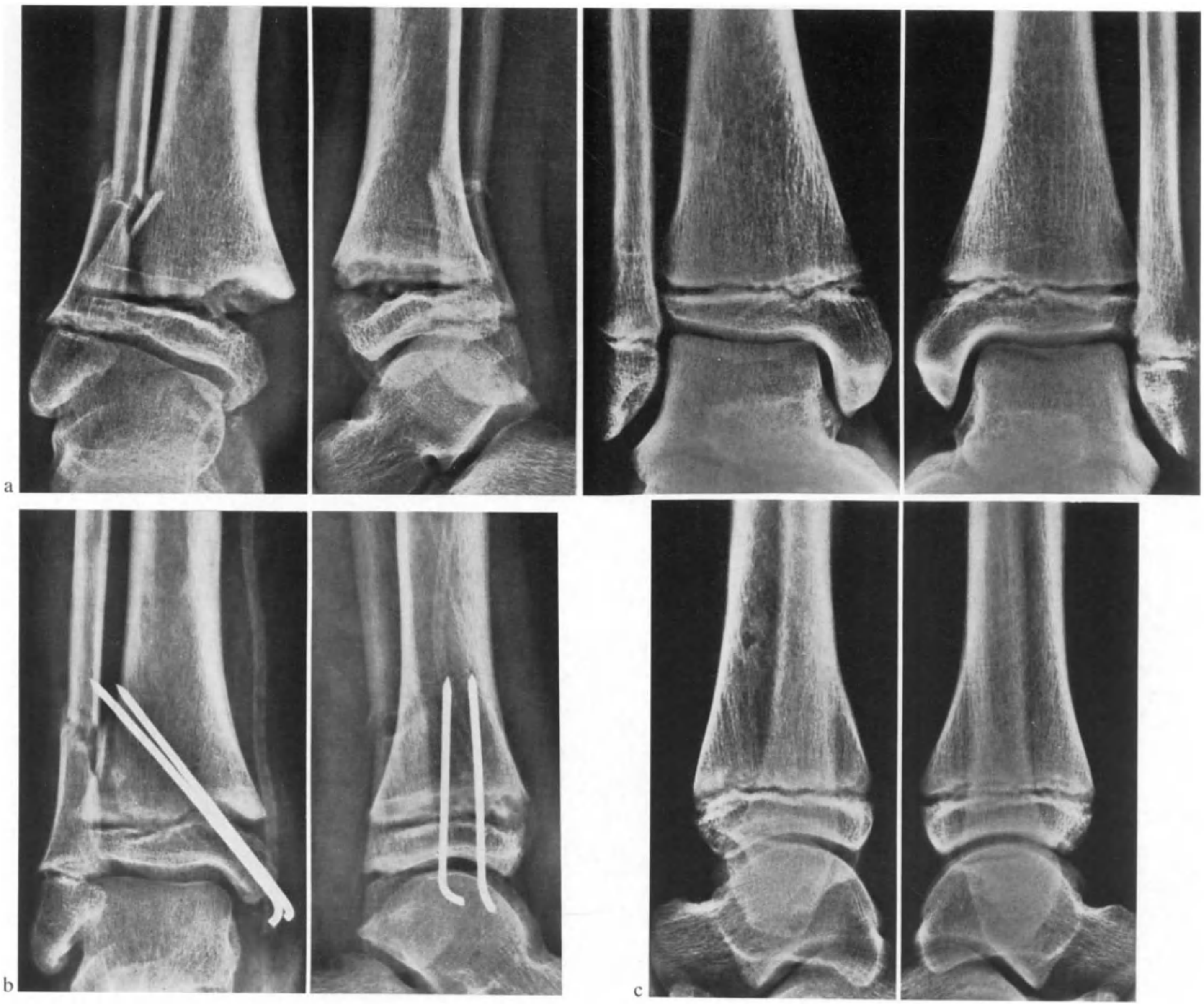
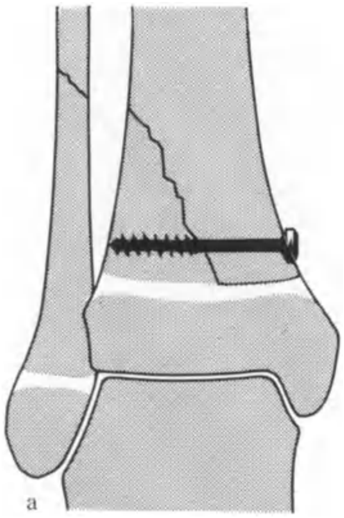


Fig. 6a–c. *Open reduction necessitated by entrapment of a periosteal flap*. M.F., ♂, aged 10 years, No. 82854.
a) Fracture separation with interposition of a very large periosteal flap.
b) An unsatisfactory attempt at closed reduction was followed by open reduction, extraction of the trapped periosteum, and *Kirschner* wire transfixation.
c) 4 years and 11 months after the accident. Symmetrical growth has continued and there are no residual signs of the fracture



a

Fig. 7a–d. *Screw fixation of a fracture separation with a large metaphyseal wedge.*
a) The osteosynthesis technique: transverse screw fixation proximal to the epiphyseal plate.
b) T.M. ♂, aged $12^1/_2$ years, No. 93183. Fracture separation with retrocurvature caused by interposition of periosteum. Closed reduction was impossible.
c) Treatment by exposure of the fracture, extraction of the interposed periosteum, anatomically precise reduction, and fixation with a lag screw placed proximal and parallel to the epiphyseal plate.
d) $3^1/_2$ years after the accident. Growth is normal, there are no residual signs of the fracture, and the two sides are symmetrical

b

c

d

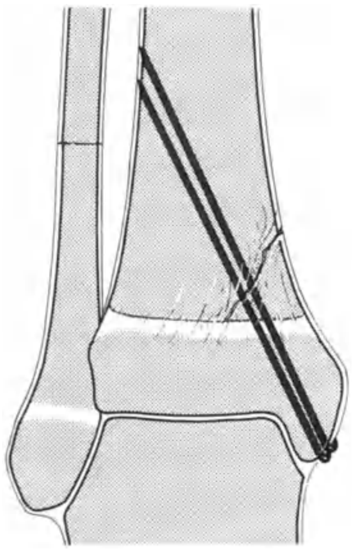
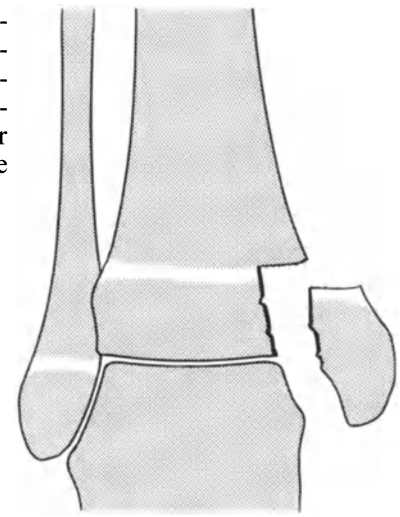


Fig. 8. *Kirschner wire transfixation of a simple separation or a fracture separation with a small metaphyseal wedge*. If the metaphyseal wedge is small, two parallel *Kirschner* wires are used for fixation. They pierce the epiphyseal plate at as near to a right angle to it as possible

Fig. 9. *Aitken Type II fracture separation with an epiphyseal fragment*. The fracture line transects the germinative cartilage layer and causes incongruence of the joint surface



Aitken Type I fractures: The metaphyseal wedge is best fixed with a screw which is aligned parallel to the epiphyseal plate (Fig. 7). If the metaphyseal wedge is so small that it cannot be fixed with a screw, only *Kirschner* wires should be used (Fig. 8). Screws should never be allowed to cross the epiphyseal plate since they would cause partial epiphyseal fusion which, in turn, results in abnormal growth.

Postoperative treatment: A plaster U-splint is applied for 1 week with the ankle positioned at 90°. Active mobilization of the joint is then begun. A below-knee walking cast is applied on discharge from hospital and is worn for 4–6 weeks. The metal is removed after 6–8 weeks.

Duration of fixation: 6–8 weeks.

2.2 Serious Injuries

These are:

Fracture dislocation with an epiphyseal fragment (*Aitken* II).

Fracture dislocation with an epimetaphyseal fragment (*Aitken* III).

The two types of injury present the same problems as regards treatment and prognosis. They differ only in the course of the fracture line; this always completely transects the epiphyseal plate, and the joint surface is interrupted by steps of variable size. These lesions have serious sequelae if treated incorrectly. They are caused predominantly by pressure and bending forces, rather than shear forces and sliding displacement.

2.2.1 Pathological Anatomy

2.2.1.1 Fracture Separation with an Epiphyseal Fragment (Aitken II)

The fracture line completely transects the epiphyseal plate, including the vulnerable germinative layer. The epiphyseal fragment separates from the metaphysis at the junction of the latter with the epiphyseal plate, thus constituting a partial epiphyseal separation (Fig. 9).

2.2.1.2 Fracture Separation with an Epimetaphyseal Fragment (Aitken III)

This is a more or less sagittally-oriented fracture or may resemble a *Volkmann* fracture (Fig. 10). The frac-

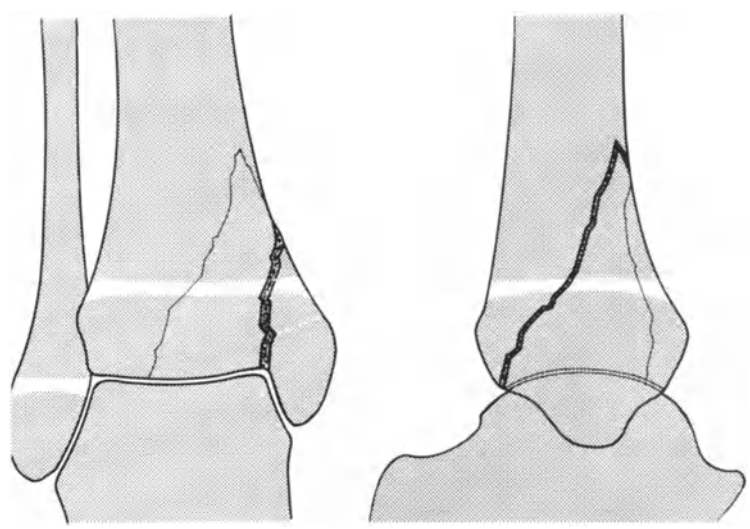


Fig. 10. *Aitken Type III Epimetaphyseal fracture*. Rare in children and mainly seen in adolescents, being analogous to malleolar fracture in an adult. The fracture transects the epiphyseal plate

ture line runs from the epiphysis to the metaphysis and crosses the germinative cartilage layer. In rare cases, an *Aitken* Type II fracture may be combined with an *Aitken* Type III lesion (Fig. 11). Sometimes the main damage caused by these fractures is not the *splitting* of the growth cartilage, but the *crushing of the epiphyseal plate*. This results when violent adduction and supination forces the medial border of the talus against the undersurface of the tibia and breaks away the medial malleolus. The resulting dislocation may be very slight. Some authors believe that crushing of the medial part of the epiphyseal plate need not be accompanied by breaking away of a bone fragment. Thus, a crush injury which appears harmless, but has serious consequences may be overlooked on the roentgenogram or assessed as insignificant. In accordance with the accident mechanism, impression of the medial border of the talus is occasionally seen (Fig. 12). The damage caused by splitting and crushing of the germinative layer of the epiphyseal plate may be compounded by a third factor, i.e., *restriction of the nutrient blood supply* as a result of concomitant damage to the epiphyseal blood vessels, which are the only ones supplying the germinative cartilage layer (Fig. 13).

For the above reason, injuries of this type are very likely to be followed by abnormal growth of the bone. In the literature, frequencies of growth disturbance following impaction of the distal epiphyseal plate of the tibia range from 33% to 100% (*Aitken, Bergenfeldt, Bishop, Carothers and Crenshaw, Ehalt, Gall, Guiliani, Goff, Salter and Harris, Titze, Witt*). Roentgenograms in two planes usually suffice for precise diagnosis. If further information is necessary, we recommend films of the opposite, intact side for comparison and oblique views which show the fracture line clearly (Fig. 14).

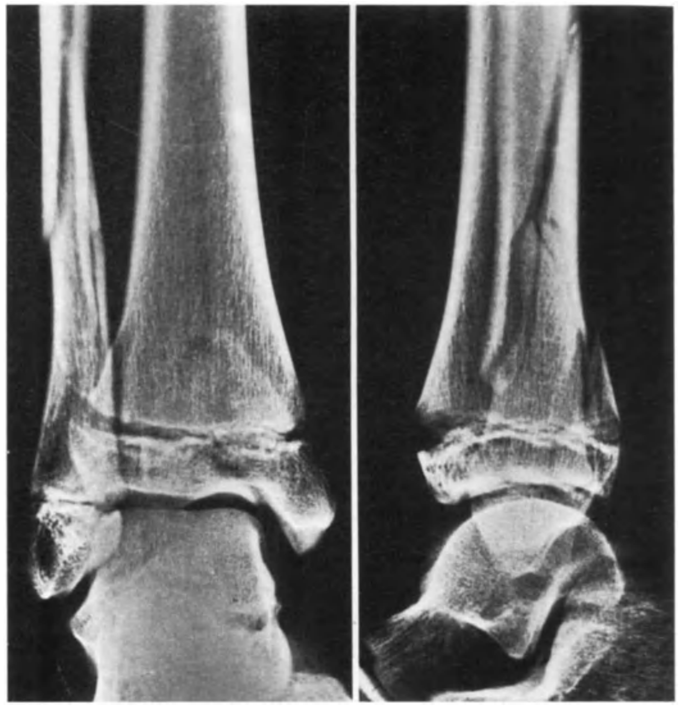


Fig. 11. *Combination of Aitken fracture Types II and III.* D.G., ♀, aged 15 years, No. 125 372. This is a true fracture dislocation of the ankle joint which is analogous to that seen in adults

2.2.2 Treatment

The serious nature of these articular fractures and their poor primary prognosis make anatomically precise reconstruction of the epiphyseal plate and the restoration of perfect congruity to the joint surface absolutely imperative. It is known that injury to the epiphyseal plate is not necessarily followed by abnormal bone growth if the plate has not been irreversibly

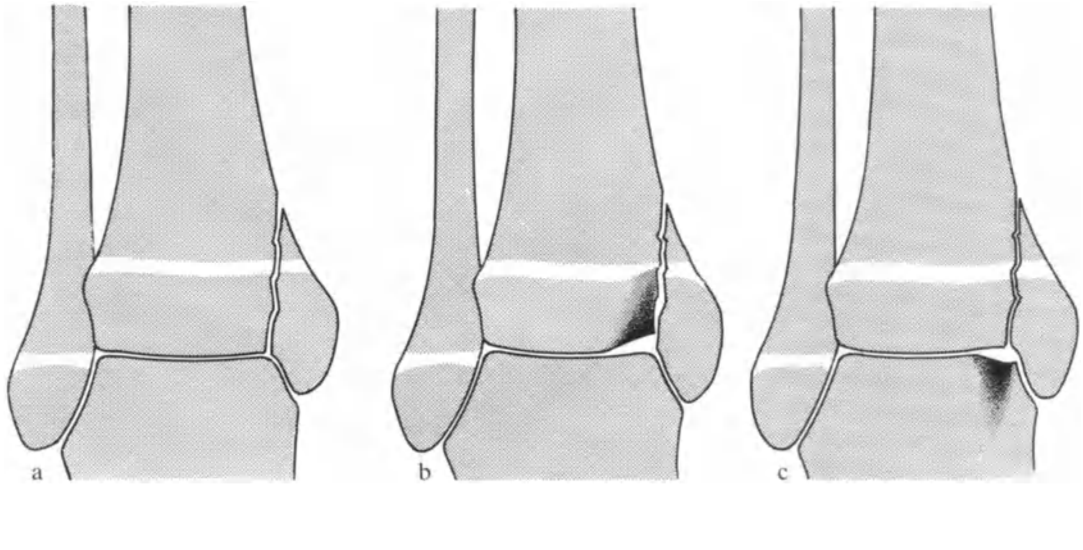


Fig. 12a–c. *Various types of fracture of the medial malleolus.*
a) Simple shear fracture.
b) Fracture of the medial malleolus with impression of the tibial epiphysis.
c) Fracture of the medial malleolus with impression of the edge of the superior articular surface of the talus

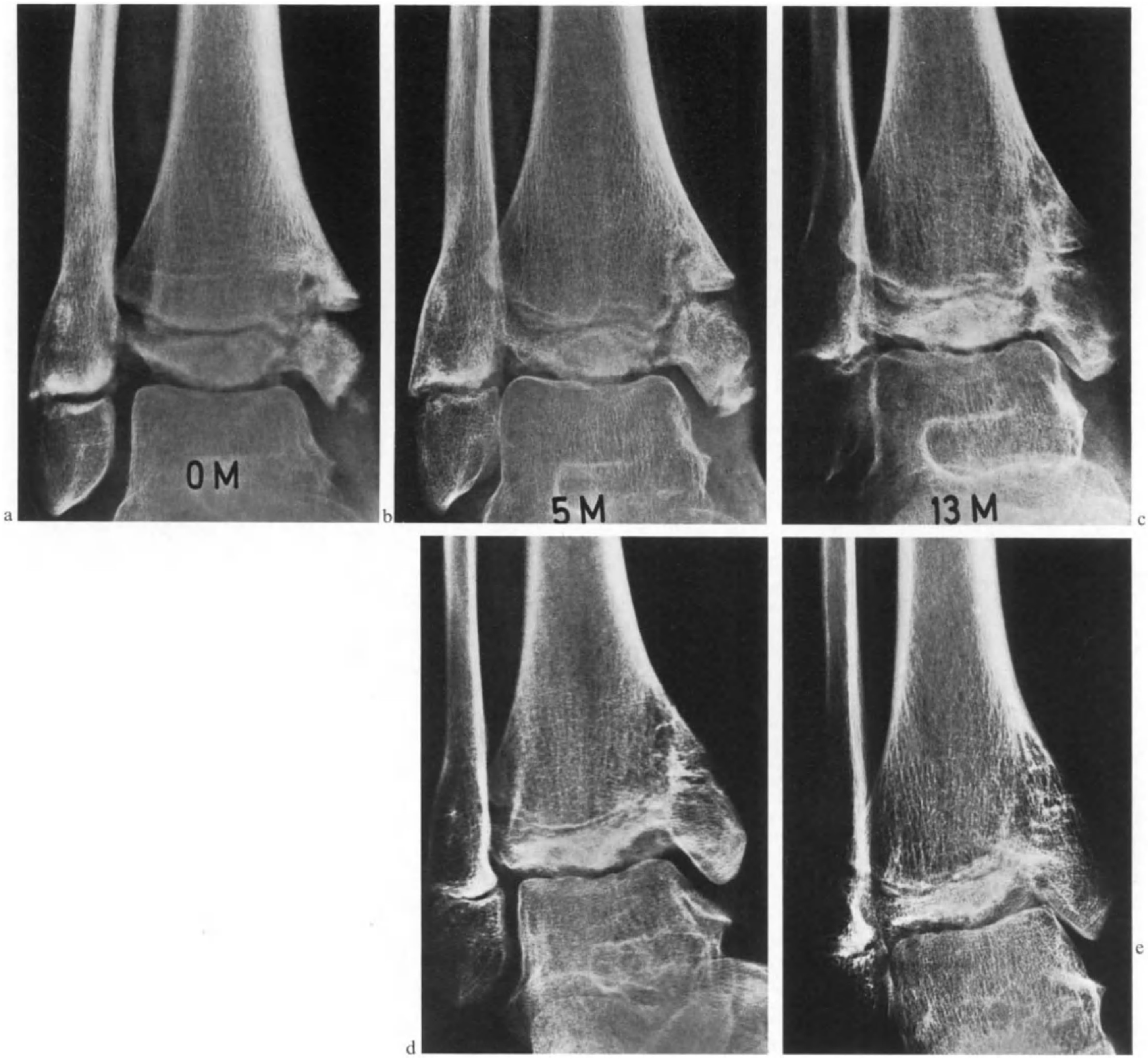


Fig. 13a–e. *Epiphyseal fracture separation with reduction of the blood supply to the epiphysis.* Sch.H., ♂, aged 11 years, No. 140420.

a) This patient was referred to us 3 months after the accident. There is an *Aitken* Type II fracture of the medial malleolus, incipient ossification in the epiphyseal plate, and haziness of the bone structure of the central part of the distal tibial epiphysis.

b) 5 months later. There is diffuse osteoporosis and an increase in the relative density of the ischemic central part of the distal tibial epiphysis. Fusion is occurring in the medial part of the epiphyseal plate.

c) 13 months later. Incipient deformity of the ankle joint is seen. The density of the necrotic tibial epiphysis is unchanged. The joint space has become narrower.

d) Increase in deformity with an increase in the density of the distal tibial epiphysis; the latter reflects incipient revascularization with deposition of calcium apatite on the necrotic bone trabeculae.

e) 45 months after the accident. Severe varus deformity as a result of the medial epiphyseal fusion. The appearance of the epiphysis is returning to normal

Fig. 14a–f. *Importance of roentgenograms in several planes for detection of a fracture*. Z.B., ♀, aged 11 years No. 190 311. a, b) Conventional views only show a metaphyseal fracture separation. On comparison with the intact side, however, an unusual radiolucency is seen at the tip of the medial malleolus.

c, d) Additional oblique views reveal a vertical fracture of the medial malleolus. Diagnosis: *Aitken* Type III fracture. Treatment: Open reduction and screw fixation.

e) Roentgenogram following anatomically precise reduction and fixation with an epiphyseal screw placed parallel to the epiphyseal plate.

f) 13 months after the accident. The fracture has healed with no sequelae. Growth in the epiphyseal plate is normal

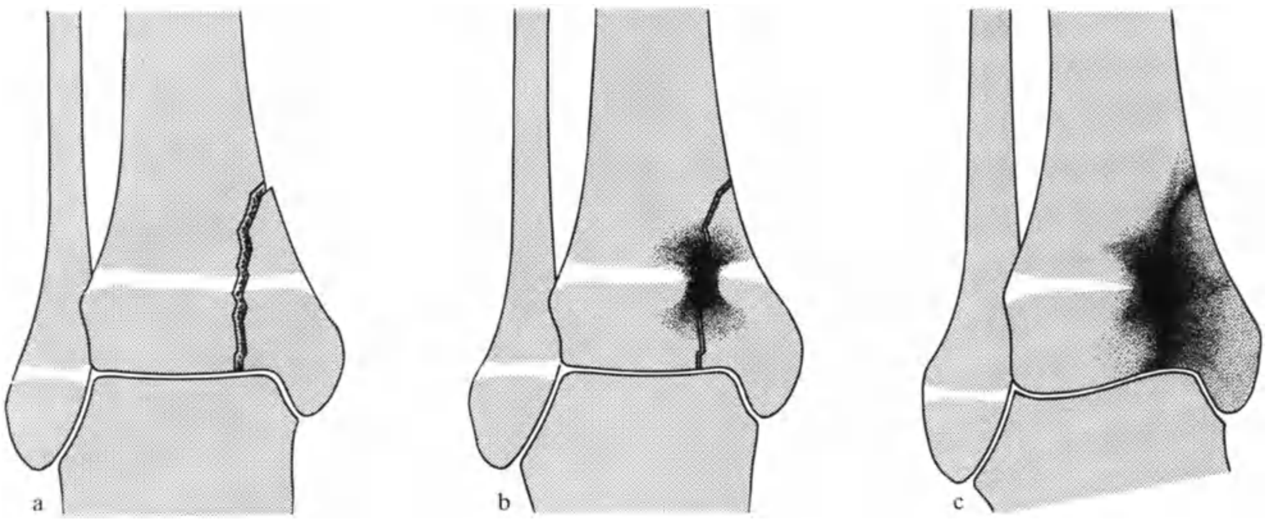


Fig. 15a–c. *"Natural" progress of a fracture of the medial malleolus in a child following nonoperative treatment.*
a) *Aitken* Type III (or Type II) fracture.
b) Incipient callus formation. A callus bridge crosses the epiphyseal growth cartilage and joins the epiphysis to the metaphysis.
c) Localized epiphyseal fusion takes place and the resulting asymmetrical growth causes angulation and shortening

damaged by crushing and if optimum conditions are provided for healing of the growth cartilage. One factor which promotes normal subsequent growth is careful, anatomically precise reduction and stable fixation of the fracture of the epiphyseal plate. Failure to close the gap in the plate in a "watertight" fashion, i.e., with perfect contiguity of the fragments, leads to ossification along the fracture line and union of the epiphysis and metaphysis by a callus bridge which is equivalent to partial epiphyseal fusion (Fig. 15). The unsatisfactory results which we have seen following nonoperative treatment are matched by reports in the literature which describe repeated, harmful attempts at reduction which not only failed, but also resulted in abnormal growth. We therefore operate on all *Aitken* Type II or III fractures immediately, i.e., without prior attempts at closed reduction.

Operative Treatment: In our opinion, a fracture of an epiphyseal plate requires surgical exposure to enable anatomically precise reduction which, in turn, is essential to prevent the callus formation which would otherwise disturb subsequent growth.

Operative procedure: Gentle exposure of the fragments is followed by anatomically precise reduction. *Aitken* Type II and III fractures are fixed with screws inserted parallel to the epiphyseal plate. The lag screw principle is applied, i.e., the screw passes through a clearance hole in the first fragment and obtains its hold in the second fragment so as to pull the two together and eliminate the gap in which callus would otherwise form (Fig. 16). If it is necessary to fix the medial malleolus to the metaphysis, *Kirschner* wires are the only implant which may be used (Fig. 17).

The fragments of severe transepiphyseal impacted fractures which may involve serious damage to the epiphyseal plate are all fixed with screws placed parallel to the epiphyseal plate (Fig. 18). This creates optimum conditions for healing without disturbance of subsequent growth.

Postoperative treatment: Plaster U-splint for 1 week, followed by active mobilization for 1 week. The fracture is then immobilized in a circular, below-knee walking cast for 4–6 weeks. The metal is removed after 6–8 weeks.

Duration of fixation: 6–8 weeks, depending on the age of the child.

2.3 Transition Fractures

2.3.1 Pathological Anatomy

Physiological epiphyseal fusion begins in the middle of the epiphyseal plate and spreads to the medial part, leaving the lateral side barely open (*Kleiger*). At this stage of cessation of growth, certain types of accidents may drive the tibiofibular mortise apart without causing a malleolar fracture. The ligaments of the syndesmosis tear away the lateral segment of the epiphysis which has not yet fused completely with the meta-

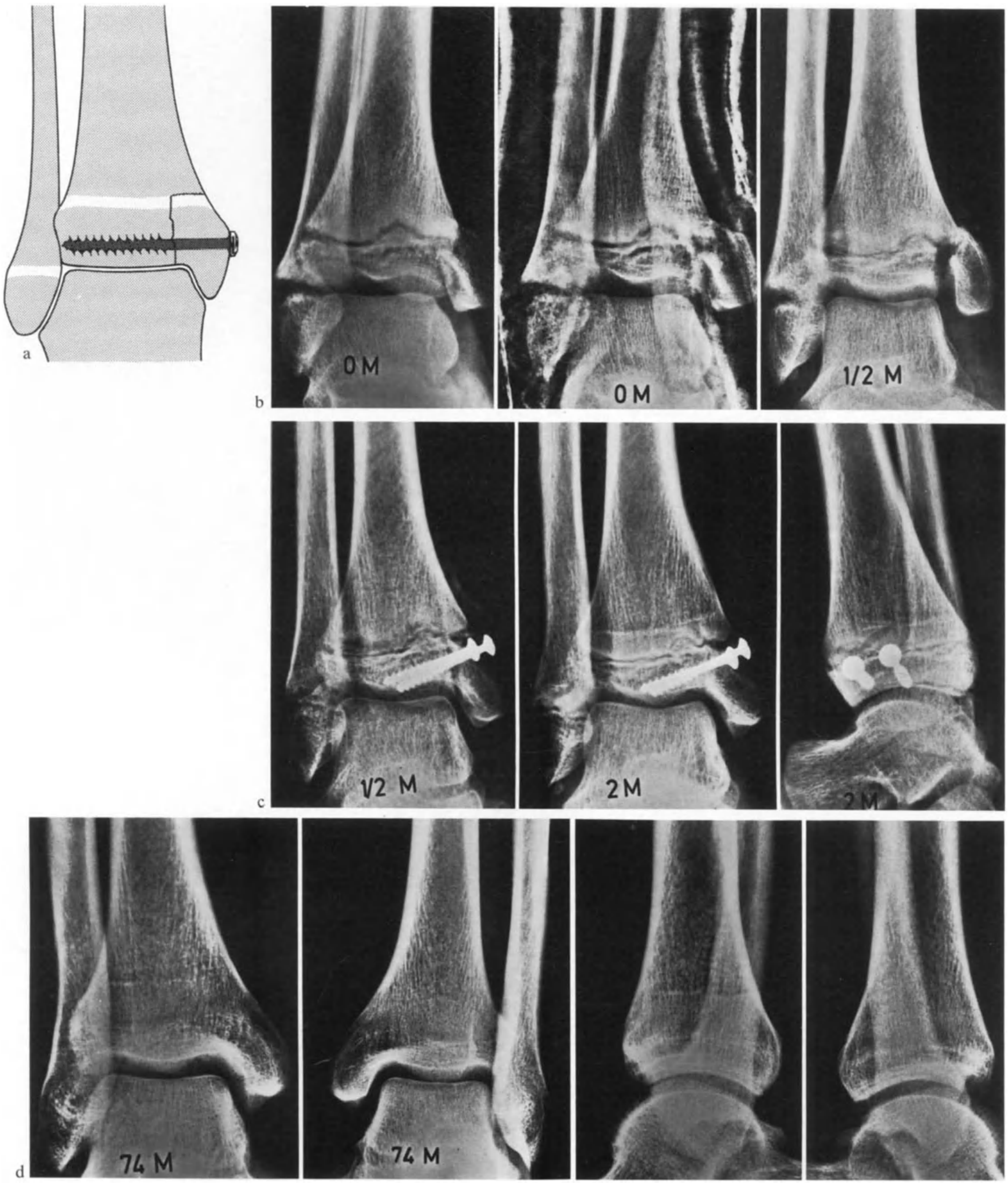


Fig. 16a–d. *Result of "watertight" osteosynthesis.*
a) Principle of the method: Transverse fixation of the medial malleolus with a screw passing through the epiphysis and parallel to the epiphyseal plate without contacting the latter.
b) B.I., ♂, aged 13 years, No. 110703. *Aitken* Type II fracture of the medial malleolus with separation of the lateral malleolus. Referral to us 14 days later because of dislocation.
c) Treatment by surgical exposure of the fracture, curettage of the callus which had formed, anatomically precise reduction of the malleolus, and fixation with screws placed parallel to the epiphyseal plate.
d) 6 years and 2 months after the accident. Symmetrical ankles with normal function

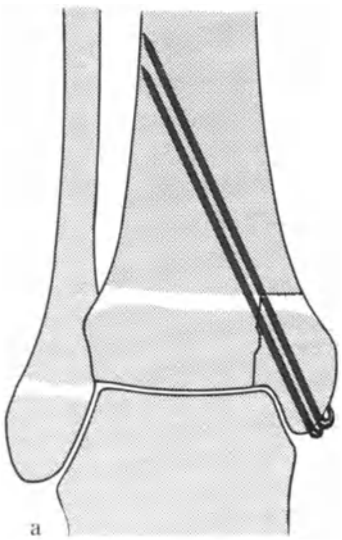
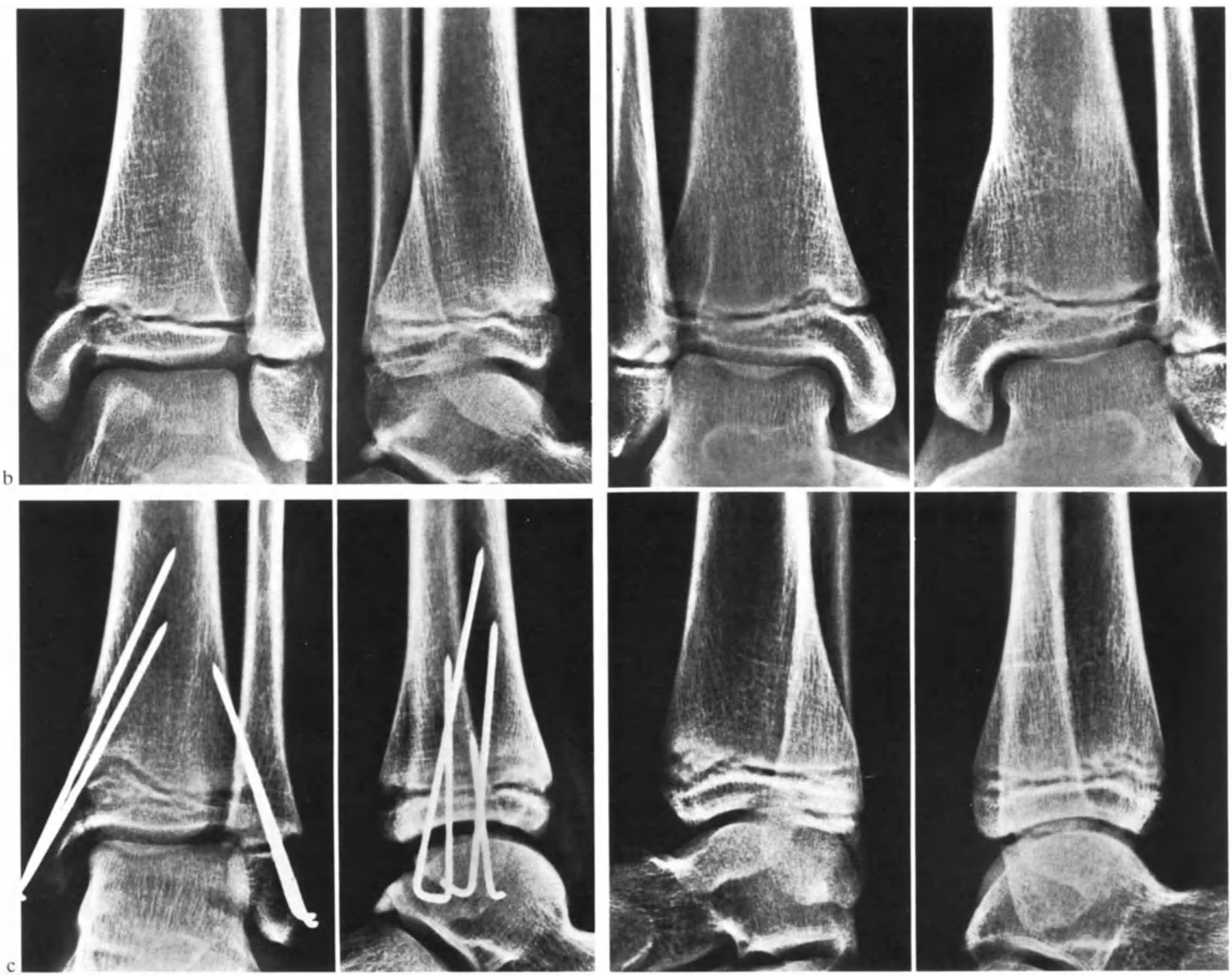
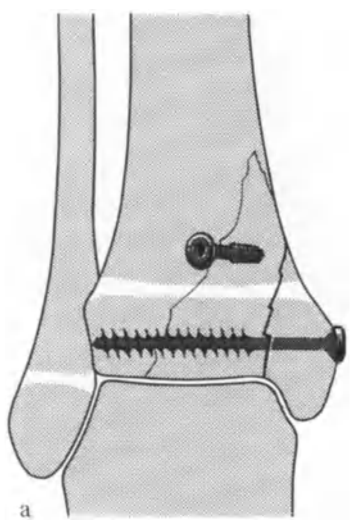

a

Fig. 17a–d. *Internal fixation technique in a small child, i.e., of a small fragment.*
a) If screw fixation is not possible, the fracture is stabilized with two *Kirschner* wires which pierce the epiphyseal plate at as near to a right angle to it as possible. Here, too, the aims of reduction and fixation are the restoration and maintenance of perfect contiguity of the fragments.
b) St. W., ♂, aged 11 years, No. 92262. Fracture of the medial malleolus with separation of the lateral malleolus.
c) Treatment by open reduction and *Kirschner* wire fixation with the fragment in the anatomically correct position.
d) 3 years and 7 months after the accident. Symmetrical ankles with no disturbance of growth. The patient is symptom-free

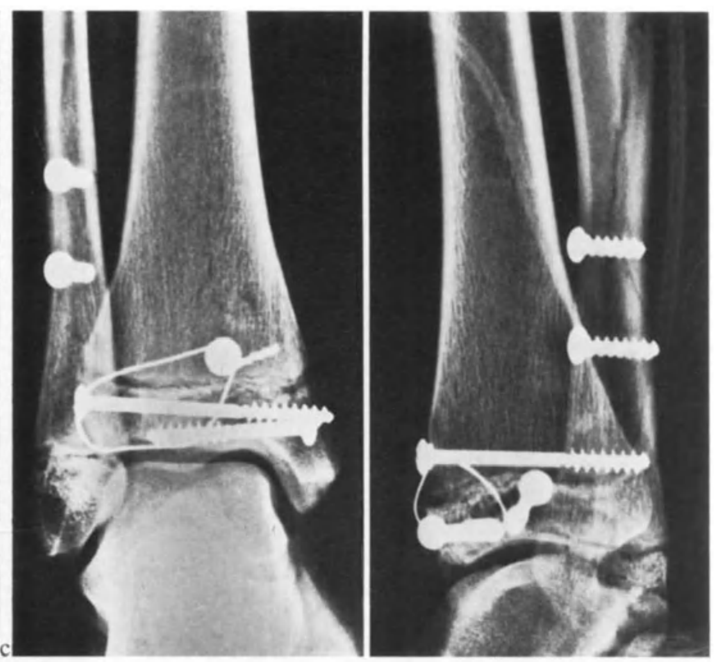

b c d



a

Fig. 18a–d. *Principle of internal fixation of an Aitken Type III fracture.*
a) Epiphyseal and metaphyseal fixation with screws, both of which are placed parallel to the epiphyseal plate and at right angles to the fracture gap.
b) D.G., ♀, aged 15 years, No. 125372. An accident sustained while playing on a meadow caused this large epimetaphyseal fracture of the medial malleolus with a triangular posterior tibial fragment (*Aitken* Type III) and metaphyseal fracture separation of the anterior part of the distal tibial epiphysis. The fibula is also fractured.
c) Treatment by open, anatomically precise reduction and fixation of the individual fractures with epiphyseal and metaphyseal screws placed parallel to the epiphyseal plate. The wire loop prevents rotation of the anterior lateral fragment. The implants were removed 8 weeks after the accident.
d) 8 months after the accident. The anatomy is normal and the patient is symptom-free. The epiphyses have fused prematurely and are beginning to ossify on the opposite side. Full anatomical and physiological recovery

b



c

d

physis (Fig. 19). The lesion always creates a step in the surface of the joint, but does not usually result in progressive disturbance of growth, since the lateral part of the epiphysis fuses shortly after the accident. In effect, the fracture corresponds to an *Aitken* Type II lesion.

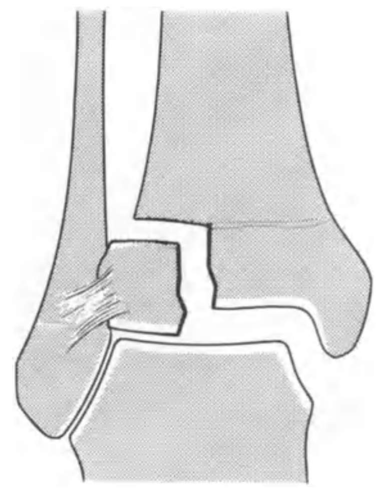


Fig. 19. *Transition fracture.* Avulsion fracture of the attachment of the anterior syndesmosis. The fracture transects the epiphyseal plate which is just about to undergo ossification (adolescence)

2.3.2 Treatment

Operative Treatment: The unusual position of the fragment is such that non-operative treatment would almost inevitably result in loosening of the mortise joint with or without a step in the joint surface.

Operative procedure: The middle and medial segments of the epiphyseal plate have already ossified and further longitudinal growth cannot therefore take place. This therefore constitutes the only case in which an open epiphyseal plate may be pierced by a screw, the latter being necessary to fix the tibial tubercules firmly in place (Fig. 20). *Kirschner* wires are also suitable but do not provide such stable fixation.

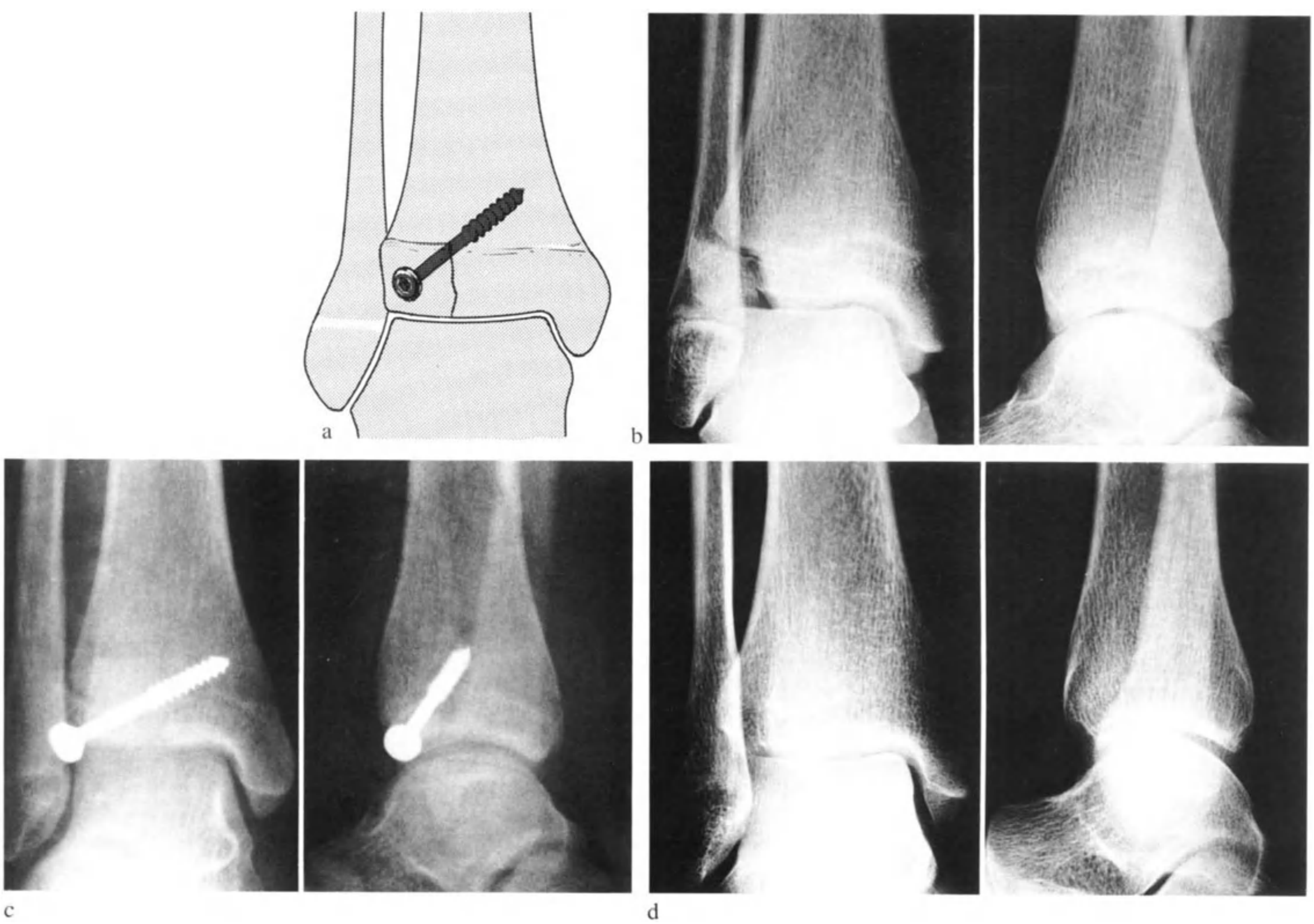


Fig. 20a–d. *Screw fixation of a transition fracture.*
a) Fixation principle. This is the one situation in which the epiphyseal plate may be pierced by a screw, since growth in the plate has ceased.
b) B.M., ♂, aged 14 years, No. 64903. Transition fracture with marked incongruence of the joint surface. The medial part of the epiphyseal plate has already ossified.
c) Treatment by open reduction and screw fixation.
d) 7 years and 3 months after the accident. A normal ankle

Postoperative treatment: Plaster U-splint for 1 week, followed by active mobilization of the joint for 1 week. A below-knee walking cast is applied on discharge from hospital and retained for 6 weeks. There is no particular necessity for early removal of the metal in cases such as these since metal-induced acceleration of longitudinal growth can no longer occur.

Duration of fixation: 8 weeks.

3 Prognosis

All injuries to the bones of the ankle joint affect the epiphyseal plate in some way or other and may therefore influence subsequent growth. The effect of the injury is largely determined by the fracture type, and the involvement of the joint creates additional problems.

3.1 Longitudinal Growth

Simple epiphyseal separations and *Aitken* Type I fractures may be followed by *premature epiphyseal closure*. This is caused by exhaustion of the epiphyseal growth potential as a result of fracture-induced hyperemia and is occasionally seen in patients who have almost ceased growing. Transient *slowing of growth*, on the other hand, occurs much more frequently. It is documented radiologically by the epiphyseal arrest lines (*Harris*) which are also frequently seen on the uninjured side (Fig. 21).

Acceleration of growth following traumatic epiphyseal separation is rare; in our series there were only four cases with slight lengthening (5 mm) of the lower leg (*Süssenbach and Weber*).

3.2 Progressive Axial Misalignment

These progressively increasing deformities occur exclusively following *Aitken* Type II and III fractures and crush injuries. An axially-directed impact on the supinated foot causes the medial border of the talus to crush the distal epiphyseal plate of the tibia and break away the medial malleolus. This is followed by ossification of the fractured cartilage and formation of a collar-stud-shaped callus bridge between the metaphysis and epiphysis. This is equivalent to a partial epiphyseal fusion and stops growth on the medial side. The lateral part of the tibial epiphyseal plate and the intact epiphyseal plate of the fibula continue to grow normally and the resulting one-sided growth causes progressive angulation and shortening. The final result is a *posttraumatic club foot* (Fig. 22). Incorrectly performed internal fixation in which the epiphyseal plate is crossed by screws has the same effect. Here too, progressive varus deformity results and eventually requires corrective osteotomy (Fig. 23). *Posttraumatic valgus deformity* may also occur as a result of an incomplete medial fracture which is situated in the vicinity of the epiphysis and which causes a disproportionate stimulation of growth on the medial side (*Lehner* and *Dubas*). Other potential causes are crushing of the fibular epiphyseal plate or unilateral destruction of the lateral part of the tibial epiphyseal plate.

3.3 Osteoarthrosis Caused by Articular Incongruence

The most frequently occurring long-term complication is *posttraumatic osteoarthrosis* secondary to articular incongruence. It is likely to result whenever a fracture line passes through the epiphyseal plate and articular cartilage, causing a step in the joint surface which is unlikely to be eliminated in the course of subsequent growth. The transition fractures which almost always cause discontinuity in the joint surface, often lead to osteoarthrosis if treated incorrectly.

4 Results

From 1961 to 1968, we treated 53 fractures of the malleolar region in children at the Cantonel Hospital in St. Gall. Twelve were treated nonoperatively and 41 operatively. The reasons for the operative treatment of simple separations and *Aitken* Type I fractures are shown in Table 1. Almost all the *Aitken* Type II and III fractures and transition fractures were operated on.

Table 1. Reasons for the operative treatment of simple epiphyseal separations and *Aitken* Type I fractures

Simple separations (4 cases)	Interposition of periosteum	3
	Rupture of the deltoid ligament	1
Aitken Type I fractures (13 cases)	Interposition of periosteum	12
	Rupture of the deltoid ligament	1

Fig. 21a–d. *Transient slowing of growth following fracture separation.* B.M., ♂, aged 11 years, No. 70252.
a) *Aitken* Type I fracture.
b) Treatment: Owing to failure of closed reduction, open reduction was carried out with extraction of a trapped periosteal flap and fixation with a metaphyseal screw.
c) 2 months after the accident. The fracture has healed.
d) 7 years and 7 months after the accident. 5 mm shortening due to moderate slowing of growth, shown by the *Harris* lines

Fig. 22a–c. *Posttraumatic club foot following nonoperative treatment of an epiphyseal fracture separation.* S.H., ♂, aged 10 years, No. 92758.
a) *Aitken* Type II fracture of the medial malleolus, which was simply treated by immobilization in a cast.
b) 3 years and 3 months after the accident. Occurrence of posterior medial epiphyseal fusion with equinovarus deformity of the ankle joint.
c) An analogous case in a much younger child. Sch.A., ♀, aged 6 years, No. 172099. Comparative roentgenogram 2 years after fracture of the medial malleolus. Extremely severe equinovarus deformity with marked shortening of the leg caused by almost complete cessation of growth, now also on the lateral side.

Fig. 23a–d. *Prohibited screw fixation of an epiphyseal fracture separation.* Sch.M., ♂, aged 13 years, No. 65702.
a) Fracture of the medial malleolus with separation of the epiphysis of the tip of the lateral malleolus.
b) Treatment by internal fixation of both malleoli. 2 (!) lag screws pierced the epiphyseal plate on the medial side. A malleolar screw has been inserted laterally in the lag manner. Predictably, partial epiphyseal fusion has taken place.
c) 2 years and 3 months later. Cessation of growth on the medial side resulting in varus club foot.
d) Supramalleolar corrective osteotomy

4.1 Results of Nonoperative Treatment: 12 Patients (Table 2)

4.1.1 Simple Epiphyseal Separation (2)

Despite a radiologically satisfactory result, one patient suffered symptoms and limitation of the range of motion of the ankle joint.

4.1.2 *Aitken* Type I Fractures (8)

An increase of 5 mm in longitudinal growth was found in two cases, and one patient suffered a reduction

Table 2. Results of nonoperative treatment in 12 patients

Simple epiphyseal separations (2 cases)	Reduced range of movement	1
	Symptoms	1
Aitken Type I fractures (8 cases)	Increase in longitudinal growth (+5 mm)	2
Primary deformity	Valgus	2
	Reduced range of motion	1
	Symptoms	1
Aitken Type III fractures (2 cases)	Reduced range of motion	2
	Symptoms	2
	Joint step	1

Fig. 24a–d. *Persistence of a scar following entrapment of periosteum in a fracture*. L.B., ♂, aged 12 years, No. 96406.
a) *Aitken* Type I metaphyseal fracture separation.
b) Treatment by closed reduction, with slight residual valgus caused by interposition of periosteum.
c) 3 years after the accident. The interposed periosteum is still clearly visible in the form of marked sclerosis.
d) 5 years after the accident. The "periosteal scar" is still detectable. Moderate valgus deformity is present. Following healing of the fracture, little corrective potential remained, i.e., skeletal growth was about to cease

in the range of joint motion with corresponding symptoms. Two primary valgus deformities were found to have been caused by incorrect reduction of the fractures, probably as a result of interposition of periosteum. A scar remained radiologically visible on the medial side of the distal tibia for several years (Fig. 24).

4.1.3 *Aitken* Type III Fractures (2)

Predictably, this was the group with the most unsatisfactory results. Both patients complained of ankle joint symptoms and reductions in their ranges of joint movement. The roentgenograms showed a small step in the articular surface of the tibia which can be regarded as a forerunner of osteoarthrosis.

Fig. 25. *Rigidification of the malleolar mortise.* Sch., ♂, aged 20 years, No. 65702 (Same case as in Fig. 23). Appearance following prohibited screw fixation of a medial malleolar fracture involving the epiphysis. Skew growth resulted, necessitating corrective osteotomy 7 years and 7 months prior to these roentgenograms. The supramalleolar tibiofibular bone bridge is particularly striking when the two sides are compared. There is incipient rigidification osteoarthrosis. Changes in the weather cause symptoms

4.2 Results of Operative Treatment: 41 Patients (Table 3)

4.2.1 Simple Epiphyseal Separation (4)

All patients were symptom-free and had normal ranges of ankle joint motion.

4.2.2 *Aitken* Type I Fractures (13)

In two cases, growth had been accelerated, resulting in 5 mm lengthening of the lower leg, and slight shortening (2 mm) had occurred in one case.

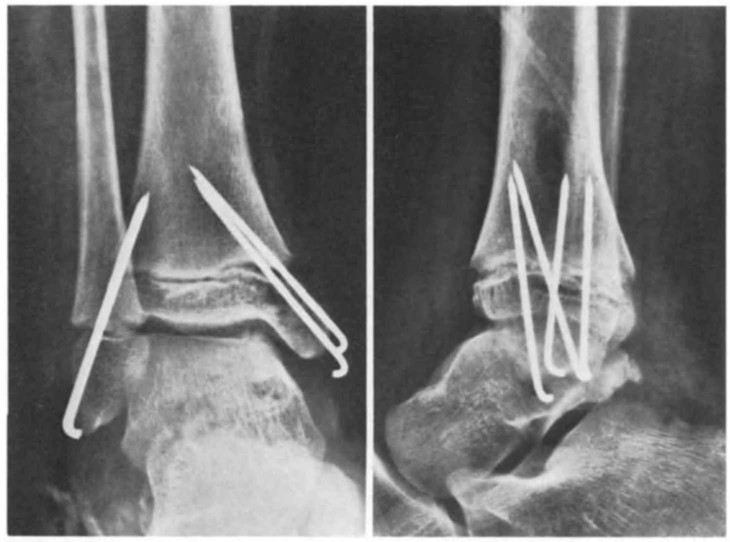
4.2.3 *Aitken* Type II Fractures (13)

Partial epiphyseal fusion occurred in one case as a result of incorrect internal fixation (screw transfixation of the medial part of the tibial epiphyseal plate). The typical progressive varus deformity eventually made corrective valgus osteotomy necessary. The patient was symptom-free at the follow-up examination, but the roentgenogram showed incipient tibiotalar osteoarthrosis which was secondary to synostosis of the fibulotibial joint (*Süssenbach* and *Weber*) (Fig. 25). In another case, slight osteoarthrosis had developed following an *Aitken* Type II fracture with additional impression of the medial border of the talus (Fig. 26). Despite this pathological X-ray finding, the patient was symptom-free and joint motion was normal.

Table 3. Results of operative treatment of 41 patients

Simple epiphyseal separations (4 cases)	All patients symptom-free No limitation of joint movement	
Aitken Type I fractures (13 cases)	Increased longitudinal growth (+5 mm)	2
	Decreased longitudinal growth (−2 mm)	1
Aitken Type II fractures (13 cases)	Progressive varus deformity (incorrect internal fixation)	1
	Slight tibiotalar osteoarthrosis	2
Aitken Type III fractures (5 cases)	All patients symptom-free No limitation of joint motion	
Transition fractures (6 cases)	All patients symptom-free No limitation of joint motion	

a



b

c

Fig. 26a–c. *Severe damage to the cartilage of the superior talar joint surface.* M.R., ♂, aged 11 years, No. 89004.
a) Fracture of the medial malleolus with separation of the lateral malleolar epiphysis. Impaction of the medial border of the talus.
b) Treatment by open, anatomically precise reduction and *Kirschner* wire transfixation. Cancellous bone was packed in the gap which appeared after reduction of the impacted talar cartilage.
c) 7 years after the accident. Pre-osteoarthrosis with widening and roughness in the medial part of the joint space. The patient is still symptom-free

4.2.4 *Aitken* Type III Fractures (5) and Transition Fractures (6)

The radiographs of all the patients showed osteoarthrosis-free joints, and the ranges of joint motion were normal and painless. In no case was there evidence of disturbance of growth.

5 Summary

The severity of an injury in the malleolar region in a child is determined by the degree of damage to the epiphyseal plates of the tibia and fibula and by the sequelae which are likely to result from that damage.

Prognostically "harmless" injuries of the *Aitken* Type I category and simple epiphyseal separation are usually reduced by closed manipulation. Only if this fails is open reduction necessary.

Aitken Type II and III injuries and transition fractures always require anatomically precise open reduction and gentle, but stable internal fixation. This is the only way of preventing secondary disturbances of growth and joint incongruence. The good results which have been achieved by operative treatment justify these recommendations.

6 References

Aitken, A. P.: The end results of the fractured distal tibial epiphysis. J. Bone Jt Surg. **18,** 3, 685 (1936).

Bartl, R.: Die traumatische Epiphysenlösung am distalen Ende des Schienbeines und des Wadenbeines. Heft Unfallheilk. **54,** 228 (1956).

Bergenfeldt, E.: Beiträge zur Kenntnis der traumatischen Epiphysenlösung an den langen Röhrenknochen der Extremitäten. Acta chir. sand. **73,** 1933.

Bishop, P. A.: Fractures and epiphyseal separation fractures of the ankle. Amer. J. Roentgenol. **28,** 40 (1932).

Carothers, Ch. O., Crenshaw, A. H.: Clinical significance of a classification of epiphyseal injuries at the ankle. Amer. J. Surg. **89,** 879 (1955).

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1960.
Ehlers, P. N., Eberlein, H.: Epiphysenfrakturen. Klinischer Beitrag zur Frage der Spätfolgen. Langenbecks Arch. klin. Chir. **305,** 213 (1964).
Gall, F.: Nachuntersuchungen von Epiphysenfugenbrüchen. Langenbecks Arch. klin. Chir. **289,** 372 (1958).
Giuliani, K.: Spätzustände nach traumatisch-mechanischen Schädigungen der Epiphyse am distalen Tibiaende. Arch. orthop. Unfall-Chir. **45,** 386 (1952).
Goff, C. W.: Surgical treatment of unequal extremities. Springfield/Ill.: Ch. C. Thomas 1960.
Harris, H. A.: Bone growth in health and disease; the bilogical principles underlying the clinical, radiological and histological diagnosis of perversions of growth and disease in the skeleton. Univ. London, Oxford: Press, 1933.
Kleiger, B.: Fracture of the lateral portion of the distal tibial epiphysis. J. Bone Jt Surg. **46A,** 25 (1964).
Lehner, A., Dubas, J.: Secondary deformities following epiphyseal separations and fractures near the epiphyseal line. Year Book orthop. traumat. Surg. 1955.
Pauwels, F.: Gesammelte Abhandlungen zur funktionellen Anatomie des Bewegungsapparates. Berlin-Heidelberg-New York: Springer, 1965.
Pauwels, F: Contributions on the functional anatomy of the locomotor apparatus. Berlin-Heidelberg-New York: Springer 1980.
Salter, R. B., Harris, R.: Injuries involving the epiphyseal plate. J. Bone Jt Surg. **45A,** 587 (1963).
Süssenbach, F., Weber, B. G.: Epiphysenfugenverletzungen am distalen Unterschenkel. Bern, Stuttgart, Wien: Huber, 1970.
Titze, A.: Sprunggelenksverletzungen bei Kindern. Kinderchir. **4,** 400 (1967).
Titze, A.: Knöchelbrüche bei Kindern und Jugendlichen. Wien. med. Wschr. **7,** 138 (1968).
Weber, B. G.: Epiphysenfugenverletzungen. Helv. chir. Acta **31,** 103 (1964).
Weber, B. G.: Die Verletzungen des oberen Sprunggelenkes. Bern, Stuttgart: Huber, 1966.
Weber, B. G.: Die operative Behandlung der Knöchelbrüche. Hefte Unfallheilk. **92,** 1967.
Weber, B. G.: Prophylaxe der Achsenfehlstellungen bei der Behandlung kindlicher Frakturen. In: Posttraumatische Achsenfehlstellungen an den unteren Extremitäten (Hrsg. M. E. Müller). Bern, Stuttgart: Huber, 1967.
Weber, B. G.: Indikationen zur operativen Frakturenbehandlung bei Kindern. Chirurg **10,** 441 (1967).
Witt, A. N.: Die Therapie der Epiphysenfugenschädigungen. Langenbecks Arch. klin. Chir. **289,** 361 (1958).

Fractures of the Talus and Calcaneus

R. Marti

CONTENTS

1 Introduction

Fractures of the talus and calcaneus are very rare in children owing to the marked elasticity of the skeleton of the foot. In most cases, the *accident mechanism* involves severe *direct violence,* such as that inflicted by a fall from a great height. The resulting axial compression may also cause injury to the vertebral column. The talus and calcaneus tend to resist forces of lesser magnitude and transmit them in an upward direction, causing fracture of the less elastic tibia or fibula (*Blount*). Therefore, unlike an adult, a child who falls a small distance and lands on his heel is more likely to sustain a fracture of the lower leg. The older the child, the greater is the likelihood of a calcaneal fracture. An analogous age distribution of talar fractures has not been shown, and the literature contains several reports of talar fractures in small children (*Chiari, Mindell*). The *indirect* forces generated by violent supination may cause a flake fracture (osteochondral fracture) of the medial or lateral talar margins. This lesion occurs more frequently in older children and adolescents, since the thick cartilage cushion which covers the bone of a small child tends to absorb the deforming forces.

2 Fractures of the Talus

2.1 Anatomy

The talus, like the head of the femur, has almost no periosteal covering and $^{3}/_{5}$ of its surface are covered by cartilage (Fig. 1). Ligaments and joint capsules are attached to various points over the remainder of the surface, leaving little space through which blood vessels can pass. The intraosseous and, therefore, most

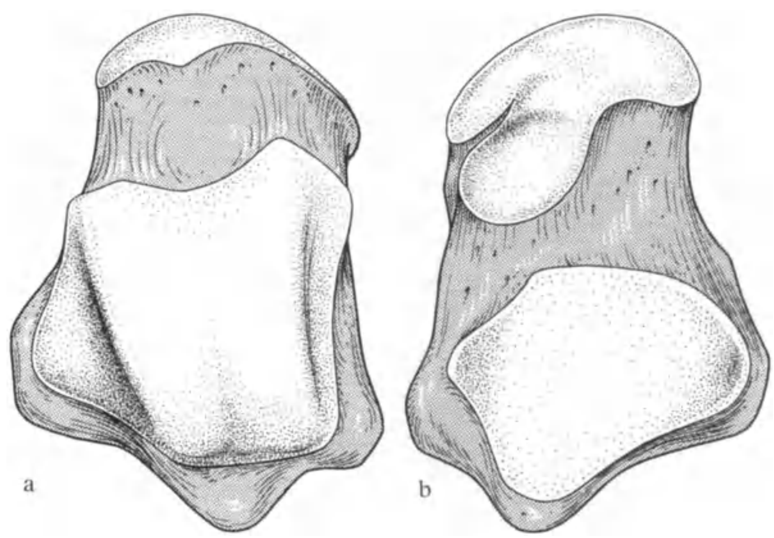


Fig. 1a, b. *Cartilaginous coverage of the talus.* The majority of the surface of the talus is covered by cartilage.
a) Superior aspect of the left talus.
b) Inferior aspect of the left talus

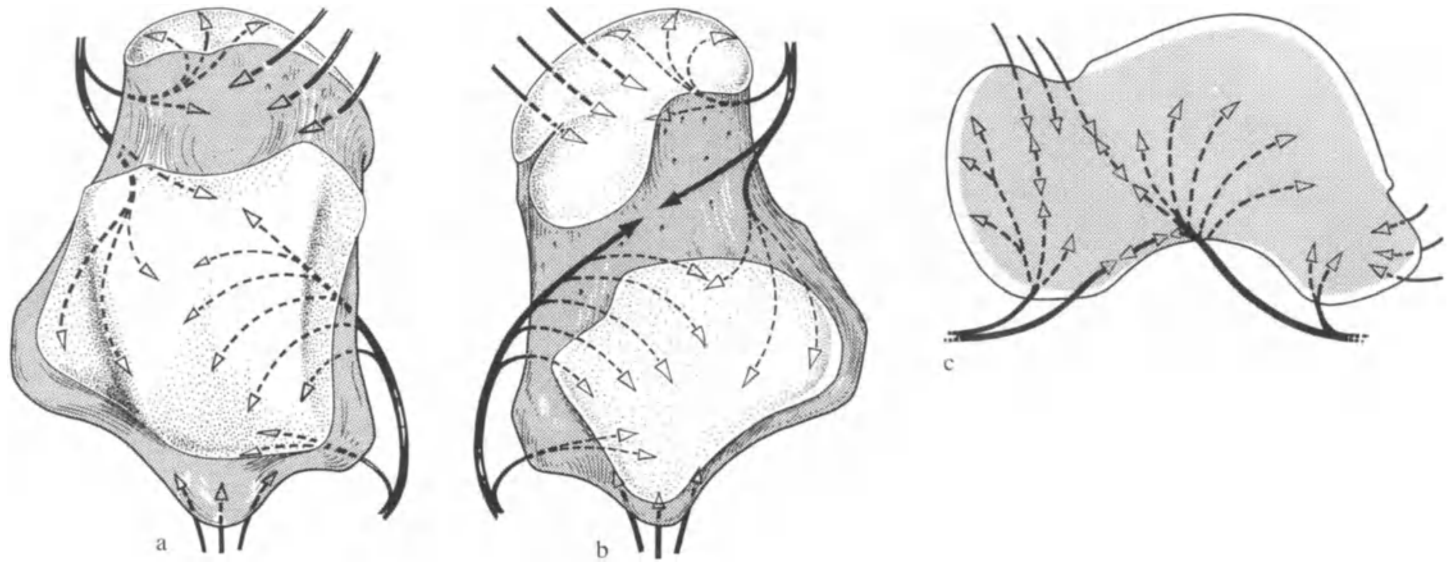


Fig. 2a–c. *Blood supply of the talus.*
a) Superior aspect. Branches of the dorsal artery of the foot enter the neck of the talus from the medial side and the arteries of the tarsal sinus enter from the lateral side. Branches of the tibialis posterior artery run in the joint capsule to the body of the talus.
b) Inferior aspect. Anastomoses are present in the tarsal sinus. A small artery supplies the posterior process of the talus.
c) Lateral aspect showing the anastomosis in the tarsal sinus

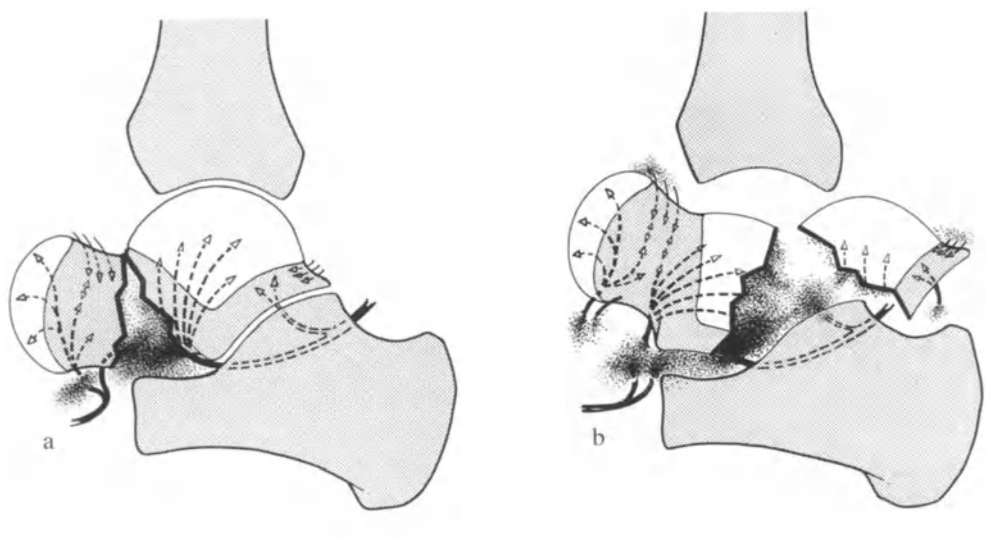


Fig. 3a, b. *Vascular damage which results from a talar fracture.*
a) Fracture of the neck of the talus.
b) Fracture of the body of the talus

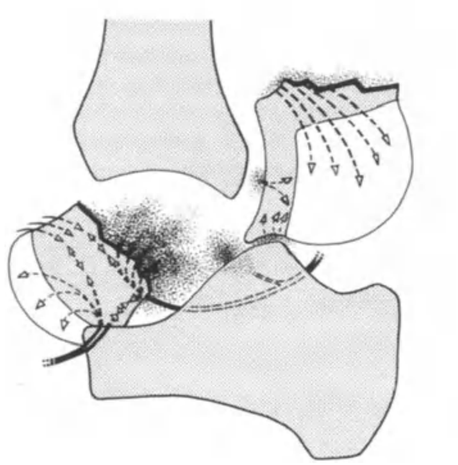


Fig. 4. *Devascularization of the body of the talus resulting from fracture dislocation.* The proximal fragment dislocates out of the malleolar mortise and becomes completely separated from its vascular supply; the auxiliary supply via the ligaments is also interrupted

important *blood supply* passes from the tarsal sinus into the talar sulcus; the arteries which enter posteromedially and anterolaterally anastomose in the tarsal sinus. A branch of the dorsal artery of the foot supplies the neck of the talus from the dorsomedial side, and the posterior process of the talus also receives its own supply (Fig. 2). Thus, the majority of the nutrient flow to the body of the talus enters from below and passes upwards. It follows that almost every proximal fracture of the neck or body of the talus may endanger the intraosseous blood supply to the body (Fig. 3) and dislocation of the proximal fragment out of the malleolar mortise (Fig. 4) leads to additional disruption of the auxiliary supply via the ligaments.

2.2 Fracture Types

In the literature, talar fractures are classified according to their radiological appearance (*Bohler*) or trauma mechanisms (*Watson-Jones*). Our classification, on the other hand, takes account of the likelihood of necrosis occurring, which is an important factor in deciding treatment (Fig. 5; Table 1).

Table 1. Classification of talar fractures

Type I	Fracture of distal part of neck	Blood supply to body intact	No necrosis
Type II	Nondislocated proximal fracture of the neck or body	Circulation largely intact	Necrosis rare
Type III	Dislocated fracture of the proximal neck or body	Intraosseous blood supply almost certainly interrupted; auxiliary blood supply intact	Necrosis frequent
Type IV	Proximal fracture of the neck with dislocation of the body of the talus out of the malleolar mortise	Intraosseous and auxiliary circulation interrupted	Always necrosis

However, the final result of a talar fracture is not only determined by the occurrence of necrosis, but also by the incongruence of the ankle joint or subtalar joint which it may cause. Complete recovery of the normal anatomy and function will not occur if necrosis or articular incongruence persists.

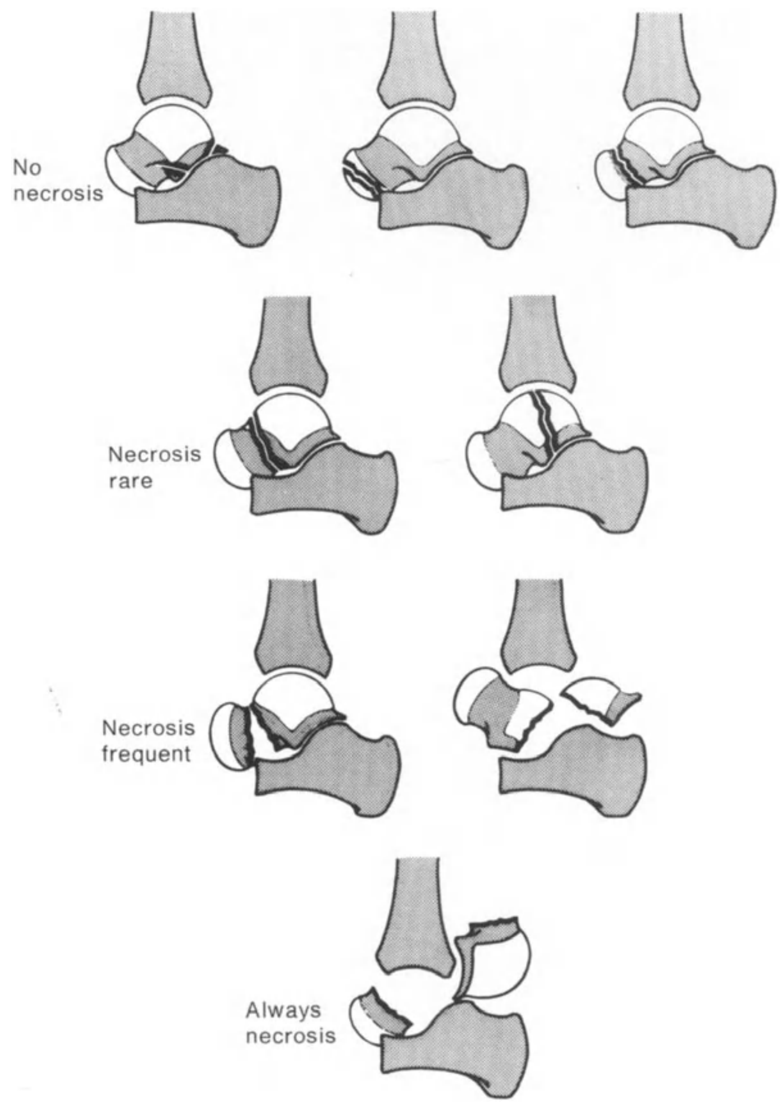


Fig. 5. *Relationship between fracture type and the danger of avascular necrosis of the body of the talus.* Fractures of the processes or small distal fractures of the neck of the talus are not likely to cause necrosis. Nondislocated fractures of the body or neck seldom cause necrosis. Dislocated fractures of the proximal part of the neck or of the body frequently lead to necrosis. A fracture of the proximal part of the neck with dislocation of the fragment out of the malleolar mortise always leads to avascular necrosis

2.3 Treatment

The aims of treatment are anatomically precise reduction of the fracture and immobilization for as long as is necessary to exclude necrosis or allow revitalization of the bone to occur. If these ends can be attained by *nonoperative treatment,* one should avoid endangering the blood supply further by performing unnecessary surgery. On the other hand, *operative treatment* is indicated for fractures which are likely to cause necrosis (Types III and IV) as well as for fractures of the articular processes.

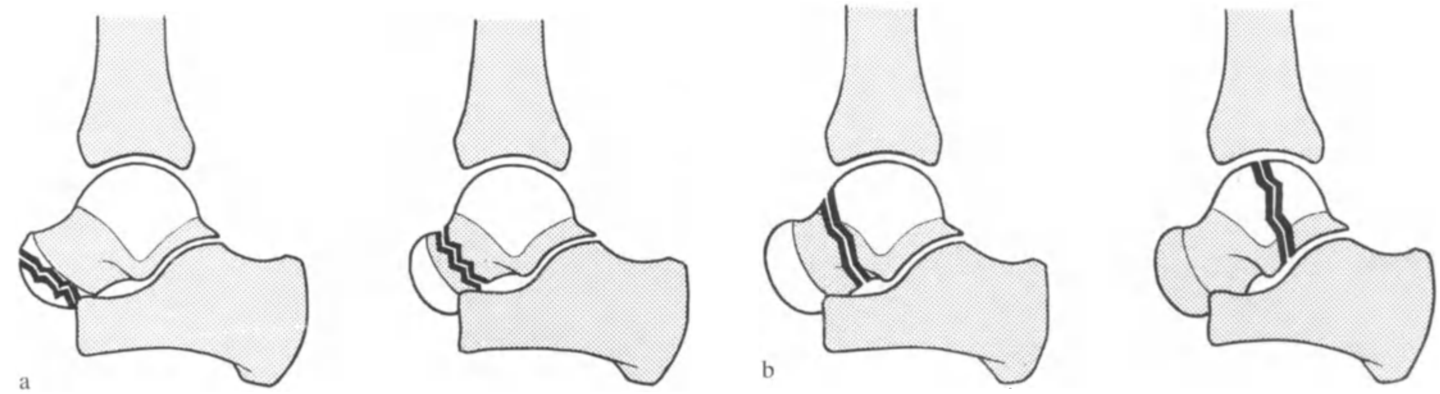


Fig. 6a, b. *Talar fracture Types I and II.*
a) Type I: Fracture at the distal end of the neck.
b) Type II: Fracture of the proximal part of the neck or of the body without dislocation

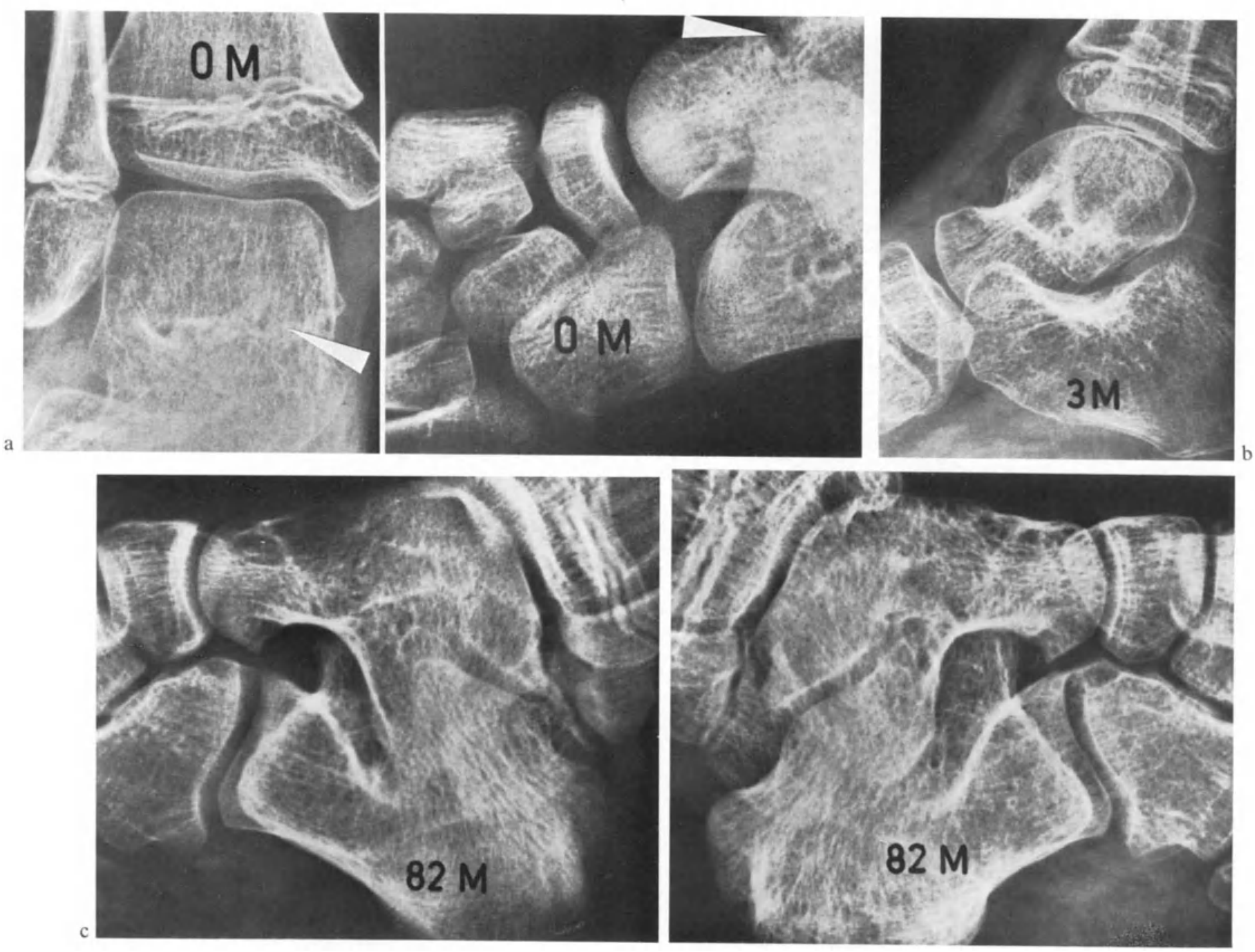


Fig. 7a–c. *Type II fracture of the talus.* M.B., ♂, aged 6 years, No. 90 928.
a) Proximal nondislocated fracture of the neck.
b) 3 months following immobilization in a cast. There are no signs of necrosis and the fracture has healed.
c) 6 years and 10 months after the accident. Perfect symmetry

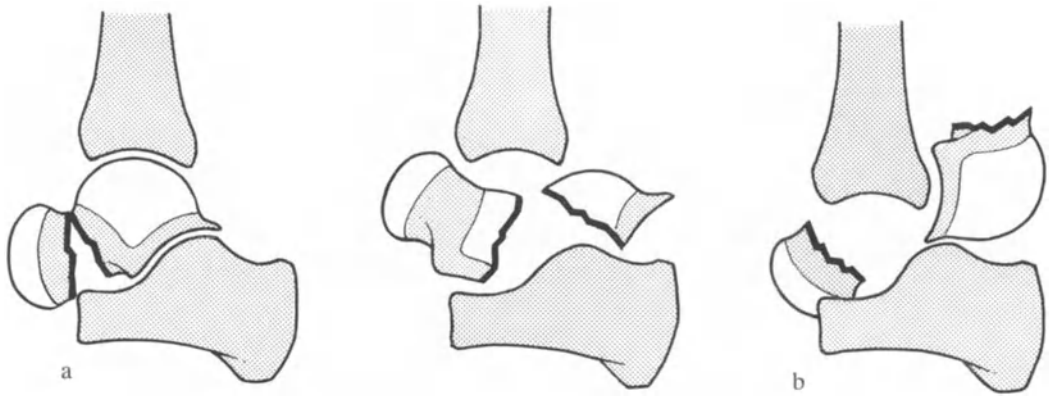


Fig. 8a, b. *Talar fracture Types III and IV*.
a) Type III: Fracture of the proximal part of the neck or of the body with dislocation.
b) Type IV: Fracture of the talus with dislocation of the body of the talus out of the malleolar mortise

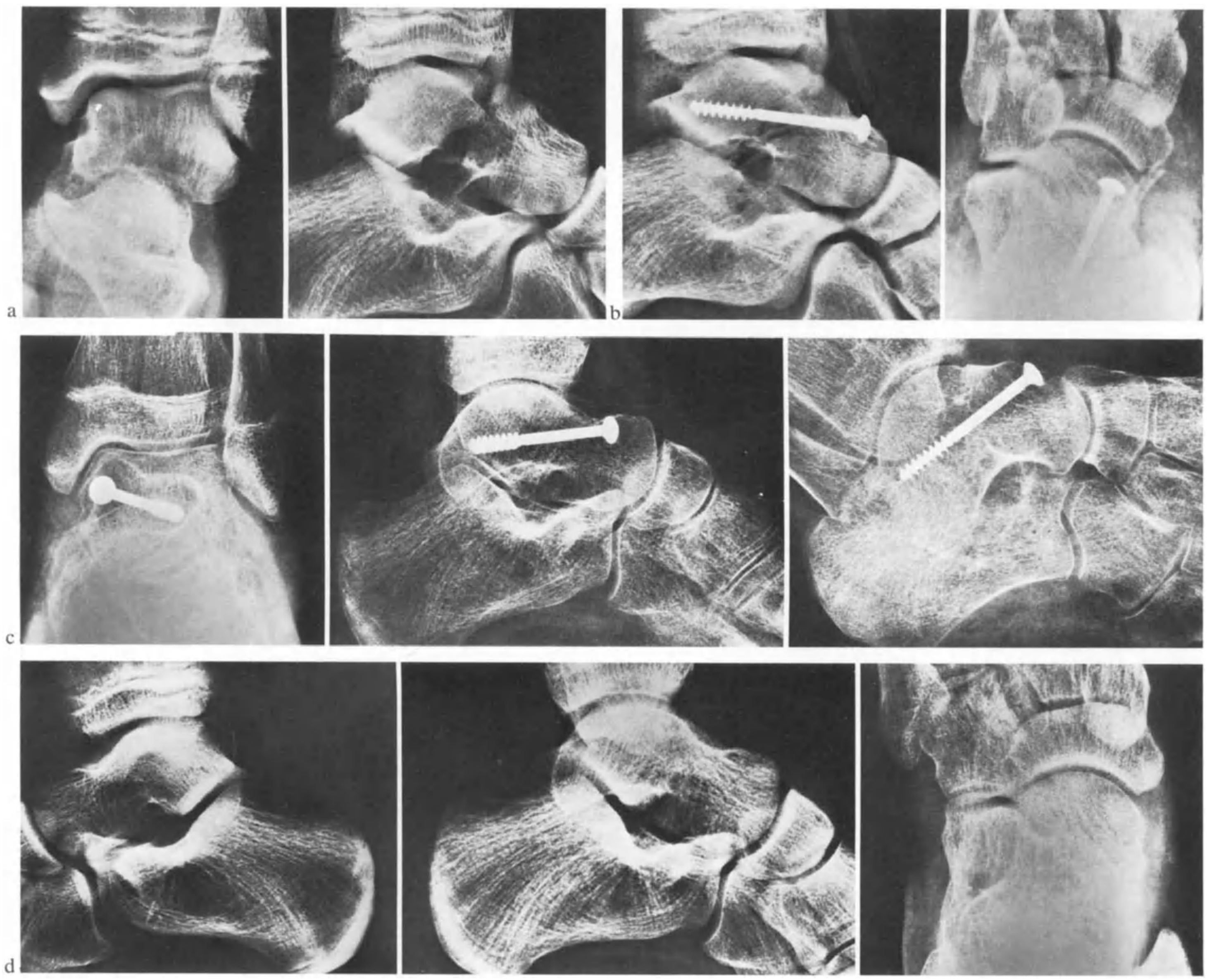


Fig. 9a–d. *Type III fracture of the talus*. Sp.S., ♀, aged 13 years, No. 150 720.
a) The fresh fracture.
b) Treatment by open reduction from the medial side followed by lag screw fixation.
c) 4 months after the operation. The fracture has healed.
d) 1 year after the accident. Perfect symmetry with no sign of talar necrosis

2.3.1 Type I and II Fractures of the Talus

Type I. Type I fractures are not accompanied by damage to the vessels supplying the body of the talus and necrosis is, therefore, unlikely to occur (Fig. 6).

Type II. Because of their site, Type II fractures are associated with a slightly increased danger of necrosis. However, the fragments are not dislocated and one can therefore assume that the blood supply is largely intact (Fig. 6). These fractures very rarely lead to aseptic necrosis of the body of the talus, and they are generally treated *nonoperatively* (Fig. 7).

Immobilization: Split circular below-knee cast with the leg kept raised. The cast is closed following subsidence of the swelling and is replaced 4 weeks later by a below-knee walking cast which is retained for 4–6 weeks.

Duration of fixation: 8–10 weeks. Depending on the radiological findings, weight bearing may have to be prevented for several months by the use of suitable calipers.

2.3.2 Type III and IV Fractures of the Talus

Type III. The site and degree of dislocation of a Type III fracture of the talus are such that the blood supply is usually interrupted, and necrosis very frequently results. The only remaining blood supply is that via the ligamentary vessels (Fig. 8).

Type IV. Type IV fractures result in the additional interruption of the auxiliary blood supply, since the dislocation of the body of the talus is accompanied by rupture of the ligaments. The proximal talar fragment therefore becomes totally ischemic and always undergoes necrosis.

Operative treatment is always indicated for fracture Types III and IV. Compression fixation does not prevent necrosis, but by eliminating relative movement between the fragments, facilitates revitalization by vessels growing in from the viable fragments.

Operative procedure: The fragments are exposed by way of a medial incision. The fracture is then gently reduced and stabilized with a lag screw (Fig. 9). Torn ligaments are sutured.

Postoperative treatment: Below-knee plaster splint until wound healing is satisfactorily advanced, followed by application of a below-knee circular cast. The latter is replaced after 6 weeks by a below-knee walking cast, which is retained for 4–6 weeks. In view of the considerable danger of necrosis, the foot should be protected from weight bearing for several months by the use of an appropriate walking caliper. The progress of revitalization of the necrotic bone should be checked radiologically at regular intervals of 2–3 months.

Duration of fixation: 10–12 weeks.

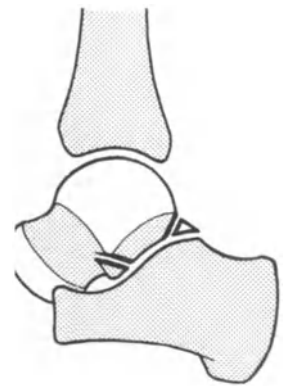


Fig. 10. *Fractures of the lateral and posterior processes of the talus.* These are intraarticular fractures and therefore require anatomically precise reduction

2.3.3 Fractures of the Lateral and Posterior Processes of the Talus. Flake Fractures (Fig. 10)

In order to prevent incongruence of the joint surface, these fractures require anatomically precise *open* reduction followed by stabilization with a lag screw (Figs. 11 and 12). Small osteochondral fragments from the lateral border of the talus may be removed; larger ones are also fixed with a suitable screw.

Postoperative treatment: Plaster splint for 2 weeks followed by a below-knee walking cast for 4 weeks.

Duration of fixation: 6 weeks.

2.4 Prognosis

The healing of a fracture of the talus is mainly determined by the fracture type, but may also be promoted by suitable treatment. The disturbance of the intraosseous blood supply which accompanies fracture Types III and IV (Figs. 3 and 4) irrevocably determines the fate of the proximal fragment, which undergoes necrosis in almost every case. In our series of cases, none of the talar fractures in children were followed by aseptic necrosis, but nevertheless, the radiological signs of necrosis and revitalization are discussed here because there are certain analogies to a medial fracture of the femoral neck.

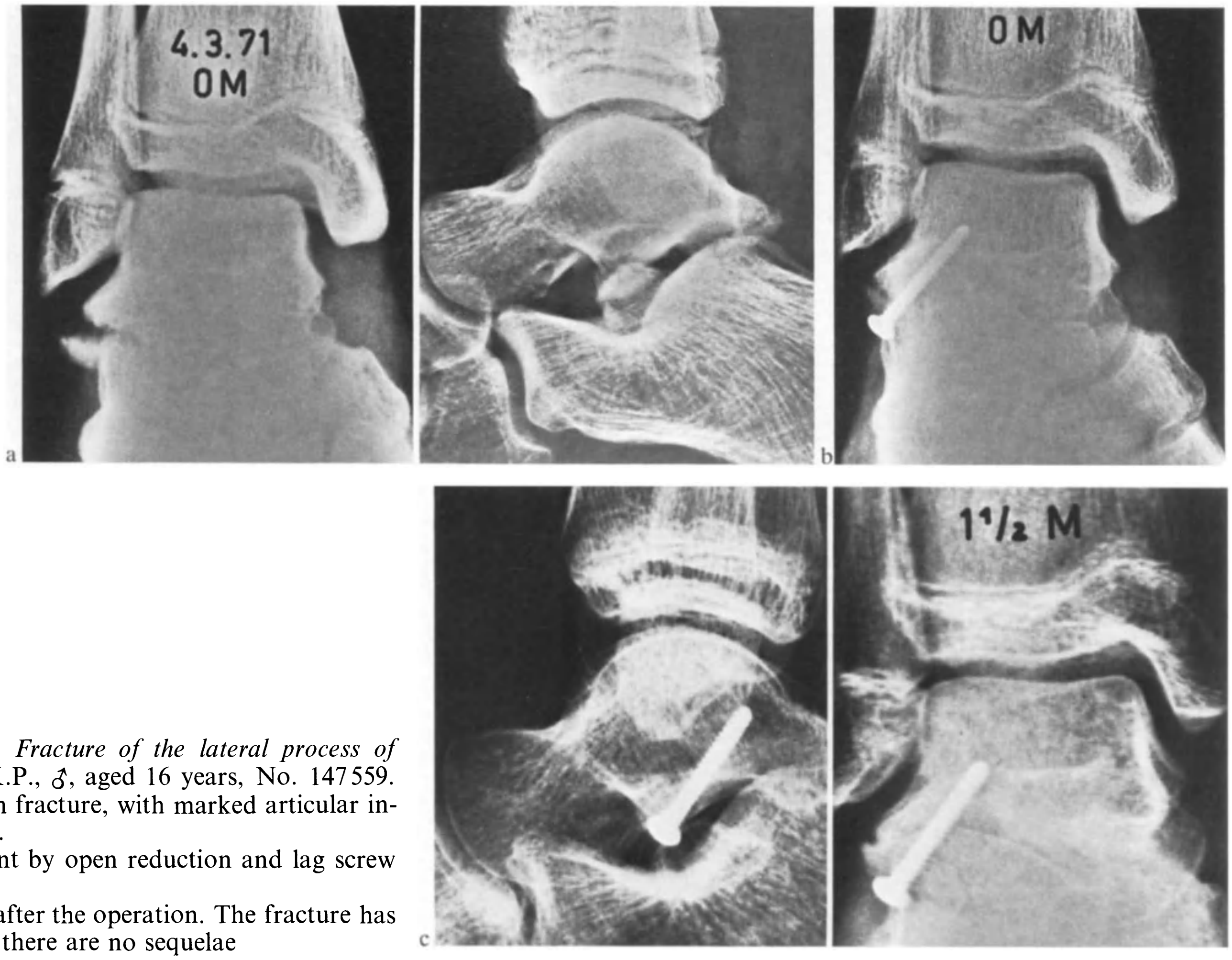


Fig. 11a–c. *Fracture of the lateral process of the talus.* K.P., ♂, aged 16 years, No. 147559.
a) The fresh fracture, with marked articular incongruence.
b) Treatment by open reduction and lag screw fixation.
c) 6 weeks after the operation. The fracture has healed and there are no sequelae

Because the blood supply is interrupted, the devitalized fragment, unlike the surrounding bone, does not undergo decalcification and therefore appears *relatively dense*. If revitalization occurs, mineral is deposited on the necrotic bone trabeculae and the resulting *absolute bone density* is greater than that on the intact opposite side. This process is difficult to detect radiologically, and roentgenograms of the opposite side are essential for comparison. Above all, the transition from a relative increase in density to an absolute increase only becomes apparent by examining serial roentgenograms or tomograms. The phase of slow recovery of the normal structure, which may last a number of years in a child (*Mindell*), is known as the *repair stage*. Scintigraphy and/or scintimetry may be useful for the diagnosis or assessment of aseptic necrosis.

2.5 Results

We treated a total of five fractures of the talus in children between 1961 and 1971. The youngest patient was 8-years old and the oldest was 16-years old; the mean age was $11^1/_2$ years.

A nondislocated fracture of the neck of the talus was immobilized in a cast and protected from weight bearing for several months with a walking caliper. Another nondislocated fracture of the neck of a talus with subtalar dislocation was treated by closed reduction and immobilization in a circular cast. Three fractures required operative treatment, i.e., a severely dislocated proximal fracture of the neck (danger of necrosis); a fracture of the lateral process of the talus; and a fracture of the posterior process. Surgery was indicated in the latter two cases because of the incongruence of the affected joint. Complete anatomical and functional recovery occurred in all five patients.

2.6 Summary

The above series of five fractures of the talus shows that they are not so very rare, and that fracture types which are seen in adults also occur in children. The therapeutic procedure is determined by the fracture

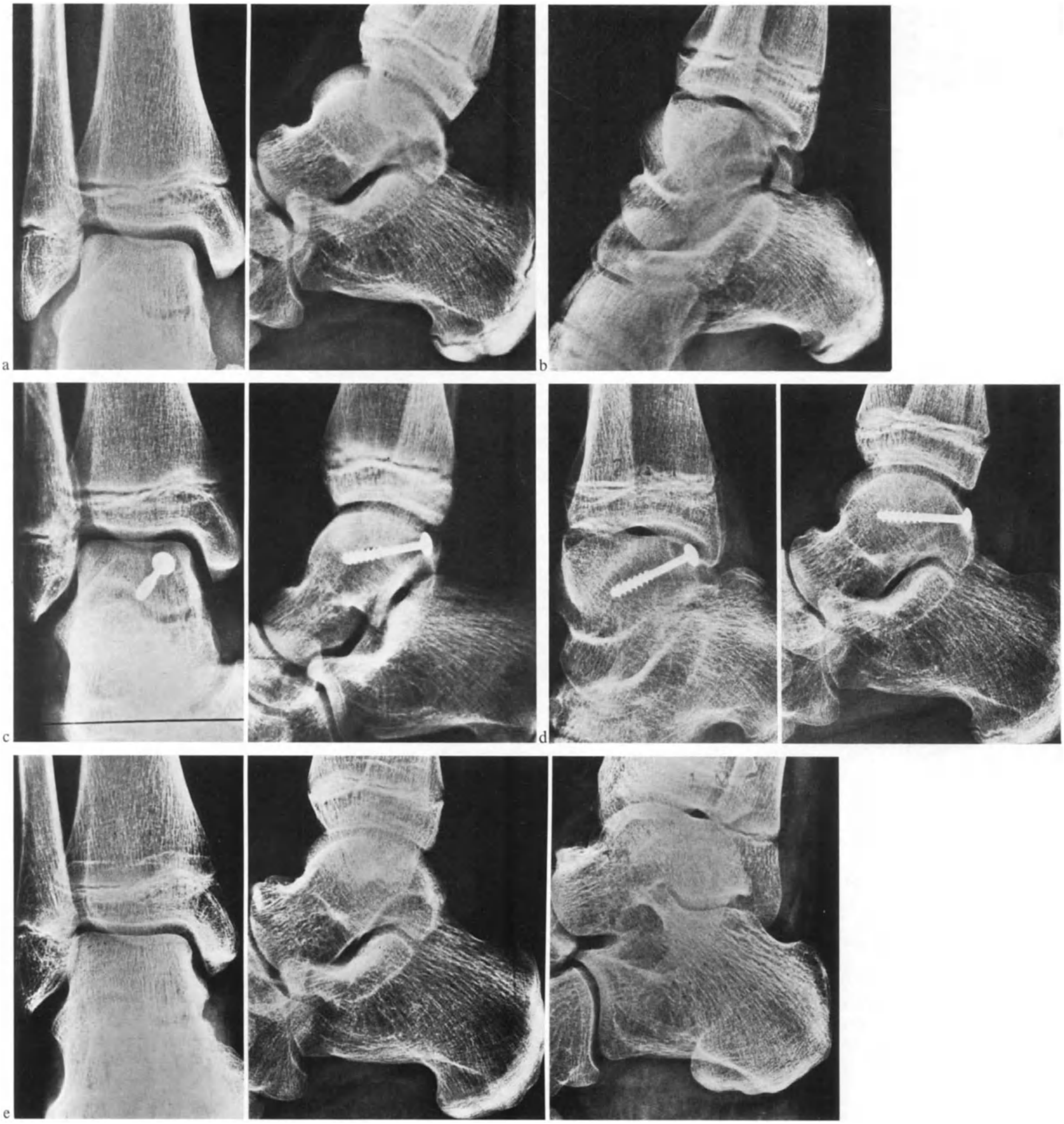
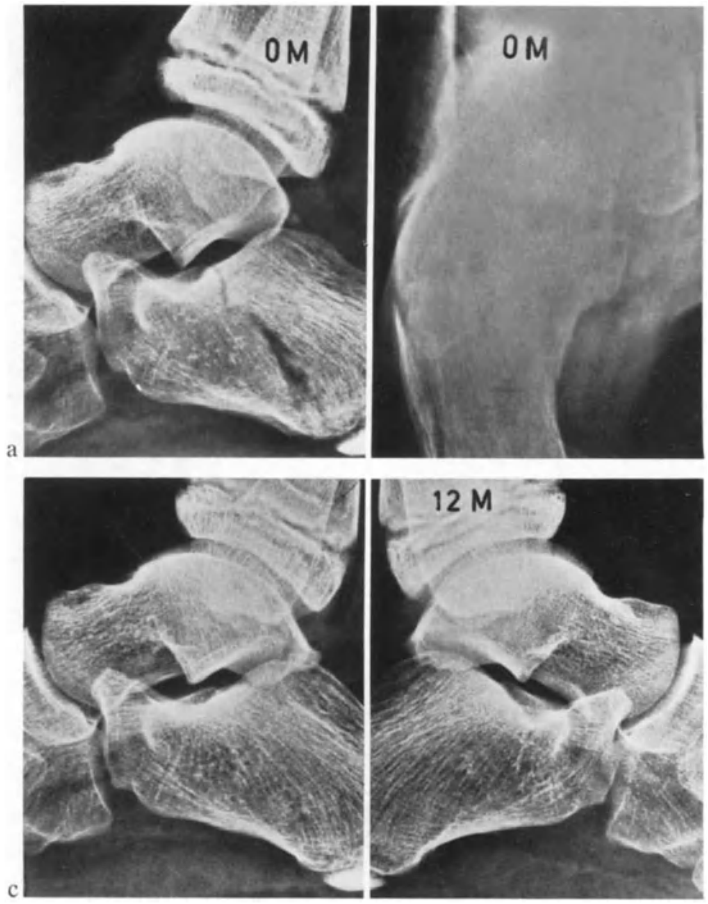


Fig. 12a–e. *Fracture of the posterior process of the talus.* T.D., ♀, aged 12 years, No. 86158.
a) The fracture is hardly visible on a-p and lateral films.
b) This oblique view reveals the fracture of the posterior process of the talus which is, in fact, quite severely dislocated.
c) Treatment by open reduction and lag screw fixation.
d) 2 months after the operation. The fracture has already healed.
e) 13 months after the accident. The original anatomy and function have been restored



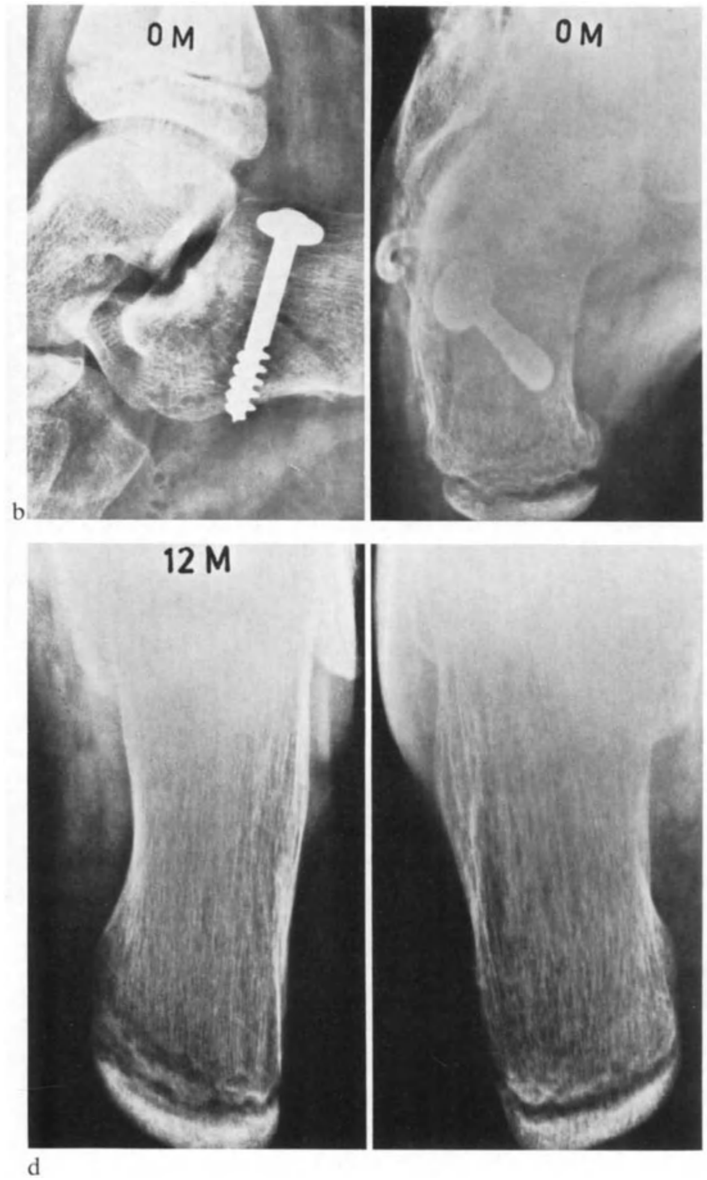


Fig. 13a–d. *Intraarticular splitting of the calcaneus.* G.M., ♂, aged 12 years, No. 104 739.
a) The fracture line runs into the posterior facet of the joint. The joint surface is incongruent.
b) Treatment by fixation with a lag screw inserted from behind.
c, d) 1 year after the accident. The original anatomy and function have been restored

type. Danger of necrosis or the formation of a step in a joint surface are indications for surgery. All five fractures of the talus were treated in accordance with these guidelines and underwent complete anatomical and functional recovery.

3 Fractures of the Calcaneus

3.1 Fracture Types

As already mentioned, fractures of the calcaneus are extremely rare in children, but the fracture types do not differ from those seen in adults. The majority are intraarticular with formation of a step in the posterior talocalcaneal joint. In addition, a sliver of bone is often broken away on the lateral side, the fracture line sometimes extending down into the *Chopart* joint (*Ehalt*). The impression and comminution typically seen in adults never occurs in children, whose cancellous bone is much harder and denser. Axial roentgenograms of the calcaneus are always necessary for precise diagnosis.

3.2 Treatment

Various authors are of the opinion that fractures of the calcaneus in children do not require operative treatment, since remodelling always occurs, even following transient aseptic necrosis (*Blount*). We consider nonoperative treatment to be absolutely sufficient for extraarticular fractures. On the other hand, a fracture of the calcaneus which has led to impression or simple discontinuity of the joint surface requires perfect reduction and reconstruction of the articular surface.

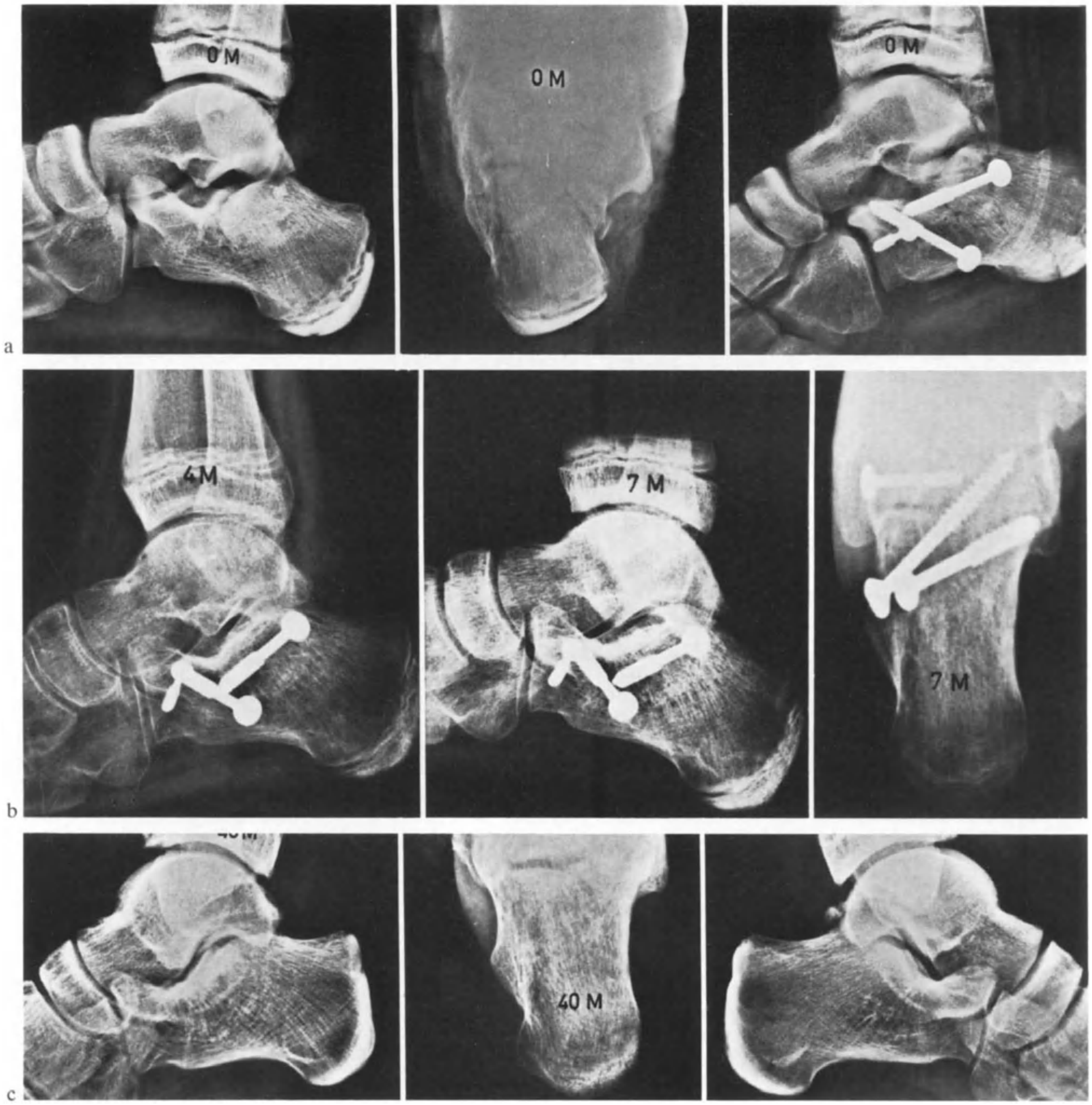


Fig. 14a–c. *Intraarticular fracture of the calcaneus without compression of the cancellous bone.* Z.J., ♂, aged 12 years, No. 114 120.
a) Postaccident and postoperative roentgenograms.
b) 4 and 7 months following internal fixation.
c) 3 years and 4 months after the accident. The original anatomy and function have been restored and there are no signs of osteoarthrosis. The opposite foot is shown for comparison

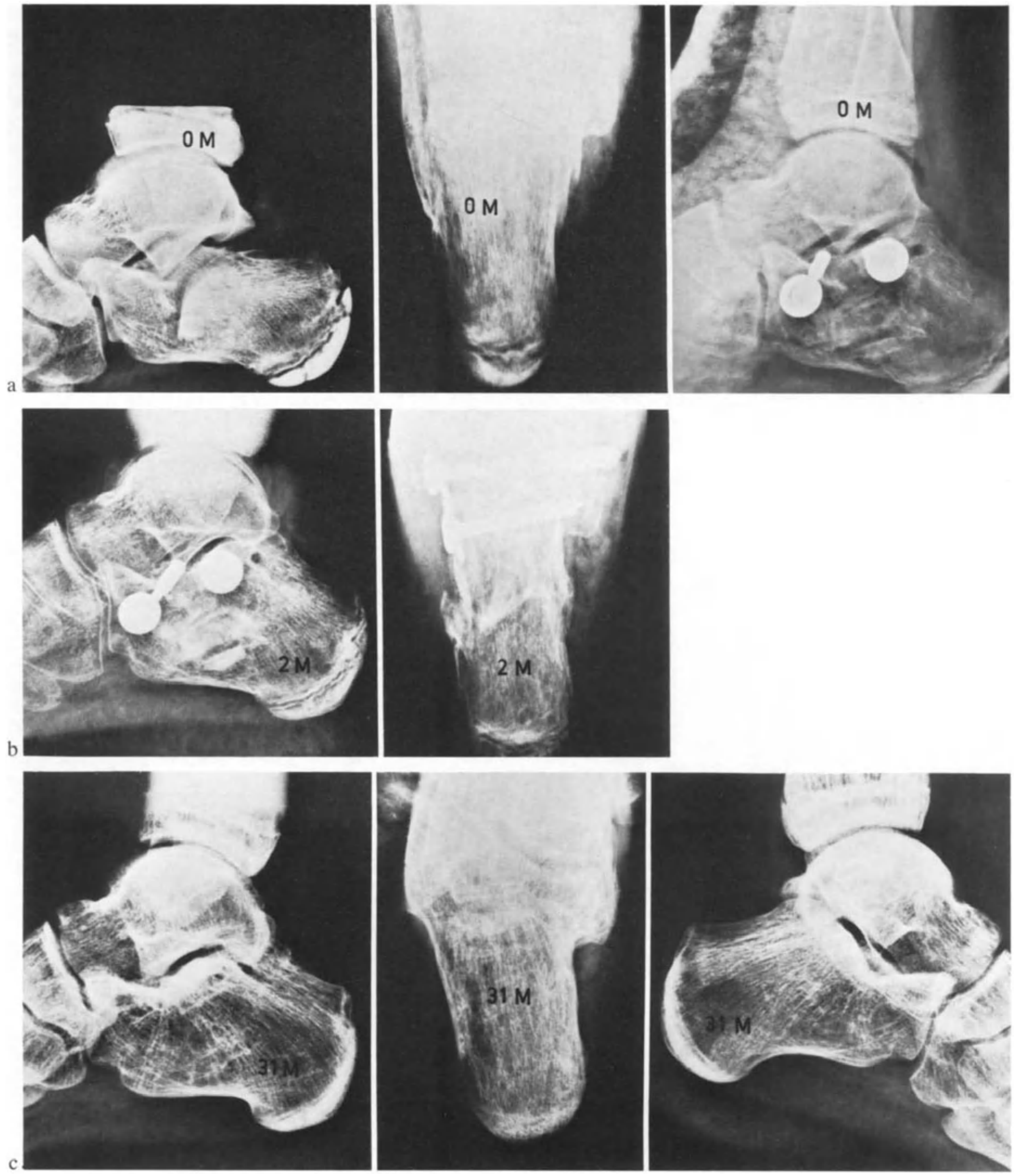


Fig. 15a–c. *Intraarticular fracture of the calcaneus with compression of the cancellous bone*. H.U, ♂, aged 15 years, No. 120746.
a) The fresh fracture and its appearance following open reduction, cancellous bone plasty, and screw fixation.
b) 2 months after the accident. Bone union has taken place.
c) 2 years and 7 months after the accident. There is no osteoarthrosis and the original anatomy and function have been restored

3.2.1 Extraarticular Fractures

The treatment is generally *nonoperative,* obviating the necessity for reduction.

Immobilization: In younger children: Split, circular, below-knee cast which is closed following subsidence of the swelling. It is replaced after 6 weeks by a below-knee walking cast which is retained for 4–6 weeks. In an older child, the leg is kept raised until the swelling has subsided and a walking caliper is then used for 3–4 months to prevent weight bearing.

Duration of fixation: 10–12 weeks.

3.2.2 Intraarticular Fractures

All articular fractures require precise reconstruction by means of open reduction and stabilization in order to prevent incongruence of the joint surfaces. The reconstruction is very difficult. The following procedure was chosen: pneumatic tourniquet; skin incision behind the lateral malleolus; mobilization of the peroneal tendons; exposure of the fracture; in the absence of impression, the fragments can be fixed from the proximal side with a cancellous lag screw (Figs. 13 and 14); if impression has occurred, however, additional autologous cancellous bone plasty is indicated, followed by stabilization of the fragments and of the lateral side-wall of the calcaneus (which has usually broken away) with cancellous lag screws (Fig. 15).

Postoperative treatment: Below-knee plaster splint with the leg raised. After 2 weeks, a walking caliper is applied to prevent weight bearing.

Duration of fixation: 3–4 months.

3.3 Results

Three fractures of the calcaneus in children were seen in our clinic between 1961 and 1971. The patients (two 12-year olds and a 15-year old) fell on to their heels from heights of more than 6 meters and sustained intraarticular fractures of the calcaneus. All the fractures were therefore operated on. The patients were symptom-free at the time of follow-up examination, which was carried out at an average of 3 years postoperatively. Only one patient showed limitation of joint movement (the range of movement of the subtalar joint was restricted by $^{1}/_{3}$) even though the joint was radiologically congruent.

3.4 Summary

Fractures of the calcaneus are very rare in children and occurred exclusively in older children in our series of cases. The fracture types are the same as those seen in adults, but impression of the bone occurs less frequently because of the increased density and hardness of the cancellous bone in children. *Nonoperative* treatment is perfectly acceptable for extraarticular fractures. Intraarticular fractures, on the other hand, require, in our opinion, *open reduction* and *fixation,* since this is the only way of restoring normal joint congruence. The three fractures in our series were treated by screw fixation, with a perfect result in every case.

4 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme, 1957.

Böhler, L.: Die Technik der Knochenbruchbehandlung, 12.–13. Auflage, 2. Band, 2. Teil. Wien: Wilhelm Maudrich, 1957.

Chiari, K.: Die traumatische Talusrollennekrose. Wien. med. Wschr. **99,** 119–121 (1949).

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1961.

Mindell, E. R.: Posttraumatic aseptic necrosis of talus. N. Y. J. Med. **62,** 1396–1398 (1962).

Watson-Jones, R.: Fractures and joint injuries, Vol. II. Edinburgh-London: E. and S. Livingstone, 1962.

Fractures of the Tarsal Bones, Metatarsals, and Toes

J. CEHNER

CONTENTS

1 Introduction

The foot of a child is much more resilient than that of an adult and the thick cartilage mantle which covers the tarsal bones partially absorbs deforming forces. *Indirect* violence is therefore largely neutralized and may only cause a sprain. If the forces are conducted proximally, they may lead to fracture of the tibia or fibula (*Blount*). A large proportion of fractures of the skeleton of the foot are caused by *direct* trauma, e.g., being run over by a vehicle, crushing by a falling object. For this reason, there is frequently concomitant damage to the surrounding soft tissues. *Fatigue fractures* of the metatarsal bones are much rarer in children than in adults. Their site (second and third metatarsals) and radiological appearance are, however, the same. Here too, the callus becomes visible before the fracture line (*Blount, Ehalt*). Occasionally, the radiological assessment is complicated by the presence of various accessory bones and aseptic osteonecrosis of epiphyses or apophyses (Fig. 1). An accessory bone may be incorrectly interpreted as a fracture fragment, and the remnants of a juvenile osteochondrosis may be assumed to be posttraumatic in origin.

2 Fracture Types and Treatment

Whereas in adults even slight posttraumatic changes in the structure and load conduction of the foot rapidly have adverse effects, the degree of tolerance in a child is much greater. The ability of the foot to heal and adapt to change never ceases to surprise one and is the reason why nonoperative treatment is successful in the majority of cases. If rigid stabilization is necessary, *Kirschner* wires which are drilled in transcutaneously and left projecting almost always suffice. These implants are very easy to remove and we have never seen infection via the site of entry.

Since direct trauma often causes concomitant damage to the soft tissues with severe swelling, we recommend that fractures of the middle and anterior part of the foot be treated according to the following plan:

Initial management	Immobilization with a plaster splint or a well-padded and split, circular, below-knee cast, depending on the state of the soft tissues.
	Keep leg raised until swelling has subsided.
	Check circulation, sensation, movement of the toes.
Later	Slightly padded below-knee walking cast which is moulded to fit the foot closely.

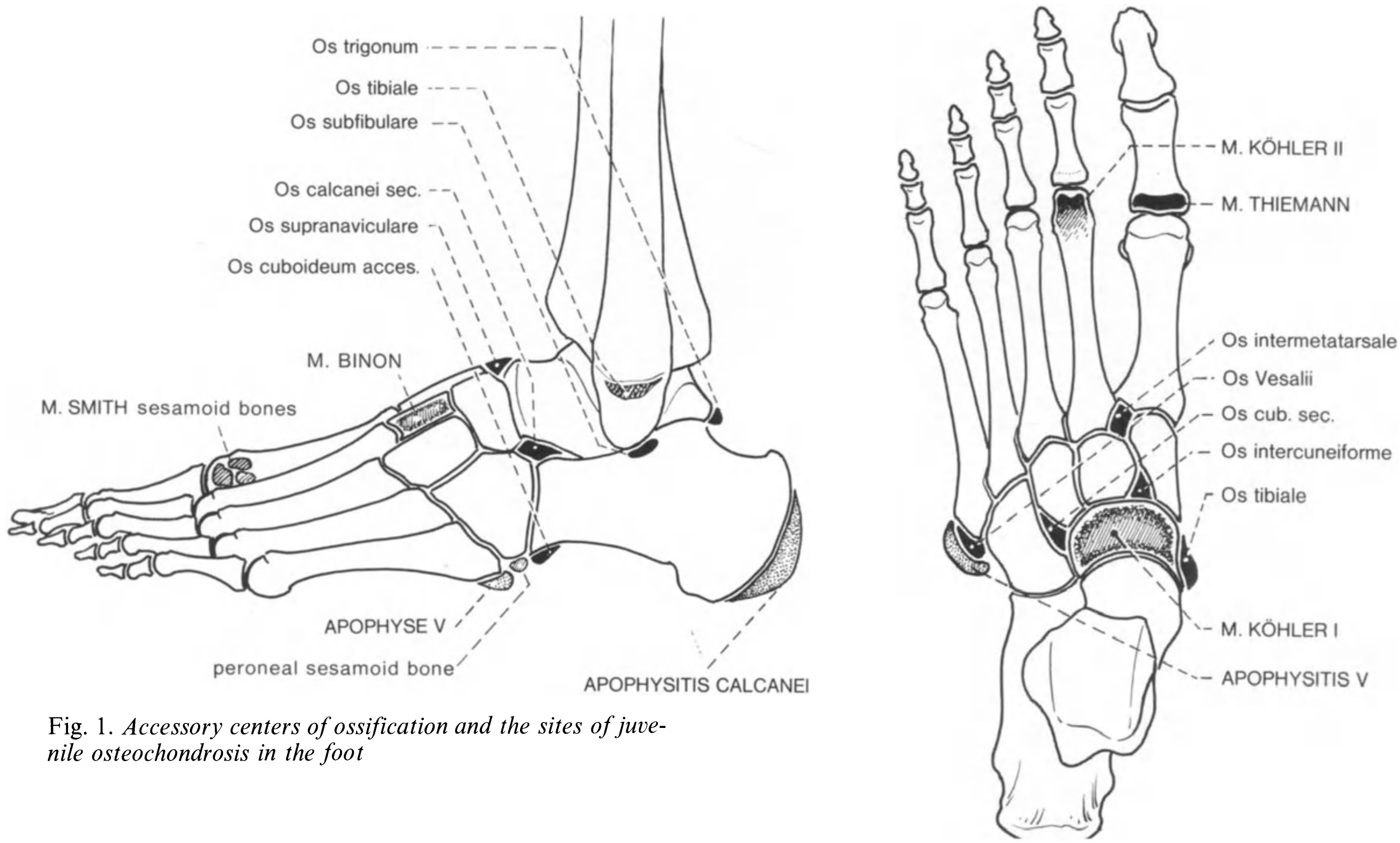


Fig. 1. *Accessory centers of ossification and the sites of juvenile osteochondrosis in the foot*

2.1 Fractures of the Tarsal Bones (Navicular; Cuboid; Medial, Intermediate, and Lateral Cuneiform Bones)

Isolated fractures of the tarsal bones are very rare. Since they are caused by severe direct violence, they are usually accompanied by other fractures of the distal foot (Fig. 2).

2.1.1 Differential Diagnosis

An os tibiale externum may be confused with a fracture of the navicular bone. If in doubt, we always X-ray the opposite intact side for comparison, since accessory bones always occur bilaterally. Aseptic osteonecrosis of the navicular (*Köhler* I) or of the cuneiform bone (*Binon*'s disease) may also be mistaken for a fracture or the sequel of a fracture.

2.1.2 Treatment

Fracture of a bone of the foot may be followed by posttraumatic planus or cavus deformity. Shoe inserts should be worn for several months following healing of the fracture.

Nonoperative Treatment: The fracture is reduced by closed manipulation under general anesthesia and is then checked with the image intensifier.

Mobilization: A circular below-knee cast is applied and immediately split, and the leg is kept raised. Following subsidence of the swelling, a slightly padded, closely contoured below-knee walking cast is applied. If avulsion fracture of the insertion of the tibialis posterior muscle has occurred, the anterior part of the foot is fixed in slight inversion. If painful pseudarthrosis follows, the fragment is either refixed with a screw or removed; in the latter case, reinsertion of the tendon is necessary.

Duration of fixation: 4–6 weeks.

Operative Treatment: If severely dislocated fragments do not remain in place in the cast following reduction, it is advisable to fix them with *Kirschner* wires which are drilled in transcutaneously.

Open comminuted fractures require débridement and evacuation of the hematoma, followed by open reduction and stabilization of the fragments with transcutaneous *Kirschner* wires.

Postoperative treatment: Immobilization with a plaster splint or a split, padded, circular below-knee

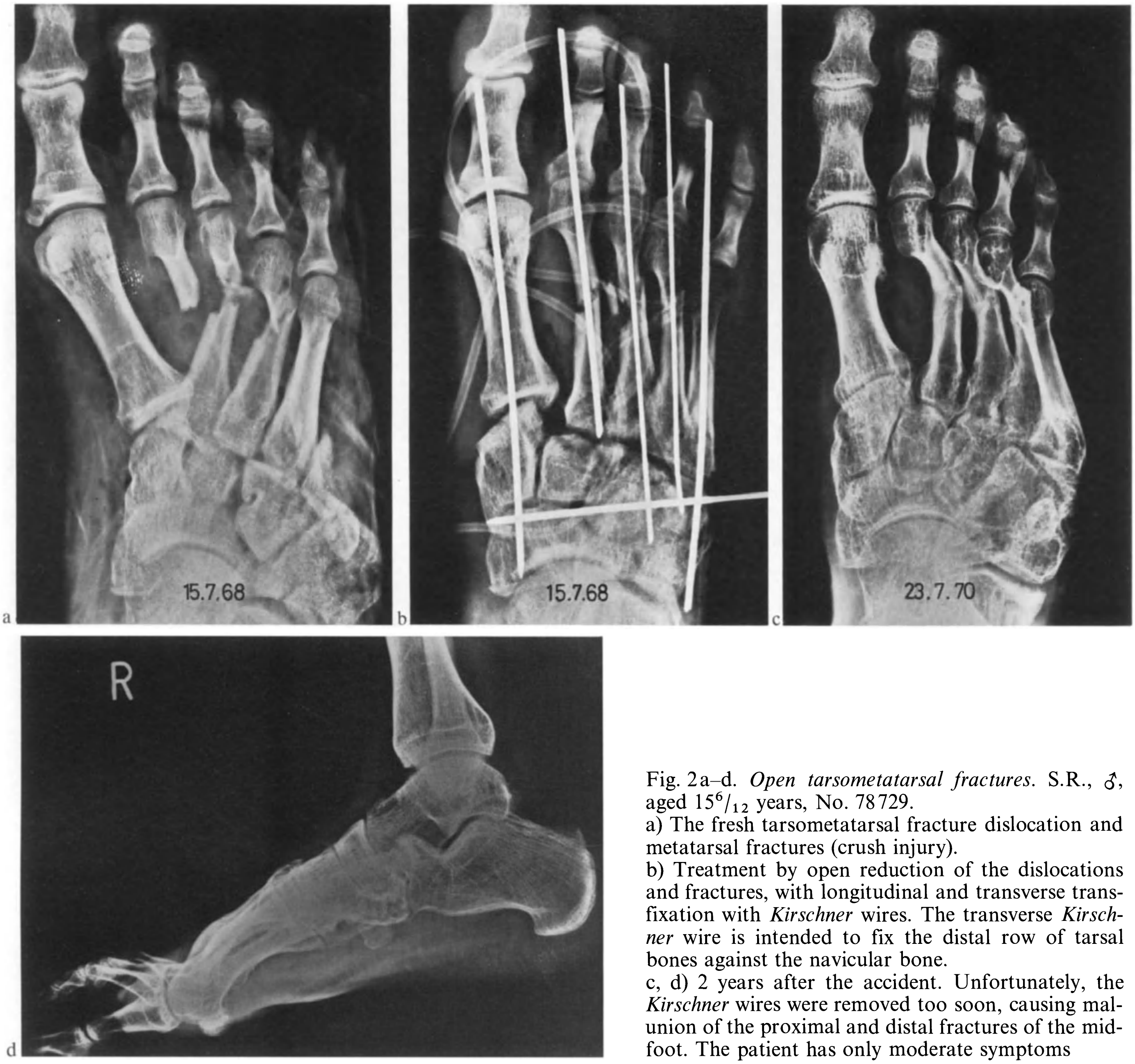


Fig. 2a–d. *Open tarsometatarsal fractures.* S.R., ♂, aged $15^{6}/_{12}$ years, No. 78729.
a) The fresh tarsometatarsal fracture dislocation and metatarsal fractures (crush injury).
b) Treatment by open reduction of the dislocations and fractures, with longitudinal and transverse transfixation with *Kirschner* wires. The transverse *Kirschner* wire is intended to fix the distal row of tarsal bones against the navicular bone.
c, d) 2 years after the accident. Unfortunately, the *Kirschner* wires were removed too soon, causing malunion of the proximal and distal fractures of the midfoot. The patient has only moderate symptoms

cast. The leg is kept raised until swelling has subsided. After 2–3 weeks, a below-knee walking cast is applied under general anesthesia. The *Kirschner* wires are removed during hardening of the cast.

Duration of fixation: 6 weeks from the date of operation.

2.2 Fractures of the Metatarsal Bones

The anterior part of the foot is very exposed to direct and torsional violence, and fractures can therefore occur at a number of sites, i.e.,

Fractures of the bases of the metatarsals,
Fractures of the base of the fifth metatarsal.
Diaphyseal fractures.
Epiphyseal separations and subcapital fractures.

2.2.1 Fractures of the Bases of the Metatarsal Bones

2.2.1.1 Pathological Anatomy

Metaphyseal basal fractures are not usually severely dislocated. They pass through cancellous bone, and thus, tend to heal rapidly. On the other hand, if the fracture is intraarticular, there may be concomitant dislocation of the *Lisfranc* joint (Fig. 3).

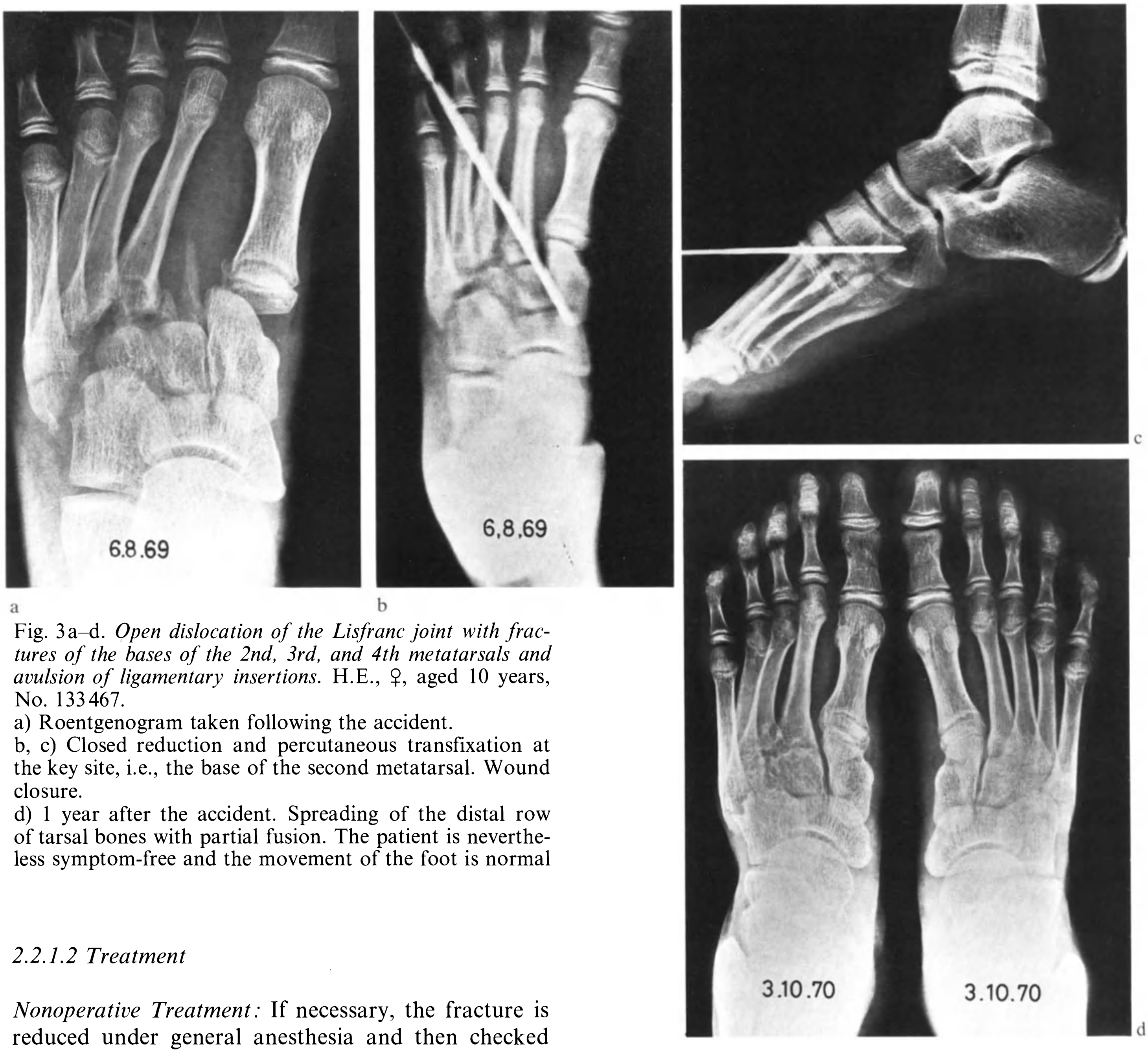


Fig. 3a–d. *Open dislocation of the Lisfranc joint with fractures of the bases of the 2nd, 3rd, and 4th metatarsals and avulsion of ligamentary insertions.* H.E., ♀, aged 10 years, No. 133467.
a) Roentgenogram taken following the accident.
b, c) Closed reduction and percutaneous transfixation at the key site, i.e., the base of the second metatarsal. Wound closure.
d) 1 year after the accident. Spreading of the distal row of tarsal bones with partial fusion. The patient is nevertheless symptom-free and the movement of the foot is normal

2.2.1.2 Treatment

Nonoperative Treatment: If necessary, the fracture is reduced under general anesthesia and then checked under the image intensifier.

Immobilization: A circular, below-knee cast is applied and immediately split. The leg is kept raised. Following subsidence of the swelling, a closely moulded below-knee walking cast with a toe plate is applied.

Duration of fixation: 4–6 weeks, depending on the age of the child.

Operative Treatment: Open reduction and stabilization is reserved for fracture dislocations of the *Lisfranc* joint which cannot be reduced by closed manipulation. The position of the fragments is maintained with transcutaneous *Kirschner* wires (Fig. 3).

Postoperative treatment: Plaster splint or a well-padded, splint below-knee cast. The leg is kept raised. After 3 weeks, a below-knee walking cast with a toe plate is applied under general anesthesia and, at the same time, the *Kirschner* wires are removed.

Duration of fixation: 6 weeks from the date of operation.

2.2.2 Fractures of the Base of the Fifth Metatarsal

2.2.2.1 Pathological Anatomy

This is an avulsion of the peroneus brevis tendon which results from sudden violent supination of the anterior part of the foot. The traction epiphysis or a sesamoid bone may simulate a fracture; if in doubt,

a b c

Fig. 4a–c. *Avulsion fracture at the base of the 5th metatarsal, followed by pseudarthrosis.* S.M., ♀, aged 13 years, No. 113 675.
a) The fresh fracture. The center of ossification of the traction epiphysis of the base of the 5th metatarsal is also visible. Treatment: immobilization in a circular cast.
b) 2 months later. Painful pseudarthrosis.
c) 3 years and 3 months following operative removal of the pseudarthrotic fragment and reinsertion of the tendon of peronaeus brevis. The normal anatomy and function have been restored

the intact side is X-rayed for comparison. This type of fracture occasionally heals by pseudarthrosis which, if painful, makes operative fixation or removal of the fragment necessary (Fig. 4). If the fragment is removed, the peroneus tendon should always be reinserted.

2.2.2.2 Treatment

Nonoperative Treatment: Immobilization: Circular, below-knee walking cast with the anterior part of the foot everted.

Duration of fixation: 4–5 weeks.

2.2.3 Diaphyseal Fractures

An isolated diaphyseal fracture in a child is a rarity and occasionally takes the form of a fatigue fracture. The accident mechanisms are such that more than one metatarsal tends to be fractured (*Müller* and *Ganz*) and there may be concomitant damage to the soft tissues.

2.2.3.1 Treatment

Nonoperative Treatment: Isolated metatarsal fractures are, if necessary, reduced under a general anesthetic with the aid of the image intensifier.

Immobilization: Split, circular, below-knee cast with the leg kept raised. Following subsidence of swelling, a below-knee walking cast with a toe plate is applied. If there is only slight swelling, the fracture can be immediately immobilized in a walking cast.

Duration of fixation: 5–6 weeks.

Operative Treatment: It is hardly possible to reduce severely dislocated multiple metatarsal fractures satisfactorily and then maintain the reduction by immobilization in a cast. The method of choice is, as with open fractures (Fig. 5), axial *Kirschner* wire fixation (Fig. 6).

Postoperative treatment: Plaster splint for 2–3 weeks with the leg kept raised. A circular, below-knee walking cast with a toe plate is then applied.

Duration of fixation: 5–6 weeks.

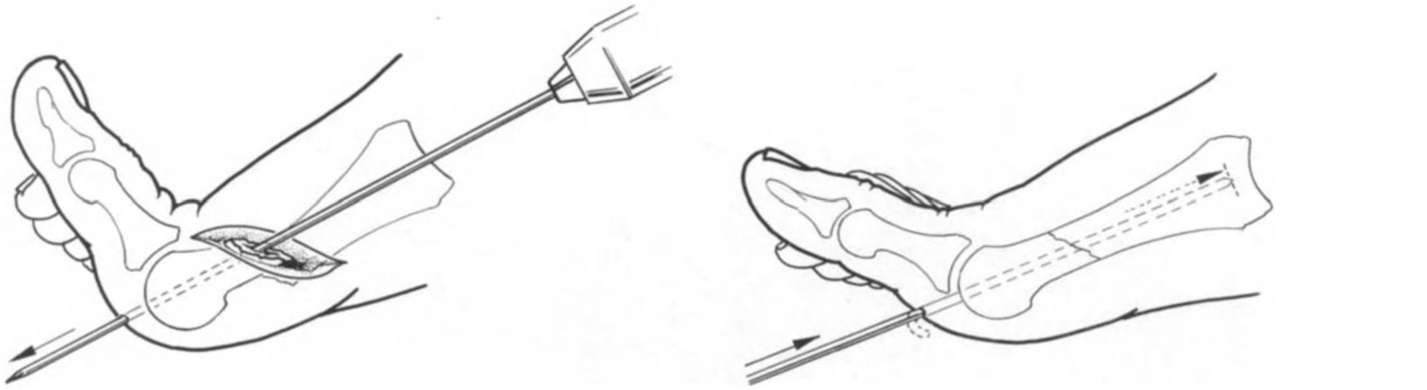


Fig. 5. *Technique of open reduction and internal fixation of a metatarsal shaft fracture*. The dorsal aspect of the fracture is exposed and the distal fragment is transfixed axially with a *Kirschner* wire inserted in a distal direction. The *Kirschner* wire is pulled through the skin and then driven back so as to transfix the proximal fragment axially

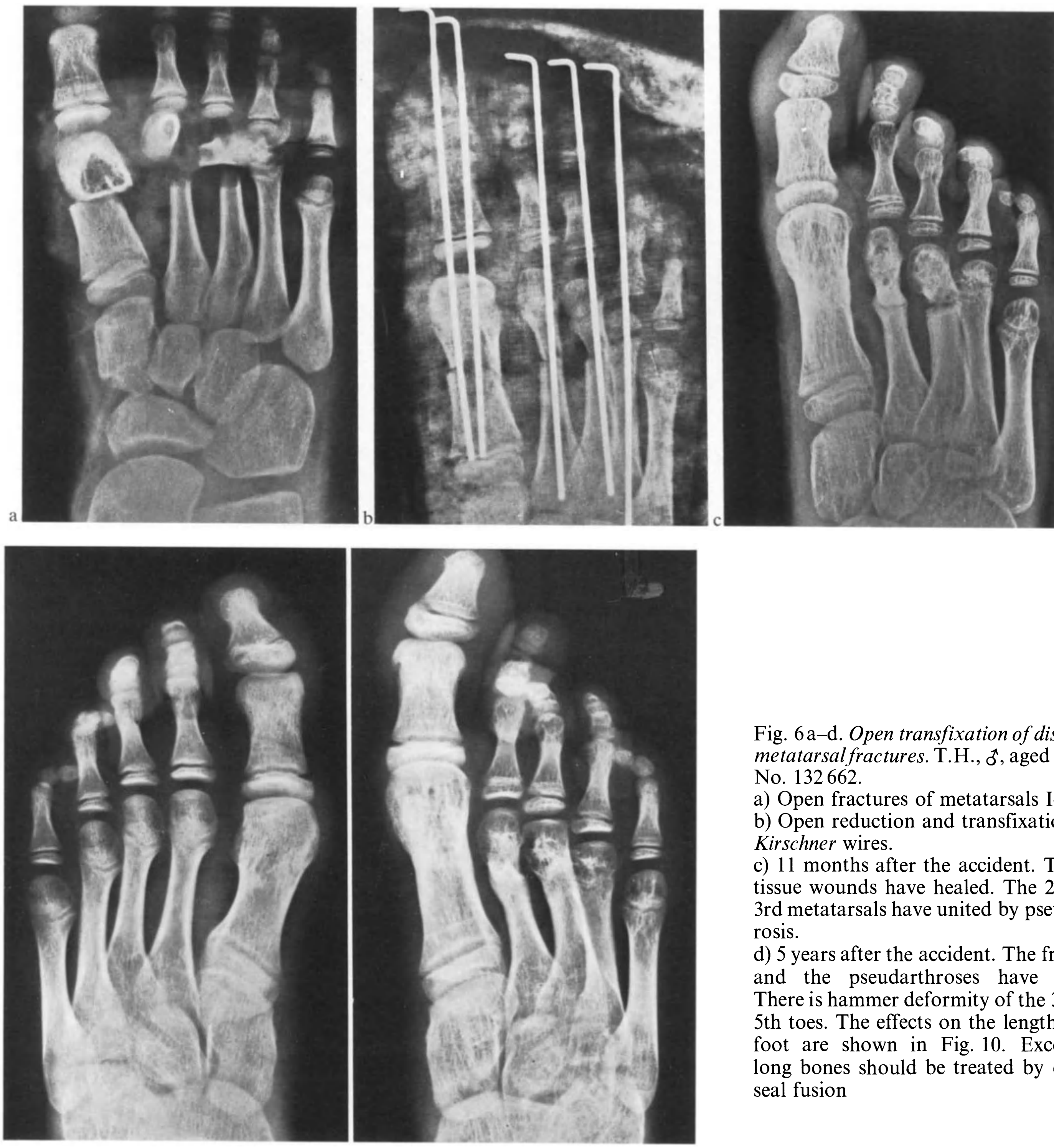
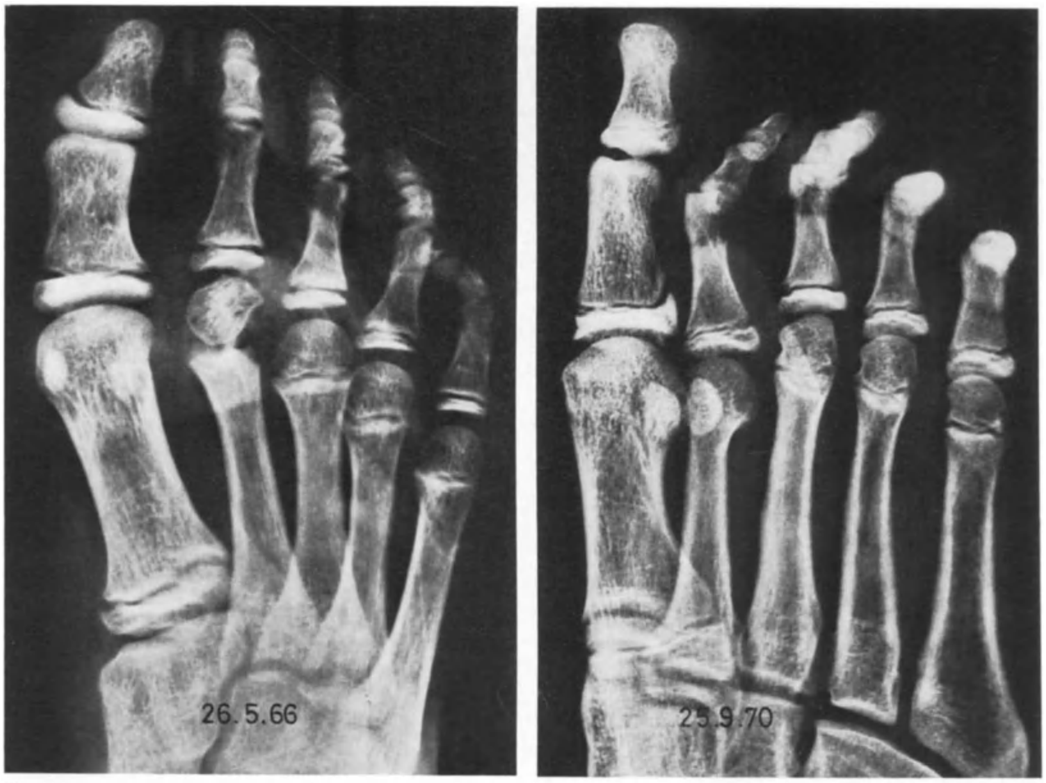


Fig. 6a–d. *Open transfixation of dislocated metatarsal fractures*. T.H., ♂, aged 8 years, No. 132 662.
a) Open fractures of metatarsals I–IV.
b) Open reduction and transfixation with *Kirschner* wires.
c) 11 months after the accident. The soft tissue wounds have healed. The 2nd and 3rd metatarsals have united by pseudarthrosis.
d) 5 years after the accident. The fractures and the pseudarthroses have healed. There is hammer deformity of the 3rd and 5th toes. The effects on the length of the foot are shown in Fig. 10. Excessively long bones should be treated by epiphyseal fusion



a b

Fig. 7a, b. *Open fracture dislocation of the epiphysis of the 2nd metatarsal.* R.U., ♂, aged 11 years, No. 104437.
a) The fresh fracture, which was treated by open reduction, *Kirschner* wire transfixation, and immobilization with a cast.
b) $4^{1}/_{2}$ years after the accident. Growth has been reduced by 8 mm, but there is no disturbance of function

2.2.4 Epiphyseal Separations and Subcapital Fractures

Like the diaphyseal fracture, this type of fracture rarely occurs singly; simultaneous fractures of several metatarsals are more common. Occasionally, a case of osteonecrosis of the head of the second metatarsal (*Köhler* II disease) is incorrectly diagnosed as a post-traumatic lesion. The principles of *treatment* are practically the same as those for diaphyseal fractures. However, the necessity for fixation with transcutaneous *Kirschner* wires is likely to arise more often, since subcapital fractures are relatively unstable and may lead to post-traumatic deformity which has adverse effects (Fig. 7).

2.3 Fractures of the Toes

These result from direct violence or from an axial impact. Fractures of the proximal phalanges are particularly important. The pull of the extensor muscles may cause plantar angulation which later gives rise to pain when weight is transferred to the ball of the foot during walking.

2.3.1 Treatment

The therapeutic procedure is determined by the site of the fracture.

2.3.1.1 Fractures of the Large Toe

Nonoperative Treatment: Reduction is advisable if the fracture is markedly dislocated. It is carried out under general anesthesia or using a nerve block, depending on the age of the child.

Immobilization: Circular, below-knee walking cast with a toe plate, the large toe being embedded in a separate groove in the plaster.

Duration of fixation: 3–4 weeks.

Operative Treatment: Wide open fractures require débridement followed by stabilization of the fragments with *Kirschner* wires which pierce the bone or are inserted alongside it.

Epiphyseal fractures (*Aitken* II and III), which are extremely rare, transect the epiphyseal plate and therefore require anatomically precise reduction in order to prevent the abnormal growth and articular incongruence which are otherwise very likely to occur. Because accurate reduction is hardly attainable by nonoperative means, open reduction is recommended, followed by "watertight" closure of the fracture gap by fixation with buried *Kirschner* wires or mini-screws. The latter should never pierce the epiphyseal plate.

Postoperative treatment: A plaster splint which reaches down to the tips of the toes is applied for 2 weeks. It is then replaced by a below-knee walking

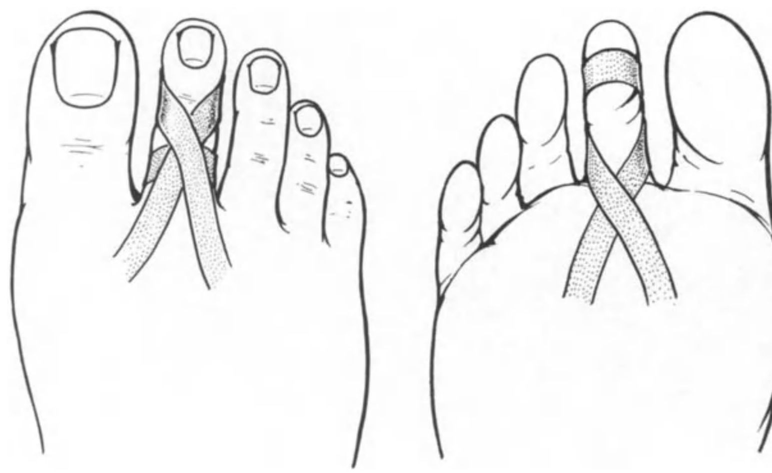


Fig. 8. *The Hohmann countertraction bandage for splinting of a toe fracture*

Fig. 9. *Use of an adjacent intact toe to splint one which is fractured (the "buddy" splint)*. A gauze pack is placed between the toes to prevent maceration of the skin. *Beware of strangulation!*

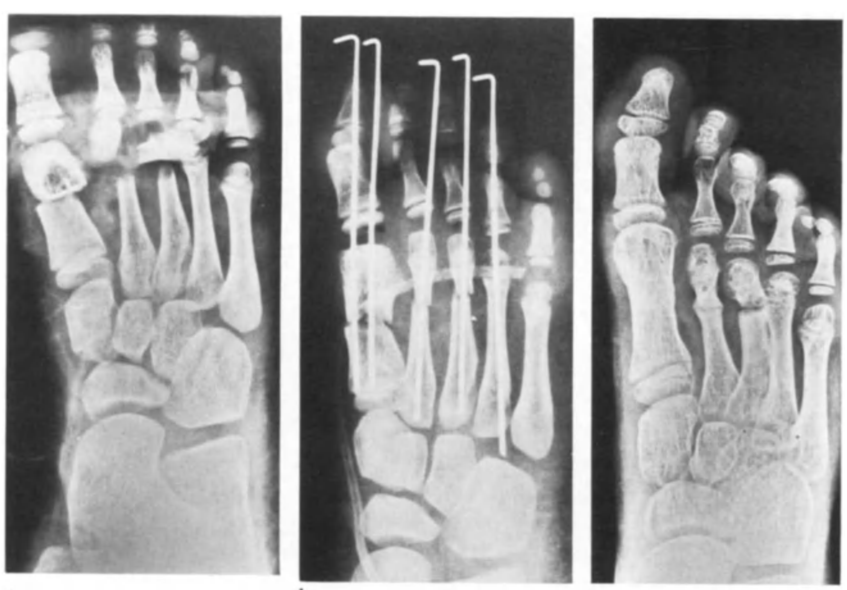
cast with a toe plate and a separate moulded bed for the large toe. The metal is removed after 6–8 weeks.

Duration of fixation: 6 weeks from the date of operation.

2.3.1.2 Fractures of Toes II–V

Nonoperative Treatment: If there is considerable dislocation, the fracture is reduced under general anesthesia or with a nerve block. The reduction is checked with the image intensifier.

Immobilization: The fracture is counter-strapped with a *Hohmann* criss-cross bandage (Fig. 8) or is splinted by binding it to an adjacent intact toe. Cotton wool or gauze is placed between the toes to prevent maceration of the skin. The adhesive plaster which



a b c

Fig. 10a–d. *Increased and decreased growth following fracture of the metatarsals.* T.H., ♂, aged 8 years, No. 132662 (same case as in Fig. 6).
a) Fresh open fractures of metatarsals I–IV. A cartilage disk which lay completely detached in the wound turned out to be the epiphyseal plate of the 4th metatarsal.
b) Following open reduction and *Kirschner* wire transfixation, the wound was left to heal by secondary intention.
c) 11 months after the accident. Pseudarthrosis of the 2nd and 3rd metatarsals has occurred with slowing of growth.
d) 6 years after the accident. All the fractures have healed. There is markedly increased growth of the 1st metatarsal. The epiphyseal fusion recommended in Fig. 6 was not carried out. The growth of the 2nd, 3rd, and 4th metatarsals is distinctly retarded. There is severe hammer deformity of the third toe. The patient is symptom-free

is used to immobilize the fracture should not be applied too tightly as it could otherwise cause ischemia of the toe (Fig. 9) (*Freuler, Wiedmer, Bianchini*).

Duration of fixation: 2–3 weeks.

3 Prognosis

Although fracture healing does not usually present problems, the seriousness of injury to the middle and anterior parts of the foot and to the toes should not be underestimated. Inadequate reduction and immobilization (Fig. 2) spoil the appearance of the foot and, in many cases, have a permanent adverse effect on the stance and gait of the patient. This particularly applies to fractures of the middle of the foot, which may be followed by posttraumatic cavus or planus deformity.

Disturbances of growth caused by partial epiphyseal fusion result exclusively from fractures of the epiphyseal plate (*Aitken* Types II and III). Slowing of growth is sometimes seen following separation of a metatarsal epiphysis with severe dislocation. The same phenomenon is known to occur following corresponding injury to a metacarpal bone and may be caused by premature epiphyseal closure secondary to disturbance of the blood supply. Conversely, excessive longitudinal growth may occur in a fractured bone, but any effect which it has on function is insignificant (Fig. 10)

4 Summary

Fractures of the tarsus and metatarsus should be correctly reduced before union takes place in order that the physiological arch of the foot remain intact. Splinting by the use of *Kirschner* wires inserted transcutaneously is often the only means of achieving adequate reduction and fixation. Epiphyseal fractures, which are extremely rare, always require open reduction and fixation since they otherwise lead to partial epiphyseal fusion which, in turn, causes progressively abnormal growth.

5 References

Blount, W. P.: Knochenbrüche bei Kindern. Stuttgart: Thieme, 1957.

Ehalt, W.: Verletzungen bei Kindern und Jugendlichen. Stuttgart: Enke, 1961.

Freuler, F., Wiedmer, U., Bianchini, D.: Cast manual for adults and children. Berlin-Heidelberg-New York: Springer, 1979.

Müller, M. E., Ganz, R.: Luxationen und Frakturen: Untere Gliedmaßen und Becken. In: Unfallverletzungen bei Kindern (Hrsg. J. Rehn). Berlin-Heidelberg-New York: Springer, 1974.

Weber, B. G.: Knöchel, Fußwurzel, Mittelfuß. In: Chirurgie der Gegenwart, Band 4. München-Berlin-Wien: Urban und Schwarzenberg, 1974.

Amputations in Children

G. MÜLLER

CONTENTS

1 Introduction

The majority of amputations in growing children are necessitated by trauma and its sequelae. The operative techniques and postoperative management are similar to those in adults. However, in children growth is an important factor. It creates problems which are specific to amputations in children and which cease to exist when the growth phase ends.

2 Amputation Stump in a Child

2.1 Length of the Stump

The length of an amputation stump remains constant in an adult, but changes in a growing child. Seventy-five to 80% of the longitudinal growth of the femur takes place in the distal epiphysis. In the lower leg, 60% takes place in the proximal epiphyses of the tibia and fibula. An above-knee stump therefore undergoes relative shortening in the course of growth, but the growth of a below-knee stump is significantly less retarded. In the arms, the opposite applies: whereas in the leg, growth is concentrated in the epiphyses adjacent to the knee, the epiphyses at the opposite ends of the bones from the elbow are those in which the greater part of the longitudinal growth of the arm (approximately 80%) is concentrated. It is therefore important that the distal epiphyses of the forearm be retained in order to prevent excessive shortening of the forearm stump. The growth of an above-elbow stump, on the other hand, is much less retarded. It follows from the above considerations that one should *disarticulate rather than amputate* (Fig. 1). One can always amputate later, if necessary. This principle is, of course, only applicable to the management of injuries; when dealing with malignant tumors, radical extirpation of the tumor tissue takes absolute priority over aesthetic and functional considerations.

2.2 Coverage of the Stump

Ideally, normal myoplastic stump coverage with a tension-free skin suture is possible. If insufficient skin is available for coverage, there are two possibilities: Following myoplasty, the stump may be covered immediately with a *split skin graft;* better skin coverage can be provided at a later date, if necessary, by grafting full skin, e.g., by transposition or pedicle grafting.

Fig. 1. *Disarticulation.* D.S., ♂, aged 9 years, No. 142986. A fall while water skiing was followed by strangulation of the left wrist by the tow rope, resulting in necrosis of the hand. Following treatment by disarticulation at the wrist, the full range of pronation and supination of the forearm remained and longitudinal growth was normal

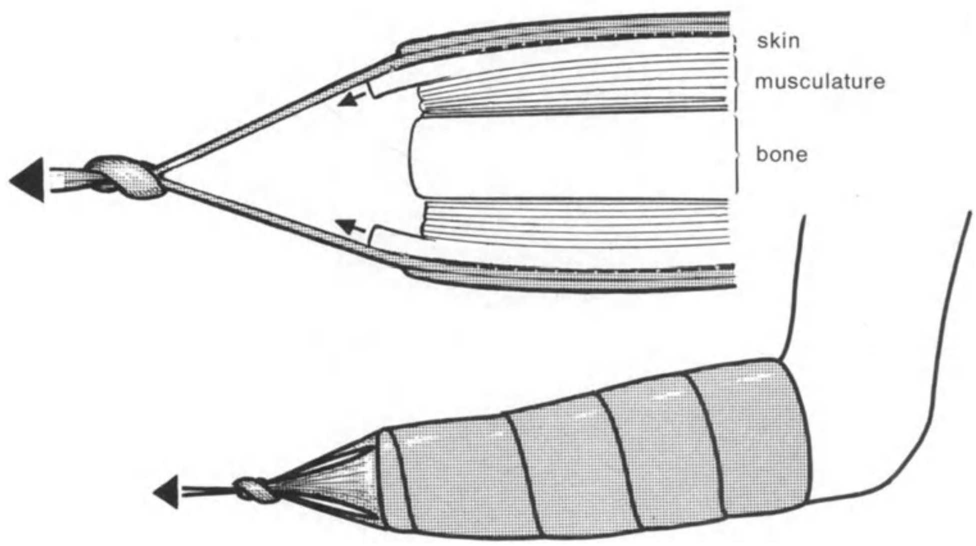


Fig. 2. *Traction with a tubular stockinette bandage on an open amputation.* The open stump is covered with a sterile dressing, and the skin is painted with sterile Mastisol, which acts as an adhesive for the tubular stockinette which is then rolled over the limb. This type of extension allows secondary wound healing without shortening the bone

Scars and skin grafts on the amputation stump of a child seldom cause problems and atypical skin flaps may therefore be used for stump coverage. An epiphyseal plate should never be sacrificed in order to facilitate immediate tension-free closure of the skin incision.

An alternative method of stump coverage is *prolonged skin traction with a tubular stockinette bandage.* If immediate, tension-free skin closure is impossible, the *amputation stump is left open* and the end is covered with a sterile dressing. Immediately following the operation, or a few days later, a tubular stockinette bandage is rolled over the stump, which is coated with Mastisol. This is followed by an elastic bandage. The stockinette tube is knotted together a few centimeters distal to the end of the stump and traction of 0.25–1 kg is applied, the exact weight depending on the age of the child. This frequently results in secondary wound healing within 2–4 weeks. The skin can always be stretched sufficiently to allow tension-free delayed suturing. This simple technique allows one to save valuable stump length (Fig. 2).

2.3 Conization of the Stump

This is the most frequent complication following amputation in children. It occurs exclusively following transosseus amputation and is *not* seen following disarticulation, the stump of which terminates in an epiphysis. Periosteal apposition at the end of the bone causes the latter to outgrow the skin. The stump takes on a conical shape, and perforation of the skin sometimes occurs. Sooner or later, the wearing of a prosthesis has to be discontinued. This complication is seen in the humerus, fibula, tibia, and femur in decreasing order of frequency. Since the conization is caused by appositional periosteal bone growth at the end of the stump, the epiphyseal fusion recommended by various authors has no therapeutic effect (*Aitken, Lambert*). Conization of the stump ceases at the end of the growth phase.

Treatment consists of resection of the end of the bone. The sooner an amputation is followed by conization of the stump, the greater are the chances of recurrence. In some cases, four or five stump resections have had to be carried out by the time skeletal growth ceases (Fig. 3).

In order to reduce the stimulation of periosteal bone growth to a minimum, proximal displacement of the periosteum in the course of amputation should be avoided and bone chips should be removed by thorough rinsing. Excessive growth of the fibula can be compensated for by shortening by several centimeters. It can also be inhibited by creating a tibiofibular syn-

Fig. 3. *Conization of the stump*. L.C., ♂, aged 8 years, No. 79284. Diagnosis: micromelia, with below-knee amputation at the age of 6 years. 2 years later, appositional growth of the tibia and fibula had caused marked conization of the stump and pointing of the soft tissues. Reoperation was necessary to reshape the stump. Further operations became necessary after 2 and 5 years

ostosis. Superperiosteal resection of the fibula is preferable when dealing with a short below-knee stump. This procedure has the additional advantage of facilitating fitting of a PTB (patellar tendon bearing) prosthesis.

3 Prostheses and Stump Complications

3.1 Lengthening and Replacement of Prostheses

The shaft of the prosthesis of a growing child should be lengthened every 6–12 months. It is particularly important that a prosthesis of the lower limb be frequently adjusted so that the child does not have time to get used to an abnormal gait. The stump increases in diameter as well as in length, and a prosthesis which becomes too tight may cause pain; this factor should be borne in mind when seeking the cause of a limp. A prosthesis usually has to be replaced completely after 2–3 years. Following the cessation of skeletal growth, this interval increases to 5–7 years, depending on the activity of the amputee. A child with an amputated limb should therefore be seen every 6–12 months by an interdisciplinary team comprised of the orthopedic surgeon, the orthotist, and the physiotherapist.

3.2 Stump Complications

The following complications which occur in adults, causing considerable distress in some cases, are much rarer, and tend to be less severe, in children.

3.2.1 Phantom Sensation and Phantom Pain

Amelia is never accompanied by phantom sensation or phantom pain and these complications are very rare following amputation of an injured limb. *Aitken* found no case of phantom pain among 350 child amputees. According to *Lambert,* it is never seen in patients below 6 years of age, is extremely rare between the sixth and twelfth years of age and occurs with the same frequency as in adults, but in an attenuated form, from the twelfth year of age onwards.

3.2.2 Stump Neuroma

These are also rare in children. *Aitken* encountered this complication in 3.2% of 196 cases. Here too, the symptoms are less intense than those in adults.

3.2.3 Joint Contracture

The postoperative management of the stump is simpler in a child than in an adult and disturbances of wound healing are rare owing to the increased tissue healing potential in children. The danger of joint contracture is therefore slight. Nevertheless, the stump should be fitted with a prosthesis at as early a stage as possible.

4 Special Amputations

4.1 Finger Amputations

When treating finger injuries, one should always try to avoid shortening the phalanges. The results of split-skin grafting, full thickness grafting, V-Y-plasty, and cross-finger plasty are particularly good in children.

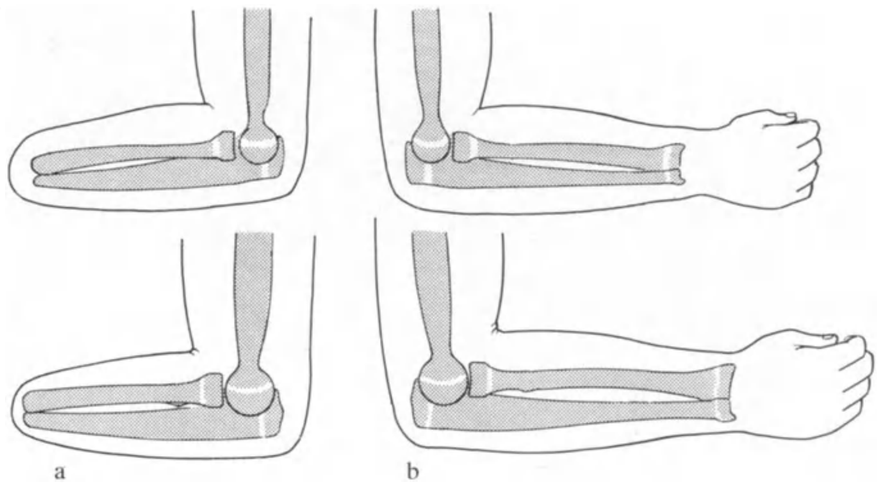


Fig. 4a, b. *Effect of including the distal epiphyseal plate in an amputation of the forearm.*
a) In the course of growth, the stump remains disproportionately shorter than the intact limb on the opposite side since the distal epiphyseal plate no longer contributes to longitudinal growth.
b) Normal longitudinal growth on the intact side

However, in the child, as in the adult, fingertip sensation should be intact or should be restored by appropriate plastic surgery. If amputation is necessary, as little of the finger as possible should be removed.

4.2 Amputations of the Hand and Forearm

When treating a severely injured hand, retention of the wrist joint with a few metacarpal stumps is much better than replacement with an artificial hand which has no sensory function. Disarticulation at the wrist joint, if it is absolutely necessary, provides a good stump. One should remember that pronation and supination are very important movements which decrease with diminishing length of the stump. If the length of the stump is a third of that of the forearm (amputation proximal to the insertion of the pronator teres muscle) little worthwhile rotation is likely to remain. If the distal radial epiphysis is missing, the relative shortening of the forearm stump will become more accentuated as the patient grows (Fig. 4).

4.3 Elbow and Upper Arm Amputations

Disarticulation at the elbow has the advantage of providing a good stump, but even if the distal humeral epiphysis has to be amputated, the remaining above-elbow stump continues to grow at a satisfactory rate.

4.4 Foot Amputations

Toe injuries which are sufficiently severe to require amputation should be treated, if possible, by disarticulation of the metacarpophalangeal joint. If this does

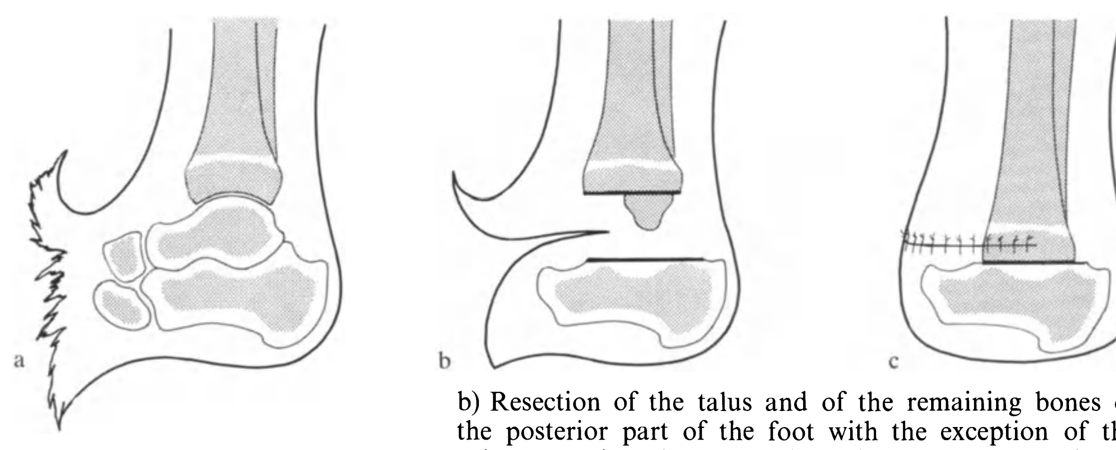


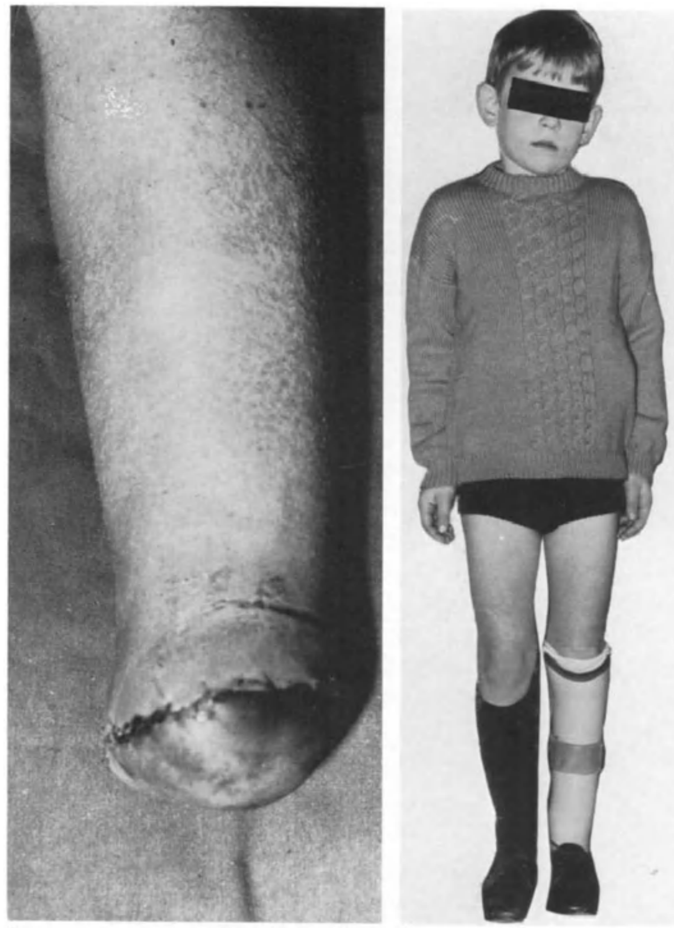
Fig. 5a–c. *Boyd amputation technique*. Crush injuries to the foot and mid-foot which have left the heel intact are treated by amputation using the *Boyd* technique.
a) The fresh injury.
b) Resection of the talus and of the remaining bones of the posterior part of the foot with the exception of the calcaneus. The calcaneus and the distal tibial epiphysis are freshened without injuring the epiphyseal plate of the distal tibia.
c) Arthrodesis by adaptation of the tibia and calcaneus is followed by loose suturing of the skin

not allow satisfactory skin coverage, transmetatarsal amputation is carried out. Since the epiphyseal plates of the first, second, third, and fourth metatarsals are situated at the distal ends of the bones, the resulting metatarsal stump will become relatively short as growth progresses.

4.5 Complications in the Posterior Part of the Foot

If severe injury to the midpart of the foot makes amputation necessary, we recommend the *Boyd* technique (Fig. 5). The talus is resected and tibiocalcaneal arthrodesis is performed. Thus, the patient continues to walk on his heel and the resulting stump bears weight well. A shoe insert with a raised heel and metal sole is necessary. A below-knee stump should always be made as long as possible. The *Syme* stump is better than that which results from below-knee amputation of the lower leg and allows the patient to walk around in the home without a prosthesis. The skin incision

Fig. 6a, b. *Syme amputation.* Z.A., ♂, aged 7 years, No. 144699.
a) A hay loader caused this traumatic amputation of the foot distal to the navicular bone. The skin of the sole of the foot is intact only as far as the calcaneus.
b) Treatment by *Syme* amputation with disarticulation of the ankle joint and retention of the tibial epiphysis. The fibular epiphysis was removed. The skin was closed with loose sutures



a b

Fig. 7a, b. *Syme amputation and the corresponding prosthesis.* Z.A., ♂, aged 7 years, No. 144699 (same patient as in Fig. 6).
a) Condition of the stump 14 days after amputation.
b) 4 months after amputation. The boy, who is wearing the Canadian *Syme* prosthesis with a plastic shell and a SACH foot, can walk with no limp whatsoever and is symptom-free

is the same as that in an adult and the heel flap is dissected away from the calcaneus subperiosteally. Instead of cutting through the tibia and fibula at the metaphyseal level, as in the adult, the ankle joint of the child is disarticulated. The malleoli are cut off level with and parallel to the distal tibial joint surface. This step involves sacrifice of the distal fibular epiphysis and epiphyseal plate. Because the tibial epiphysis is retained, the tibial stump continues to grow distally and does not undergo relatively shortening (Fig. 6). Many surgeons are not aware of this important difference between the operative procedure in a child and that in an adult and prefer not to use the *Syme* technique because of the shortening which follows transosseus amputation at the metaphyseal level.

The aesthetic appearance of the *Syme* prosthesis has been improved considerably by the introduction of a thin-walled plastic shell and the SACH-foot (SACH = solid ankle cushion heel) (Fig. 7).

4.6 Amputations at the Knee

Amputation of the distal femoral epiphysis, especially if carried out in a young child, results in severe progressive shortening of the thigh stump as the child grows. For this reason, disarticulation should be carried out at the knee joint whenever possible. The stump created by this procedure provides a good seat for a prosthesis, both in adults and in children. The anterior skin flap should include the tough infrapatellar skin, i.e., it should be $1^1/_2$–2 in longer than the posterior flap.

The various transosseus amputation procedures, which may be indicated under certain circumstances, are carried out in the same manner as in adults.

5 Summary

If amputation is necessary for the treatment of an injury in a child, the stump should be kept as long as possible and the epiphyses should be retained whenever practicable. Disarticulation is therefore to be preferred to amputation at the diaphyseal level. As in the adult, preparation of the stump involves appropriate myoplasty. In the child, however, a split thickness graft suffices for initial skin coverage; it may turn out to be permanent, and anyway provides immediate stump coverage, thus allowing definitive coverage by an appropriate plastic surgical procedure at a later date. Fitting and maintenance of the prosthesis is best entrusted to an orthotist who is experienced in dealing with children.

6 References

Aitken, G. T.: Surgical Amputation in Children. J. Bone Surg. **45A,** 1735 (1963).

Boyd, H.B.: Amputation of the foot with calcaneotibial arthrodesis. J. Bone Surg. **21,** 997 (1939).

Frantz, C., Aitken, G. T.: The Juvenile Amputee. J. Bone Surg. **46A,** 1376 (1964).

Lambert, C.: Amputation of the Lower Extremity. Surg. Clin. N. Amer. **45,** Nr. 1, Februar 1965.

Lambert, C.: Personal Discussion.

Summary

B.G. WEBER

The purpose of our book is to provide the reader with *basic information* and to impress upon him that a fracture of the growing skeleton is not the same as a fracture in an adult. No *textbook of orthopedic surgery* can replace *clinical training*. The only way to gain *experience* is to witness success and failure in the course of one's *undergraduate* and *postgraduate training* and in *clinical practice*. I feel it is appropriate to end this book with a summary of the *pathophysiology of fractures in children and its practical consequences*.

Special features of fractures in children and adolescents	Practical consequences for treatment
Rapid formation of a large amount of callus, i.e., fixation of the fracture within a few days.	It is especially important that the initial reduction and fixation be carried out correctly, since subsequent readjustment of the fracture is often impossible.
Within certain limits, angular misalignment is corrected by subsequent circumferential growth.	Even quite severe malunion in a small child is of little consequence. In an adolescent, however, the slightest degree of angular misalignment is unacceptable.
Tilting of an epiphyseal plate (angulation or residual dislocation following separation) is corrected in the course of subsequent longitudinal growth.	Corrective longitudinal growth may be expected in a small child, but is unlikely to occur in an adolescent. In the latter case, therefore, perfect reduction should be aimed for.
Many diaphyseal fractures are followed by excessive longitudinal growth.	Diaphyseal fractures in growing children should be allowed to unite with slight shortening; in an adolescent, however, shortening should be avoided.
Malrotation, unlike axial misalignment, is permanent.	Malrotation should be completely eliminated prior to union of a diaphyseal fracture.
True epiphyseal fractures cause steps in the joint surface and partial epiphyseal fusion. The results are articular incongruence, skew growth, and shortening.	Anatomically precise, open reduction of the fracture with total elimination of the gap in the epiphyseal plate and restoration of congruity to the joint surface is an essential prerequisite of complete recovery.
Prolonged immobilization of fractures in children has no permanent adverse effect.	Nonoperative treatment does not cause positive harm. Internal fixation should not be carried out simply to prevent immobilization.
A child is less sensitive to pain than an adult. The pain caused by an injury subsides within a few hours.	Pressure damage caused by a circular cast should be prevented by careful application of the cast and adequate padding at strategic points.
Persistent pain following a fracture in a child always has a specific cause.	Damage to nerve and vessels should be excluded by repeated, thorough examination. Concomitant neurovascular injury is not uncommon and usually requires immediate operative treatment.

Subject Index