Treatment of Fractures in Children and Adolescents

Edited by

B.G. Weber · Ch. Brunner · F. Freuler

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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.

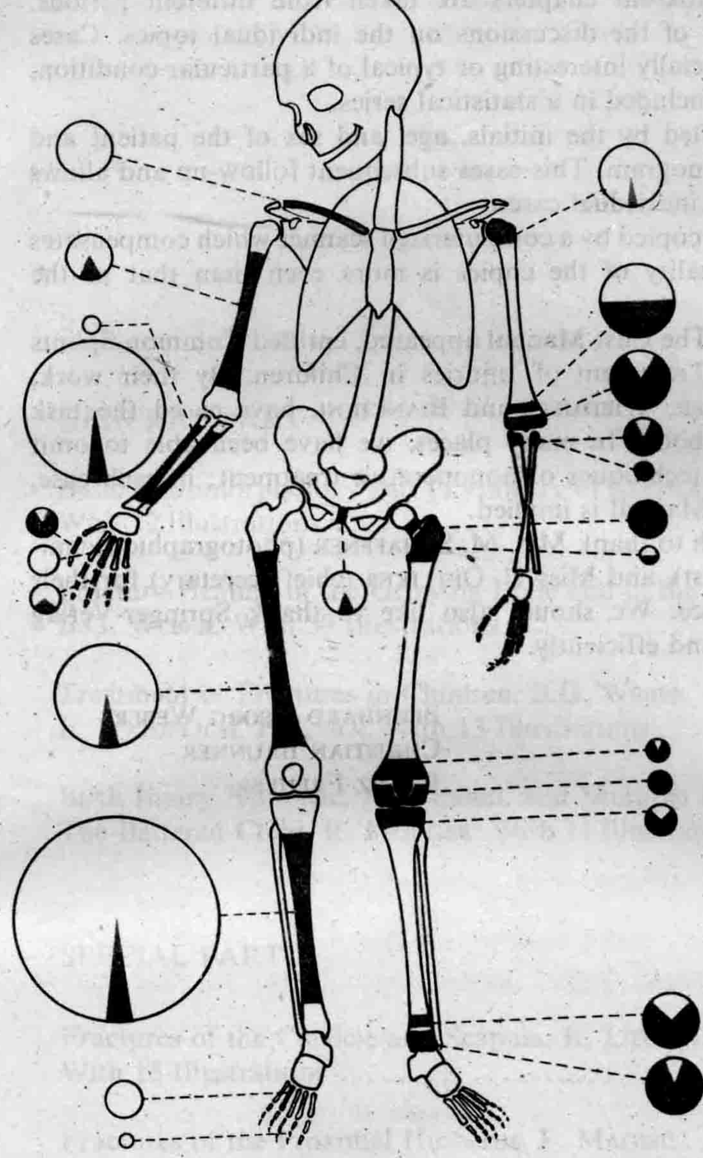

Fig. 1. *Operative indications according to fracture localization.* The size of the circle shows the frequency of each type of fracture, the size of the dark segment the relative frequency of the operative treatment

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

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SPECIAL PART

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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. 1 a). 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,

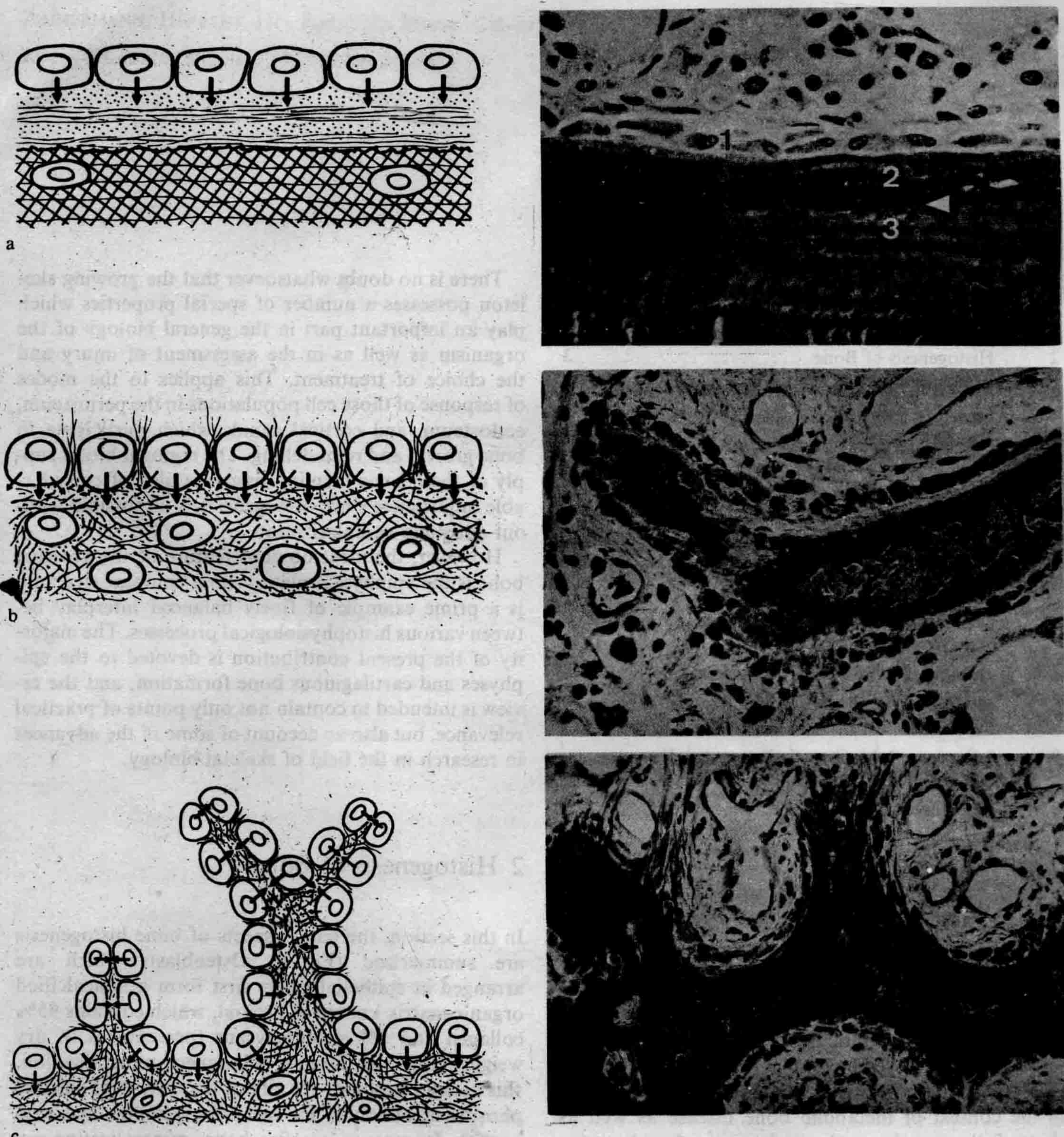


Fig. 1 a–c. *Histogenesis of bone tissue*. Nondecalcified microtome sections stained by the Goldner method, with explanatory diagrams.
a) Area of apposition in lamellar bone seen in an iliac crest biopsy. (*1*) osteoblasts; (*2*) osteoid; (*3*) mineralized bone. *Arrow* indicates mineralization front. 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. 1 b).

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. 1 c). 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. 1 a). 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. 1 b), 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.

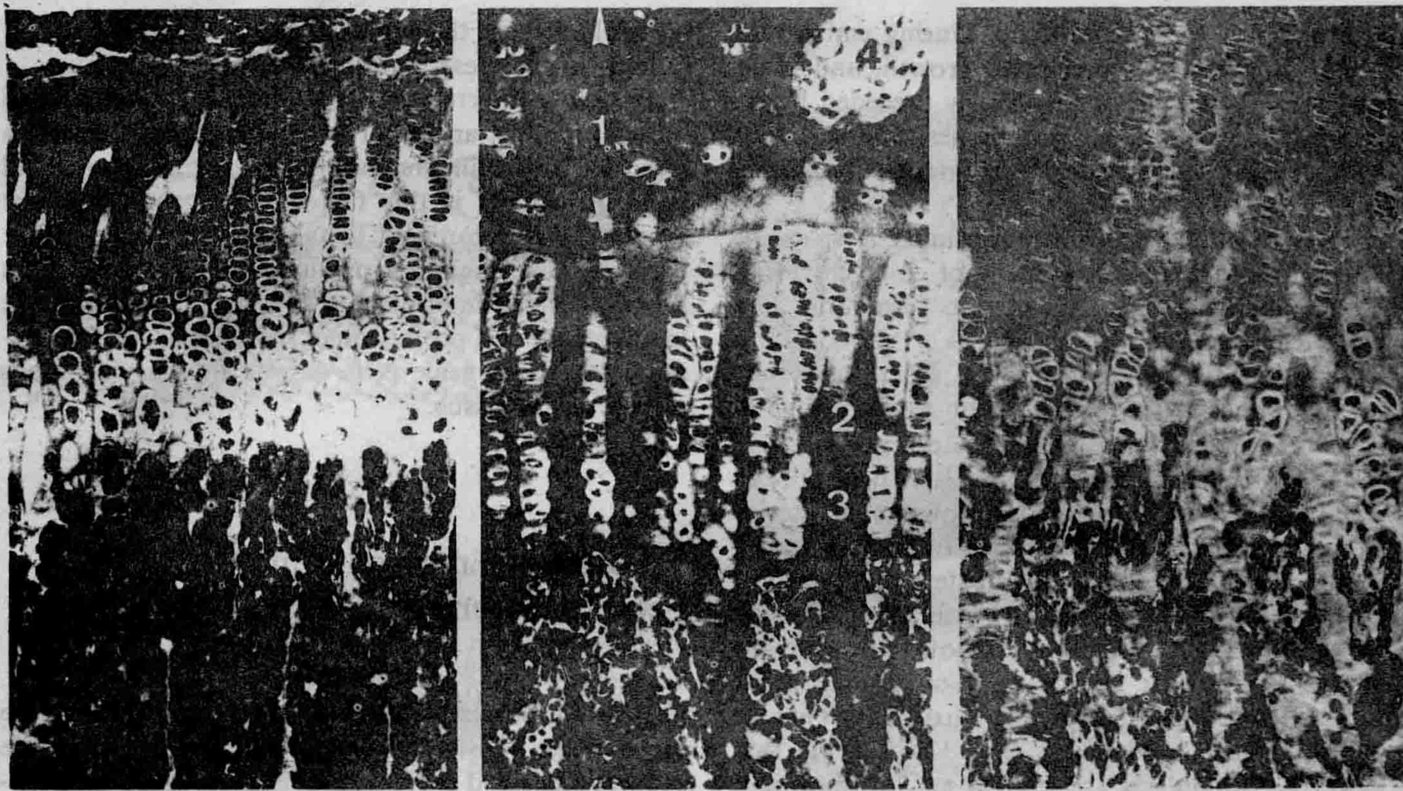
In order to understand bone formation, the reader should be aware of the decisive importance of the very close relationship between the osteoblasts and a functionally adequate capillary network. In the German literature, knowledge of this factor is primarily ascribable to the concept of "primary angiogenic 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