Management of Fractures in Children

*John E. Handelsman, M.D., M.Ch.Orth., F.R.C.S.**

Children's fractures deserve special consideration: they are not just broken bones in small adults. Some of the special features are well known. The periosteum is thick and strong and frequently acts as a convenient hinge in reduction. Healing is rapid, and the incidence of nonunion is rare. There are also significant difficulties and dangers. When a bony epiphysis has not yet appeared, as at the elbow, there may be a real diagnostic problem. Remodeling and molding of a child's fracture is better than in an adult, but not in all planes and locations. Children have open growth plates, and fractures that involve the epiphyseal areas may result in growth disturbances and deformities. In this article, no attempt will be made to describe every fracture that may occur in a child; rather, the anatomic, biomechanical, and physiologic features will be discussed, and illustrative and important examples highlighted.

ANATOMIC FEATURES

There are varying amounts of radiolucent growth and epiphyseal cartilage in a child's skeleton. At times, the presence of a fracture may only be inferred from displacement of adjacent bones or relative widening of the growth plate. Comparative x-ray films on both sides are usually essential, and stress radiographs are often helpful.

A young child's thick periosteum is strong and quickly produces an extensive callus.

BIOMECHANICAL FEATURES

Bone

The osteoid of a child's bone is no less calcified than that of an adult, but the density is less because young bone is more porous, as the haversian canals occupy a relatively greater part of the bone. For this reason, children's bones deform more easily and the extension of a fracture line

*Professor of Orthopaedic Surgery, Brown University; Director, Division of Pediatric Orthopaedic Surgery, Rhode Island Hospital, Providence, Rhode Island

tends to be delayed by the holes of the porosity. Although compact adult bone fails in tension only, the more porous child's bone may fail in compression as well.

This porosity permits the occurrence of fractures specific to childhood.

Buckle Fracture. These are produced by compression failure of bone. Also called a torus fracture, they occur near the metaphysis, where porosity is greatest and can be recognized by a ringlike elevation of the cortex circumferentially, with virtually no displacement (Fig. 1). These fractures occur usually in younger children.

Greenstick Fracture. Angulation of a bone beyond the limits of bending causes failure of the tension site of the bone and bending on the compression side. Greenstick fractures are only slightly angulated but may well tend to angle further because displacement during the fracture was probably considerable, before elastic recoil reconstituted a more anatomic position.

Figure 1. A buckle or torus fracture of the distal radial shaft in a young child. The bone fails in compression and produces a ringlike elevation of the cortex circumferentially.

Spicules on the tension side may jam and prevent complete correction, and for that reason, overcorrection of the deformity is usually needed during treatment.

Bone Bending. This usually occurs in the fibula and ulna. There is evidence that a child's forearm bone may bend 45° before a greenstick fracture is created. If no fracture is caused, elastic recoil will gradually straighten the bone, but does so incompletely.[3,8]

Growth Cartilage and the Epiphysis

The epiphysis and metaphysis are firmly connected internally by mammillary processes and, more significantly, externally by the periosteum. Joint capsules are stronger than both, however, and in a child, epiphyseal separation almost always occurs before a dislocation. Violence producing epiphyseal separation in children, however, is frequently of the same character as that producing dislocations in adults.[24]

Growth cartilage also has a degree of elasticity that allows for compression and some widening within the confines of the perichondrium.[6] This capability protects both bone and the adjacent joint surface from crushing injuries.

Separation of the epiphyseal plate occurs most easily when torsional forces are applied and least easily with traction.[5]

Periosteum

The thicker, stronger periosteum in a child is less readily torn than in an adult. When intact, this lessens displacement. An intact periosteal hinge provides stability in reduction and when used correctly helps achieve that reduction.

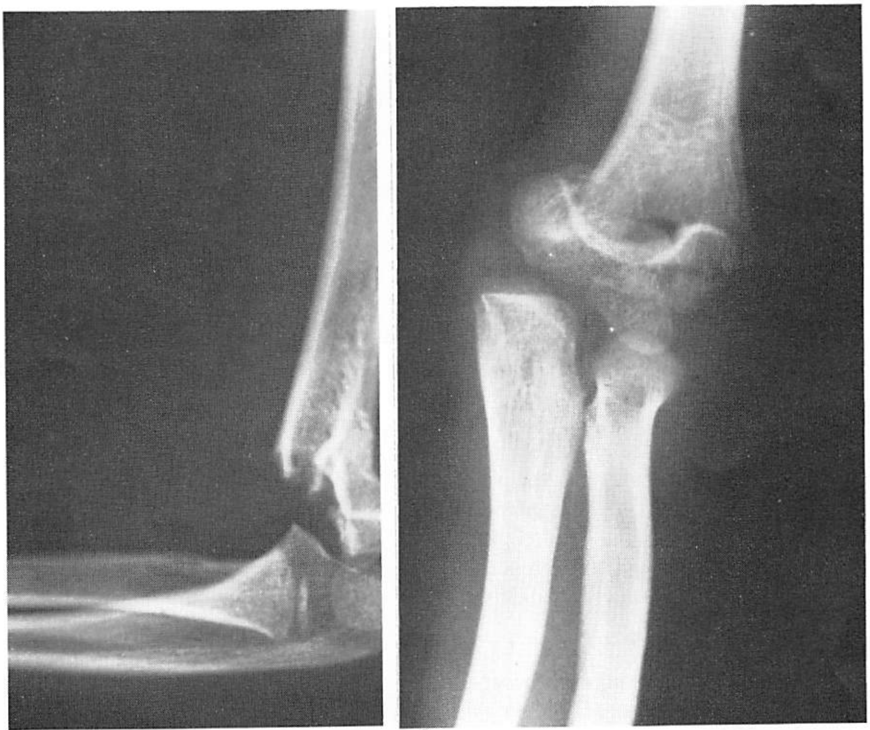
PHYSIOLOGIC FEATURES

Remodeling

The younger the patient, the greater is the potential for remodeling. A fracture of long bones, such as the humerus or femur, which joins in an angled position, will improve in appearance by layers of periosteal new bone forming in the concavity of the angulation and osteoclastic reduction of the angular outer cortex. In addition, a true reduction of the original angulation occurs with growth. As the bone increases in girth and length, any irregularities are further diminished, but also a nearby growth plate tends to become realigned,[26] presumably in response to the lines of stress.

However, remodeling is by no means predictable and will not correct (1) rotation, (2) angulation at right angles to the plane of movement of a joint, (3) fractures crossing a growth plate, (4) displaced intra-articular fractures, (5) significant shortening, and (6) significant angulation in the middle of the shaft of a bone.

Remodeling can be expected to occur when (1) the fracture is close to the growing epiphysis, (2) the angulation is in the plane of movement of the nearby joint, and (3) the growth plates are not expected to close in under two years.



A B

Figure 2. *A*, A recently healed supracondylar fracture of the humerus is shown. Besides the posterior displacement and angulation, the width of the proximal and distal fragments is different, indicating a rotary deformity. The anteroposterior view (*B*) reveals medial shift of the distal fragment, and a medial angulation, a combination invariably associated with a rotary deformity.

The degree of remodeling that may occur is highly significant in the management of several fractures in the upper limbs. An example is the supracondylar fracture of the distal humerus. It is common practice to accept some posterior tilt of the distal fragment (Fig. 2*A*). Frequently, however, a rotatory deformity is also present, as demonstrated by the difference in widths of the shaft of the proximal and distal fragments and the associated element of lateral or medial angulation (Fig. 2*B*). A combination of remodeling and growth will permit the ultimate return of full flexion and extension, for even if there is a bony block to flexion by the end of the proximal fragment, this will move away from the joint area as the bone elongates. The rotatory deformity may be compensated for by the ball and socket effect of the shoulder joint, but the angulation at right angles to the joint that is concomitant with the rotatory deformity never alters, and the carrying angle will be permanently abnormal (Fig. 3).

Accurate rotatory reduction in fractures of both bones of the forearm is very important. Remodeling may correct angulation and produce striking

Figure 3. A year after the supracondylar fracture seen in Figure 2, the patient had regained full flexion of the affected right arm (*A*), but extension revealed a marked varus deformity that will be permanent (*B*). He required an osteotomy to correct the deformity.

radiographic correction, but the range of pronation and supination will be permanently impaired.

Fractures at the distal end of the radius and ulna usually angle in the plane of wrist motion. There is perhaps more leeway for remodeling in this situation, but bear in mind that deformity at the wrist, because the bones are subcutaneous, is extremely obvious, and it is painful both for the parents and the surgeon to await correction. Furthermore, accepting minor angulation after reduction may permit further displacement in the cast, and for these reasons, the aim should be an accurate initial reduction. After ten to 14 days, however, attempts at reduction of these fractures may produce harmful heterotopic ossification, and they are then best left alone.

Overlap of long bones other than those of the forearm will become less obvious with passage of time, and in certain circumstances, such as in the shaft of the femur, some overlap may in fact be desirable (see overgrowth). Remodeling will take care of irregularity as long as the alignment is good and the rotation correct (Fig. 4).

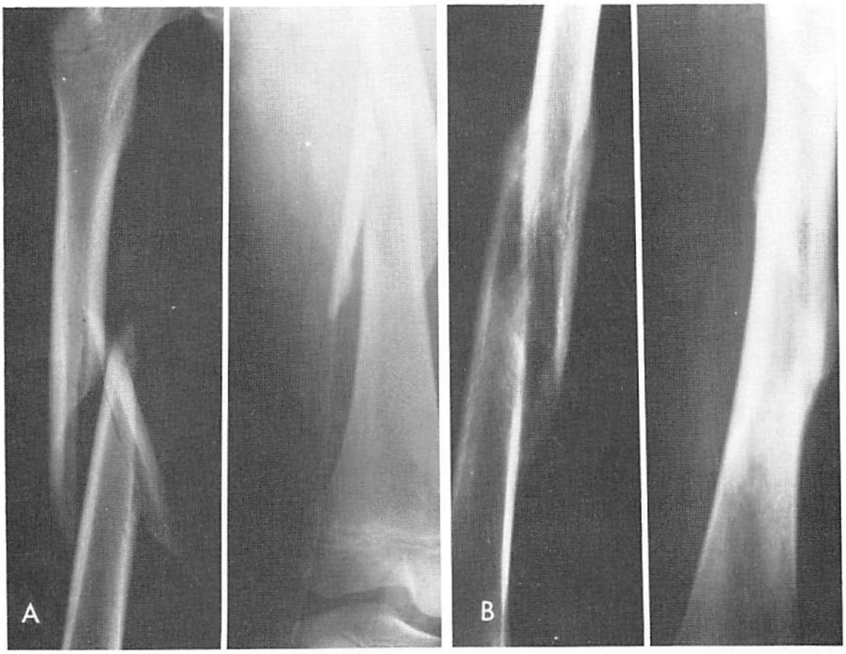


Figure 4. A spiral fracture of the shaft of the femur with a separate butterfly fragment. This fracture was treated by traction with the limb resting on a Thomas splint and eight weeks later had united in good alignment (*B*). Molding has already removed many of the bony irregularities.

Overgrowth

The hyperemia associated with healing stimulates the growing epiphyses, and a fractured long bone will overgrow in the course of a year or so. Thus, a fracture in the midshaft of the femur reduced end on, may result in a 1 cm and occasionally as much as a 2 cm overgrowth. For this reason, some surgeons deliberately overlap a fracture of the shaft of the femur. The overgrowth, however, is not sufficient to support this practice. An end-to-end reduction has the advantage of stability and cannot overshorten. Treat the fracture on its merits. The ultimate difference in adulthood is insufficient for overgrowth to be a factor in the management of such a fracture.

Other Special Features

Comminution is unusual in children's fractures. The increased flexibility of their bones tends to dissipate fracturing forces. Speed of healing is quicker, especially near growth plates. Thus, treat expeditiously and do not overimmobilize.

Nonunion is rare unless there is gross interposition of soft tissue or unless an intraarticular epiphyseal fracture is widely separated and displaced. (See lateral epicondylar fracture of humerus.)

Progressive Deformity

The presence of an active growth plate and epiphysis accounts for the fundamental difference between fractures in children and adults at the ends of long bones. Permanent damage may cause progressive shortening, angulation, and joint deformity. This important area will now be discussed.

EPIPHYSEAL AND GROWTH PLATE INJURIES

Anatomy of the Epiphysis

A bony center, the epiphyseal nucleus, appears at varying times within different cartilage epiphyses. This expands centrifugally, so that cartilage is replaced by bone. The process ceases in the area of the growth plate and at the periphery where cartilage cells remain to form articular cartilage and adjacent surface cartilage. The epiphyses at the ends of long bones involved with longitudinal growth are all articular and are termed "pressure epiphyses." Those that form in relation to major points of tendon attachment are called "traction epiphyses" or "apophyses." The latter usually receive a generous blood supply from muscle attachments, and avascular necrosis is rare. Pressure epiphyses, on the other hand, depend on nutrition from joint fluid externally and penetrating blood vessels internally. Those that are totally intraarticular, such as the head of the femur and the head of the radius, are particularly sensitive to any interference with blood supply. The epiphysis in the head of the femur is especially at risk. Relatively small amounts of fluid in the hip joint, be this blood, pus, or a simple irritative effusion, may produce enough pressure to compromise blood flow, damaging the epiphysis and sometimes the adjoining growth plate.

Epiphyseal Fractures

Fractures through the epiphysis usually involve the growth plate. Occasionally, however, isolated fractures do occur.

Avulsion Injuries. These are seen at the sites of ligamentous attachments. Examples are avulsions of the base of the phalanx after a hyperextension injury to the finger, the ulnar styloid, and the tibial spine. The last is a significant fracture; it follows a knee injury that stretches the anterior cruciate. This is more likely to avulse the tibial spine than to disrupt the ligament (Fig. 5). The avulsed fragment is vascularized by the tendon attachment, but if displacement persists, union may occur by fibrous tissue. The anterior cruciate ligament may then be functionally too long, and the displaced fragment may block full extension. For these reasons, these fractures must be accurately reduced. Closed manipulation by hyperextension of the knee may achieve this, but when there is doubt, an open operation and internal fixation is preferable.

Osteochondral Fractures. An angulation injury in a joint may skive off articular cartilage and underlying bony epiphysis. This commonly occurs in the distal femur and tibia, and sometimes a corner of the patella and the head of the radius may be involved (Fig. 6). Unless completely undisplaced, osteochondral fractures require open surgery. If the fragment is small, it

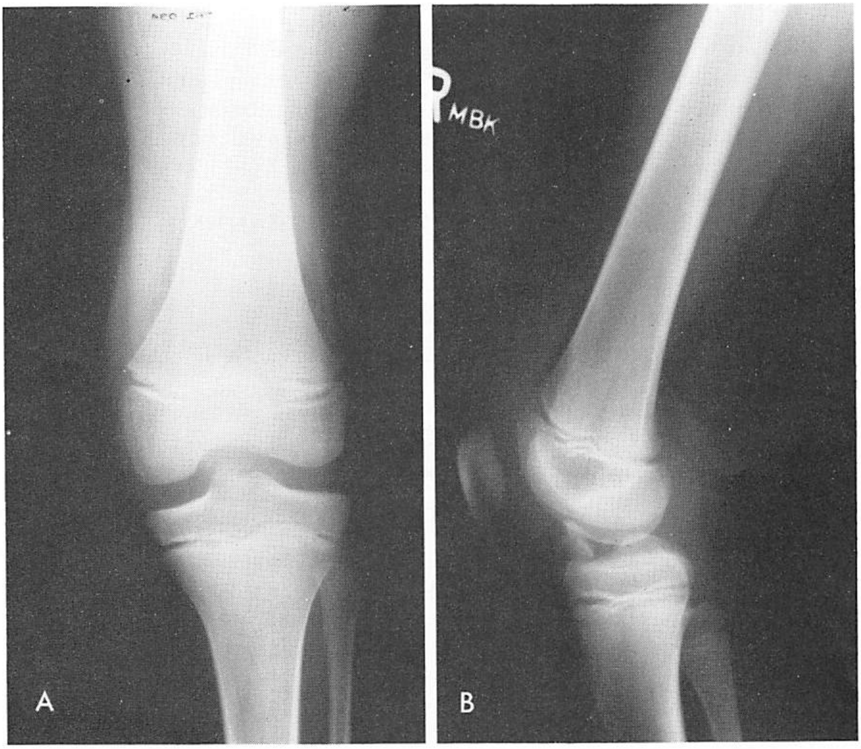
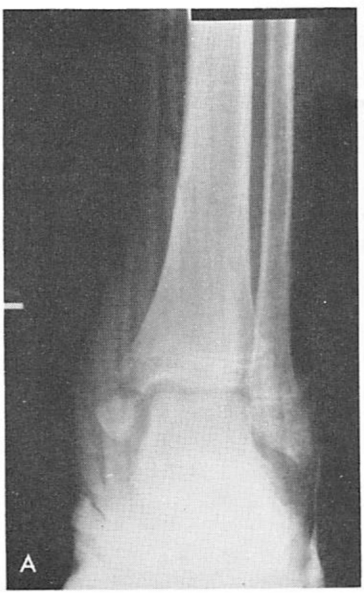


Figure 5. Avulsion of the tibial spine after an injury that stretched the anterior cruciate ligament. The AP view (*A*) shows only a hazy shadow, but the lateral projection (*B*) reveals that the spine has been pulled forward and rotated out of its bed.



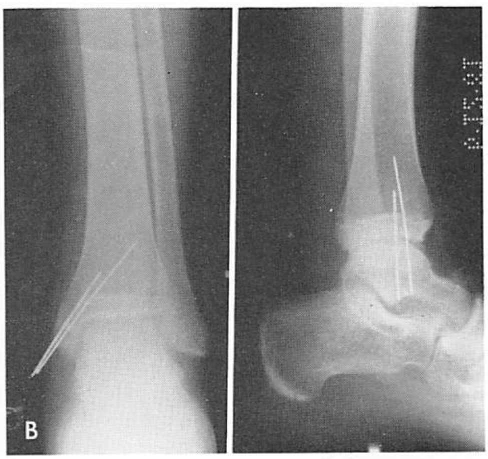


Figure 6. An avulsion fracture of the medial malleolus (*A*). This involves the articular surface, but not the growth plate. This was accurately apposed and held reduced by Kirschner wires (*B*) to maintain the integrity of the articular surface.

must be removed, or it will form a loose body in the joint. If it is large and significantly displaced, it should be pinned back in situ.

Compression Fractures. Compression damage to the epiphysis is rare because of the resilience of the growth plate that absorbs vertical forces.[6] In the older child whose growth is near the end, and in situations of disuse osteoporosis, these fractures are occasionally seen, particularly in the tibial plateau.

Anatomy of the Growth Plate

The growth plate is an organ concerned primarily with longitudinal growth and is composed principally of cartilage, divided functionally into various zones. It lies between the bony nucleus of the epiphysis and the metaphysis. The latter forms part of the growth plate from the functional viewpoint. The cartilaginous portion is surrounded by a fibrous band, the perichondrial ring of LaCroix. The growth plate receives its blood supply from three vascular groups. The epiphyseal vessels penetrate the secondary bony epiphysis and send branches to the cartilaginous portion of the growth plate. Metaphyseal vessels invade the opposite surface and are concerned with the replacement of cartilage by bone. The fibrous perichondrium is supplied by the perichondrial arteriole.

The cartilage cells of the growth plate are more or less aligned in columns and undergo specific changes towards the metaphyseal side (Fig. 7). Close to the epiphysis, the cells appear to be resting (reserve zone). As one approaches the metaphysis, they initially proliferate (proliferative zone), hypertrophy, and degenerate (the hypertrophic zone, consisting of the zones of maturation, degeneration, and provisional calcification). Linear growth occurs largely in the proliferative zone, because of cell proliferation and also matrix production. In the bottom of the hypertrophic zone, the oxygen tension is very low, and glycogen has been depleted. Because there

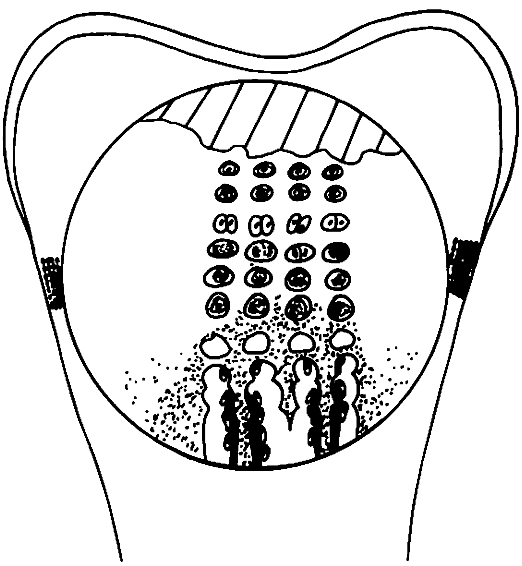


Figure 7. A diagrammatic representation of the growth plate illustrating from above down, the reserve zone, the proliferative zone where mitosis can be seen, followed by the hypertrophic zone where the cells mature and degenerate. Provisional calcification occurs in this area. On the metaphyseal side of the plate, the vascular invasion is depicted. Fractures occur through the junction of the calcified and uncalcified matrix, thus preserving the germinal cell on the one side and the vascular loops of the metaphysis on the other.

is no source of energy for the mitochondria to retain calcium, this is released to form the zone of provisional calcification. Loops of metaphyseal vessels grow towards this region and lay down bone on this cartilaginous matrix, thus forming the edge of the metaphysis.

Fracture of the epiphysis almost always occurs through the junction of calcified and uncalcified cartilage where matrix has been depleted by the vascular ingrowth. Thus, most of the growth plate, and in particular the important germinal part, remains with the epiphysis. Since the plane of separation is distal to the loops of metaphyseal vessels, bleeding is not a feature of these fractures.

Fractures of the Growth Plate

Approximately one third of fractures in children involve the growth plate. These are highly significant because of their potential for deformity, shortening, and joint incongruity. Fortunately, the majority of fractures in the area of the cartilaginous growth plate heal rapidly and without unpleasant sequelae.

The gap is filled by fibrin, and initially the plate will appear wider on x-ray film because cartilage cells continue to proliferate without the metaphyseal new bone being deposited. Within two weeks, however, vessels again invade the zone of provisional calcification, and the plate narrows to its usual width. At this stage, healing has occurred, and no signs of the injury remain.

Growth may be disturbed by any of the following: (1) formation of a bridge of callus between the bony epiphysis and the metaphysis, either around or through the growth plate, (2) a crushing injury to the growth plate, (3) regional hyperemia producing local overgrowth, and (4) nonunion.

An understanding of the various types of growth plate injuries is necessary for their proper management.

Classification of Growth Plate Injuries

In 1898, Poland[24] first described various fracture separations and this was modified by Aitken and Magill in 1952.[1] The classification of Salter and Harris, described in 1963,[29] is lucid and in common usage. They describe five types.

Type I. The fracture completely separates epiphysis from metaphysis (Figs. 8 and 9). If the periosteum is intact, there is no displacement, and the x-ray film may be normal or present with very slight widening of the plate. Clinically, these injuries may resemble a sprain, but there is local tenderness over the growth plate and soft tissue swelling. Torn periosteum on one side may allow considerable displacement but easy reduction without crepitus because the fracture surfaces are both cartilaginous. Type I injuries are usually the result of torsion, avulsion, or shearing forces. Pathologic fractures are seen in scurvy, rickets, particularly renal rickets, and other conditions of hormonal imbalance.

Type I fractures heal rapidly and usually without complications. However, there may be an element of crushing in any epiphyseal injury that may alter the prognosis. Avascular necrosis may occur in the nearby epiphysis, particularly in the head of the femur. Nonunion may occasionally complicate a traction injury, such as the medial humeral epicondyle.

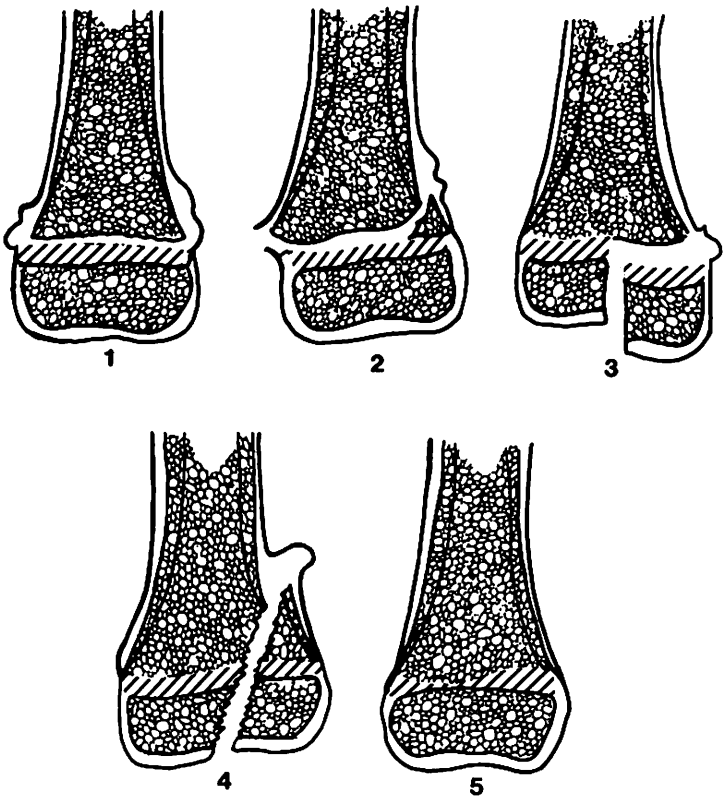


Figure 8. The Salter and Harris classification of growth plate injuries.

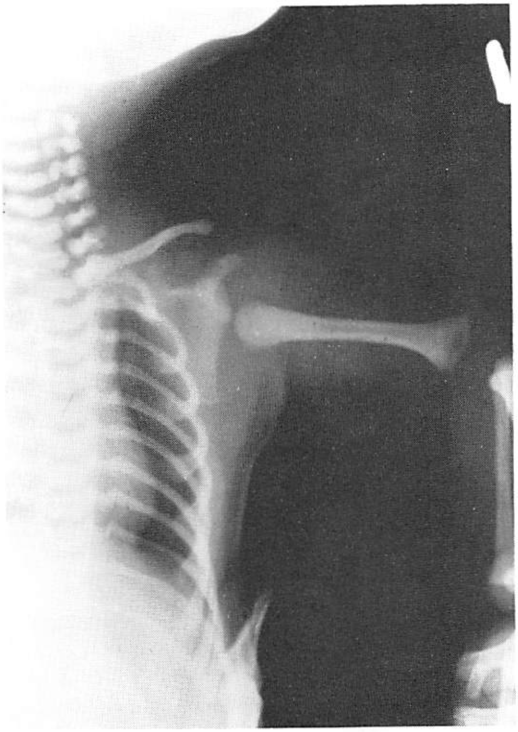


Figure 9. Type I fracture of the growth plate. The head of the humerus is all cartilaginous and does not show in this film, so that at first glance, the injury appears to be a dislocation of the shoulder. In fact, the cartilaginous epiphysis is normally situated within the glenoid, and there has been complete separation of epiphysis proximally and shaft distally through the growth plate fracture. Periosteum is intact superiorly.

Figure 10. Type II fracture of the growth plate. The head of the radius has slipped off the metaphysis laterally and has rotated through 75°. The metaphyseal fragment that delineates the type II fracture can be seen attached to the growth plate and the epiphysis.

Type II. This fracture separation is essentially similar to type I. The main injury takes place through a nongerminal layer of the growth plate, but because there is a lateral displacement force, the periosteum on one side is always torn and a small triangular metaphyseal fragment is broken off on the opposite side as the fracture opens (Figs. 8 and 10). These fractures reduce easily and are stable because of the intact periosteum and the bony fragment on one side. Occasionally, the metaphyseal fragment may pierce the periosteum and impair reduction. As in the type I injury, healing is rapid and usually uncomplicated. Occasionally, a crushing element may alter the prognosis dramatically, particularly in a type II fracture of the distal femur, when considerable forces are involved. Parents must be warned that femoral shortening, angulation, or both may occur (Fig. 11).

Type III. This fracture transgresses both growth plate and joint cartilage at a right angle and therefore carries a much more guarded prognosis and demands anatomic reduction. The plane of separation passes initially along the growth plate as in the type I and II injuries, then continues vertically downward across the growth plate and into the joint (Figs. 8 and 12). Accurate reduction will prevent articular malalignment and a bony bridge forming in the growth plate that will disturb longitudinal growth. Open reduction is usually needed.

Type IV. This fracture is effectively similar to the type III in that it transgresses the joint surface and growth plate, but because the line of injury usually commences at the joint surface, it runs vertically up into the metaphysis (see Fig. 8). If allowed to heal with displacement, there will be not only joint incongruity but also contact of bone of the epiphyseal ossific nucleus and the metaphysis. A bony bridge will form across the growth plate, producing a major growth disturbance.[31] This fracture demands accurate reduction, almost inevitably by open reduction and internal fixation. The aim is perfect alignment of the articular surface and an anatomic reduction of the growth plate. The commonest example of this fracture is that of the lateral condyle of the humerus (Fig. 13).

Type IV injuries may vary. The usual fracture has been described (Fig. 14 [1]). In the less mature child, however, the fracture line may skirt the bony epiphysis and pass entirely through contiguous cartilage from the joint surface to the growth plate (Fig. 14 [2]). Here the risk of bony bridging is less. The third variety is a stepped fracture in which there is a vertical element through the articular cartilage and growth plate, a horizontal element through the growth plate itself, and a metaphyseal fragment (Fig. 14 [3]). This fracture, seen usually in the distal tibia as the triplane fracture, is inherently stable and often amenable to closed reduction.

In the very young patient, when the growth plate, epiphysis, and articular surface are contiguous cartilage, a type IV fracture may be missed because cartilage casts no x-ray shadow. Nonunion may result, and separate ossific nuclei form. The two halves grow independently with little distortion. However, when a single fragment is widely separated, such as the lateral capitellum of the humerus, the fragment will grow but with marked deformity.

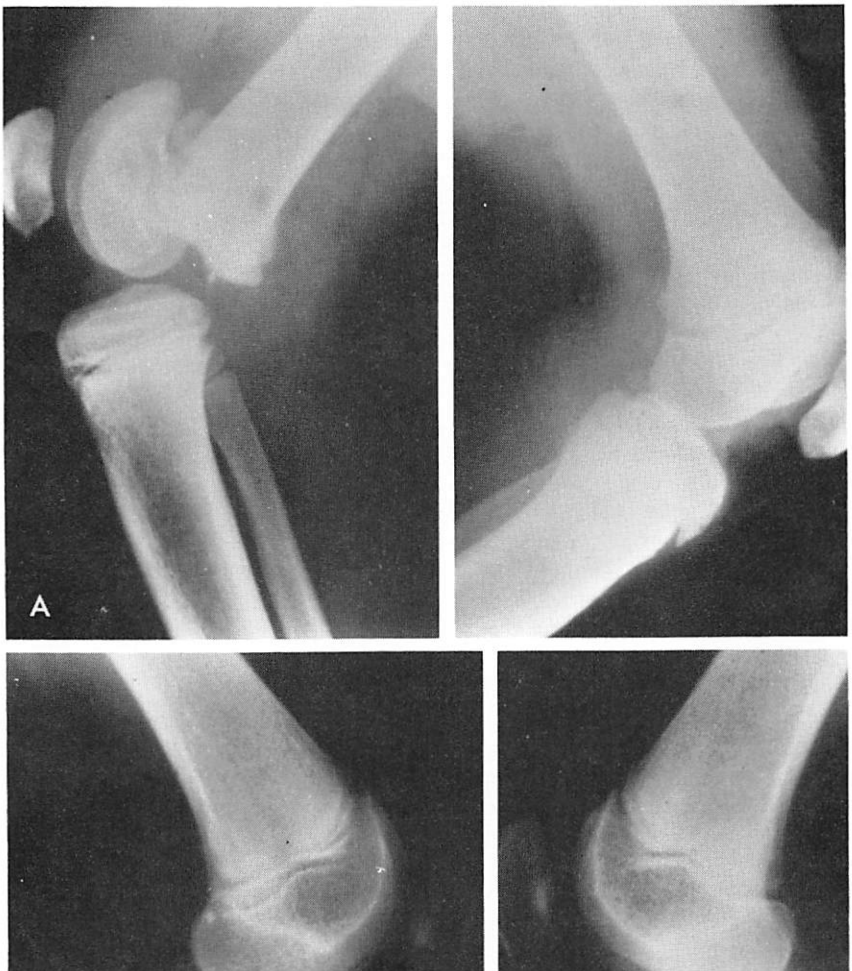


Figure 11. *A*, Type II fracture through the distal growth plate of the patient's right femur. The dorsal displacement shown here endangers the blood supply to the limb, and these fractures require expeditious reduction. This fracture went on to heal rapidly (*B*). However, the forces required to produce this fracture may have crushed part of the growth plate, and growth disturbance may subsequently occur.

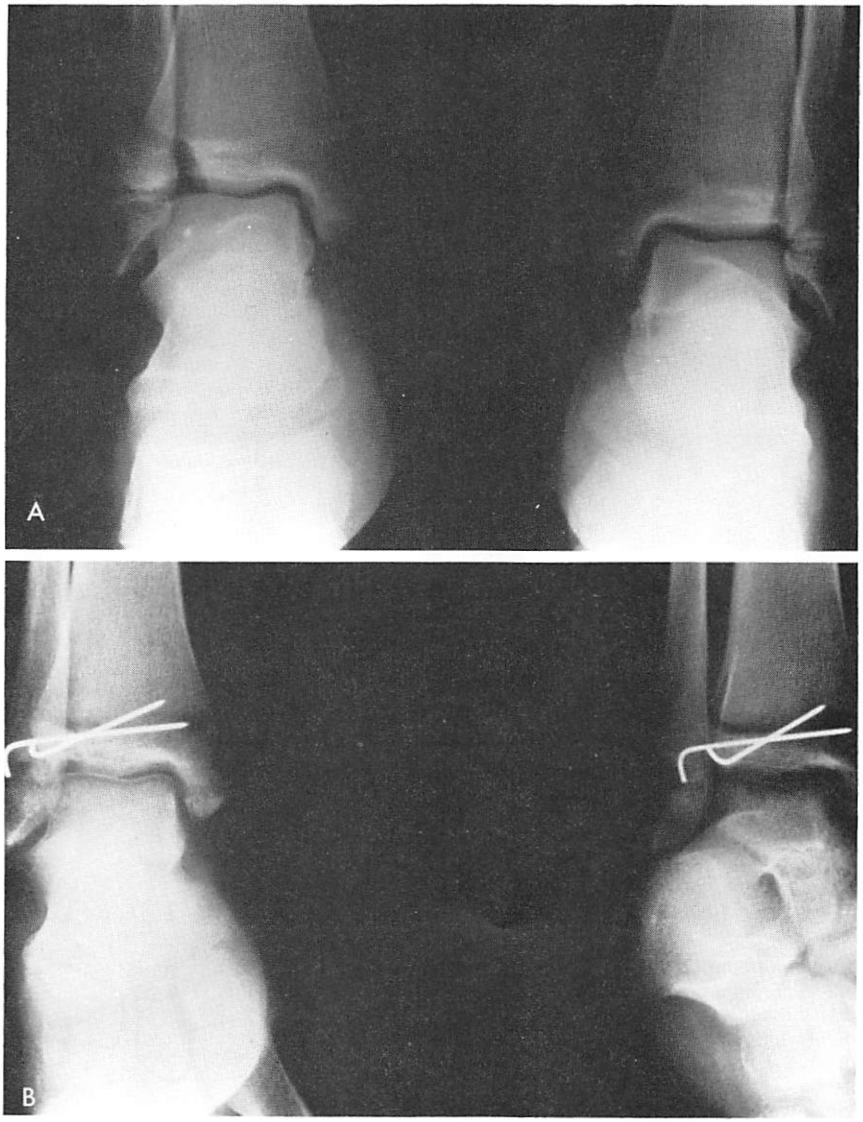


Figure 12. Type III fracture on the distal tibia in an adolescent. The fragment is largely concealed behind this patient's right fibula on the left side of the film. The fracture line passes vertically upwards across the articular cartilage, the epiphysis, and the growth plate and then travels laterally in the same plane as the type I and II fractures. This fracture occurs because the medial two thirds of the growth plate has already closed, while the lateral third is still open. It is known as the Tillaux fracture (*A*). Accurate reduction is obtained by open operation and Kirschner wire fixation (*B*).

Figure 13. Type IV fracture of the lateral humeral condyle. This fracture transgresses the articular cartilage of the growth plate and a portion of the metaphysis. In this example, only the metaphyseal fracture is visible on the film, as none of the ossific nuclei around the elbow has yet appeared. Accurate reduction and suitable fixation are mandatory.

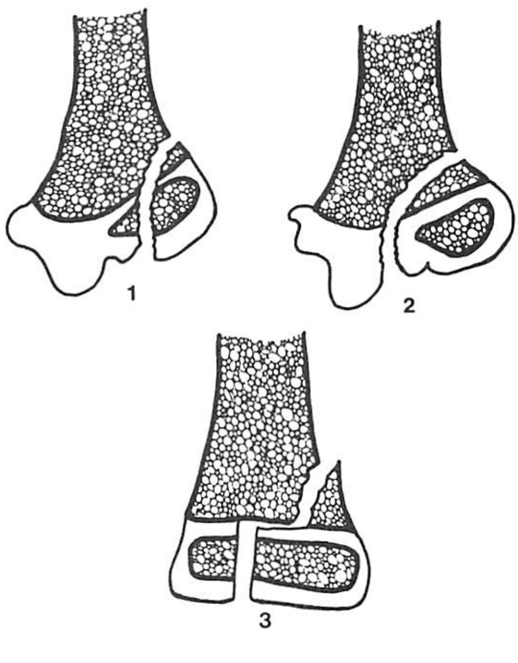


Figure 14. Varations of type IV injuries. The fracture line may transgress a bony epiphysis (1) or skirt the epiphysis and pass entirely through cartilage (2), examples of which are seen in the distal humerus. In the distal tibia, there may be a horizontal element similar to a type III fracture before the metaphyseal fragment breaks off. This triplane fracture is inherently stable (3). (Redrawn after Rang, M.: Children's Fractures. Philadelphia, J. B. Lippincott, 1974.)

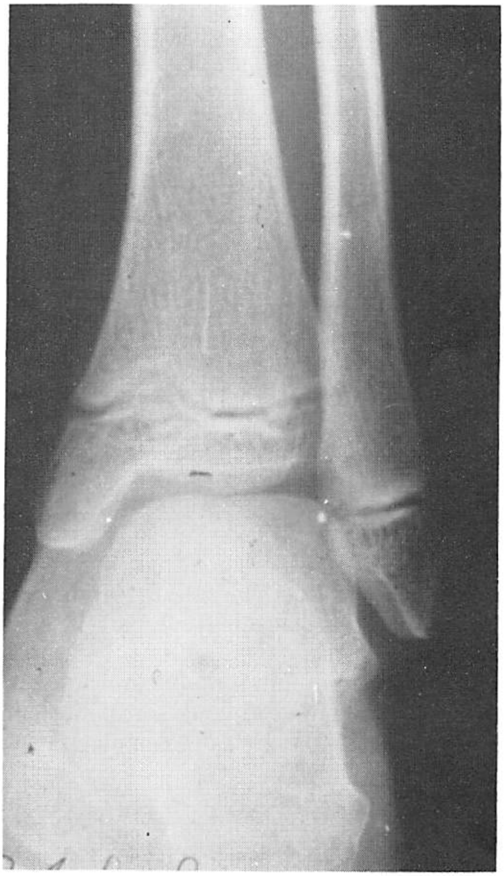


Figure 15. Type V fracture. Six months after an injury to the distal tibia and ankle because of a fall from a height, a portion near the medial edge of the growth plate has become beaked upwards and is thinner than the rest of the plate. The articular surface is beginning to assume a similar contour. The tibia was already 0.5 cm shorter than the opposite side. Crushing of the growth plate was assumed.

Type V. This classification describes the late result of a presumed crushing injury to the growth plate, which initially had a normal x-ray film. With time, there is clinical and radiologic evidence of growth plate distortion, alteration in the shape of the epiphysis, disturbance of linear growth, and possibly angulation (Figs. 8 and 15). Compression of the plate with growth disturbance is thought to have occurred. The validity of this classification has been challenged by Peterson and Burkhart in 1981,[23] and it may well be that bleeding in the region of the plate permits an area of bony bridging.[31] Nevertheless, serious growth disturbance can follow what appear to be relatively trivial injuries at the ends of long bones, and a guarded prognosis for all is wise. All growth plate-related injuries should be observed for a year or more to ensure that there is no angulation, shortening, or joint surface deformity.

Salter-Harris types I and II fractures are usually easy to reduce closed, heal rapidly, and carry a good prognosis unless there is a crushing element. Type III and IV injuries require meticulous reduction, almost always by an open operation with internal fixation. Even then, the prognosis must be guarded. Parents must be warned of the possibility of a type V crushing injury in all situations.

Principles of Management

An accurate diagnosis and classification is important, and as a general rule, comparative views with the uninjured side are most helpful. Oblique views and even arthrography may be necessary. In the young patient with a lot of cartilage at the end of the bone, particularly the distal humerus, it is safer to explore than to ignore. Generally, type I and type II fractures can be treated closed. Perfect reduction is not essential because remodeling will occur. Type III and type IV fractures almost always require open operation. Sutures in the thick periosteum may suffice to hold type III injuries reduced; Kirschner wires for type IV fractures are usually safer. The ends of these should be bent and left just below the skin so that the risk of infection and chondrolytic destruction of the growth plate are avoided.

Perichondrial Ring Injuries

Because the perichondrial ring regulates the diameter of the growth plate, injuries characteristically produce remodeling problems. Rigal[27] has shown that displacement of part of the ring produces an exostosis or osteochondroma.

More important, scraping injuries that remove part of the perichondrial ring permits bony bridging across the outer part of the growth plate that tethers growth on one side. Angulation and some total loss of linear growth are the result.

Treatment of Bony Bridging of the Growth Plate

In 1972, Bright[4] established that it is possible to resect growth plate bony bridges and prevent their recurrence by inserting silicone rubber implants. Since then, other workers[15-18] have used fat instead of silicone rubber with equal success. These techniques are important new steps in the surgical management of these injuries and can prevent deformity of the joint and the need for multiple corrective osteotomies for angulation and limb equalization surgery for shortening.

SOFT TISSUE INJURIES

A discussion of damage to skin, muscle, and the central and peripheral nervous system is beyond the scope of this article. However, vascular damage is so intimately related to supracondylar fractures at the elbow, elbow dislocations, fractures of the distal third of the femur and proximal third of the tibia, and some foot fractures, that a brief discussion is warranted.

Types of Vascular Occlusion

Complete Arterial Occlusion. A cold, white limb, absent pulses, empty veins, and severe muscle pain are the signs of complete occlusion. Pain

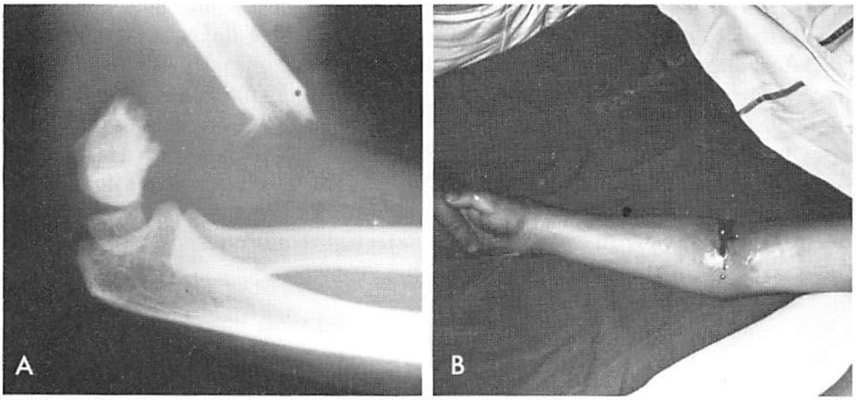


Figure 16. A severe posteriorly displaced supracondylar fracture of the humerus (*A*) has produced compartment ischemia. A radial pulse could be heard with the Doppler apparatus but was not palpated. The forearm was tense, swollen, and painful. Finger sensation was abnormal, and perfusion poor (*B*). Exploration revealed an intimal tear in the brachial artery. This was resected and replaced with a vein graft. A complete open forearm fasciotomy was performed.

disappears as nerve conduction fails and anesthesia and paralysis occur. The condition is pregangrenous.

Compartment Ischemia. There is incomplete occlusion, and the limb as a whole will survive. A pulse will often be present, but perfusion of the muscles is inadequate. Hypoxic muscle swells within a closed fascial compartment, further obstructing small vessel flow (Fig. 16). If a whole muscle is infarcted, Volkmann's ischemia occurs, and, ultimately, severe contracture will result. Patchy necrosis results from a lesser form of compartmental compression, but the ensuing loss of muscle and contracture from muscle scarring may nevertheless be striking.

Collateral Compensation. Particularly with a supracondylar fracture, the pulse may be absent, but the limb displays no signs of nerve or muscle ischemia. Here, the collateral blood vessels maintain an adequate circulation, and usually the Doppler apparatus will detect pulsations. Watchful expectancy is the right treatment under these circumstances.[25]

Diagnosis

Muscle pain, at least until ischemia blocks nerve impulses, is the cardinal sign. Even when there is no discomfort at rest, when extension of the digits produces pain in the flexor musculature, suspect a compartmental syndrome. A lack of peripheral pulses, peripheral pallor or color changes, paralysis and paresthesias are all danger signs. Beware muscle compartment ischemia in the presence of a palpable pulse.

When in doubt, measure compartmental pressures by the insertion of a wick catheter.[21] A reading of 30 mmHg or more will prevent adequate muscle perfusion and calls for adequate fascial release.

Prevention. Avoid tight casts, excessive traction, forced flexion of a swollen elbow, and hypotension. When simple measures of relieving pressure do not bring results in a few minutes, immediate action is called for. Arteriography is only helpful if it does not cause delay.

Fasciotomy. When the artery is intact, and a compartmental syndrome may occur, a fasciotomy alone is indicated. A formal open fasciotomy is mandatory.[19]

Arterial Exploration. The nature of the vascular lesion can only be properly determined by direct inspection. There may occasionally be discontinuity, but usually there is a lesion in continuity, such as an intimal tear or contusion with spasm. Proper arterial exploration and repair techniques are required.

PRINCIPLES OF FRACTURE TREATMENT

Diagnosis

A correct diagnosis is the basis of proper treatment, and the presence of a growth plate and epiphyseal cartilage may make this difficult. For example, stress films may be necessary to show a separated epiphysis in a long bone. A Salter type I fracture at the proximal humerus in an infant may mimic a dislocated shoulder because the unossified epiphysis is not seen radiographically (see Fig. 9). Multiple views and, in particular, comparative views to the opposite side are most helpful. As in the adult, an x-ray film of the joints above and below the fractured bone will prevent an embarrassing associated dislocation, such as in a Monteggia fracture, from being missed.

Achieving Reduction

In both adults and children, there are fractures, such as the shaft of the femur, for which traction and balanced suspension without manipulation are appropriate. When reduction is called for, consider the use of sedation and either local hematoma or regional block, which is particularly appropriate in the upper limb, where its use can avoid a general anesthetic and the need for hospitalization. The presence of a strong, intact periosteal hinge often makes reduction easy, and simple techniques are appropriate. Beware of the greenstick fracture: if not slightly overcorrected, it will frequently redeform.

Holding the Reduction

Plaster Casts. The principles of casting are no different in a child than in an adult. Hold the fracture first, then immobilize nearby joints. Augment the natural hinge of the thick periosteum by using Charnley's three-point pressure technique (Fig. 17).[9] Leave fingers free at the metacarpophalangeal joints and place joints in a position of function wherever possible. Do not hesitate to split casts when the question of swelling or vascular compromise is even remotely considered. Use above-knee and above-elbow extensions to hold desired rotations.

Traction Techniques

Skin Traction. Although reputedly more finicky than skeletal traction, skin traction is extremely useful, particularly in very small children, and

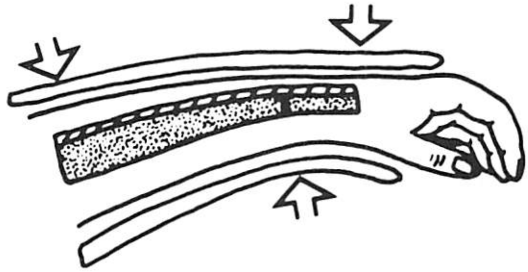


Figure 17. Three-point fixation in a forearm cast. A natural hinge of the periosteum is augmented by two distal pressure points, counteracted by an opposing third pressure point at the fracture site.

when only light traction is required. The use of moleskin or nonstretch traction Elastoplast separated distally with a spreader, adhering to skin that had been properly prepared with tincture of benzoin, can be trouble-free. This application is particularly appropriate for Bryant's overhead traction in fractures of the shaft of the femur in children under the age of two years (Fig. 18). In this and any form of skin traction, the blood supply to the

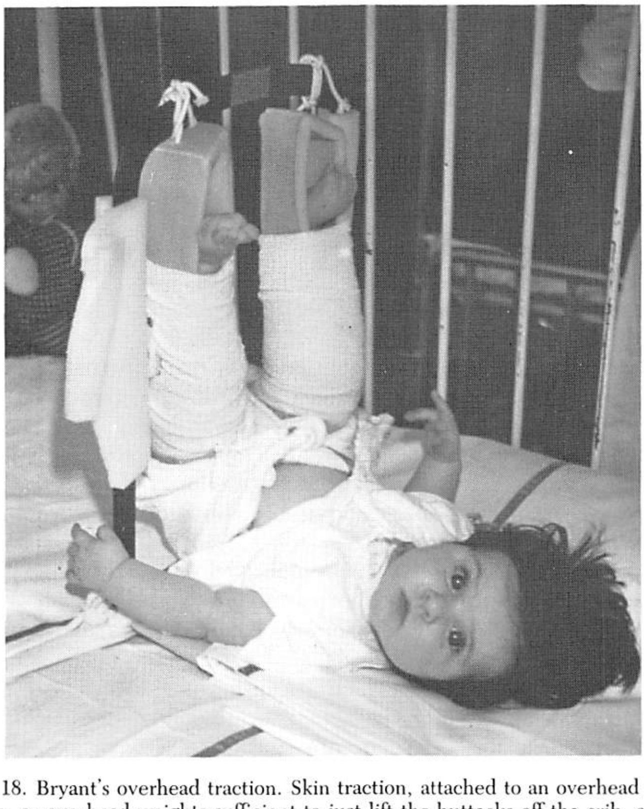


Figure 18. Bryant's overhead traction. Skin traction, attached to an overhead frame as in this example, or overhead weights sufficient to just lift the buttocks off the crib, are ideal for fractures of the shaft of the femur in a child under the age of two years. Circular bandages must not be constricting, and the blood supply to the feet must be closely monitored.

Figure 19. Overhead skeletal traction through the proximal ulna for a difficult supracondylar fracture. An ulnar screw is a useful alternative to the use of a Steinmann pin and spreader in this situation.

extremity and also the skin must be watched very closely for any signs of allergy or blistering.

Skeletal Traction. Steinmann pin traction through the proximal tibia, distal femur, or proximal ulna is indicated when more than 8 lb of traction is required, and when control of rotation is mandatory. The small danger of a pin traction infection is frequently offset by the relative ease of management compared with that for skin traction. The use of a threaded pin that prevents sideways slip is advisable, but not in the proximal ulna, where the ulnar nerve is close by.

In the upper limb, skeletal traction is used primarily for a complicated supracondylar fracture of the humerus and may be overhead (Fig. 19) or Dunlop's lateral traction. When properly balanced, the patient can retain considerable mobility.

In the lower limb, skeletal traction can be used either with a balanced Thomas splint, which can effectively be used to control angulation in a shaft fracture by apposing the gastrocnemius pull (Fig. 20), or as 90-90 traction (Fig. 21), which is appropriate for high fractures where the iliopsoas muscle angles the proximal fragment into flexion (Fig. 22). With either system, the weights and pulleys should balance the weight of the limb, allowing mobility of the patient in bed without losing alignment of the fracture. Hamilton-

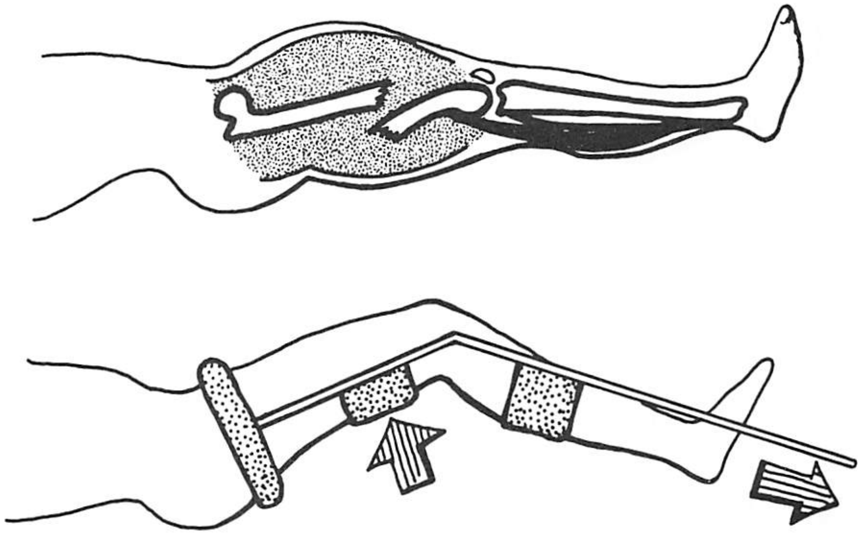


Figure 20. Flexion of the distal femoral fragment is caused by the pull of the gastrocnemius attachments. This is counteracted by the sling of a Thomas splint, and with distal traction, reduction may be achieved. (Redrawn after Rang, M.: Children's Fractures. Philadelphia, J. B. Lippincott, 1974.)

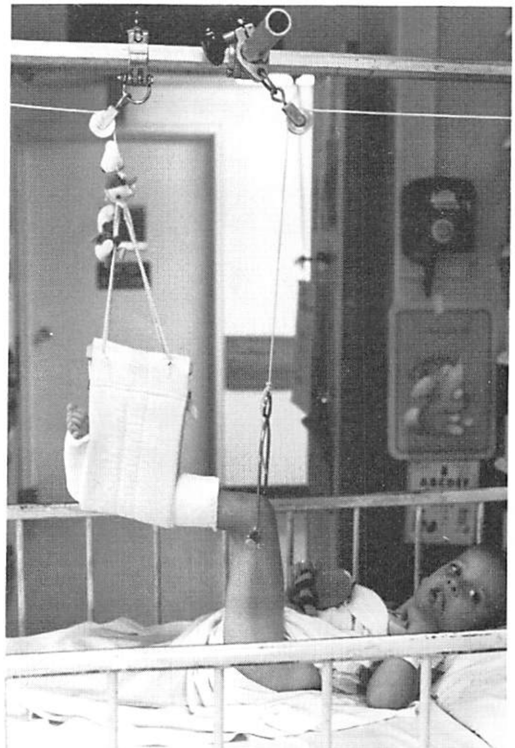


Figure 21. 90–90 traction, employing skeletal traction through the distal femur is an easy way to treat most femoral shaft fractures but is particularly applicable to those of the proximal shaft. The cast below the knee maintains the foot in a plantigrade position.

Figure 22. High femoral shaft fracture in which the iliopsoas muscle flexes the proximal fragment. This is most easily reduced and treated by 90–90 traction.

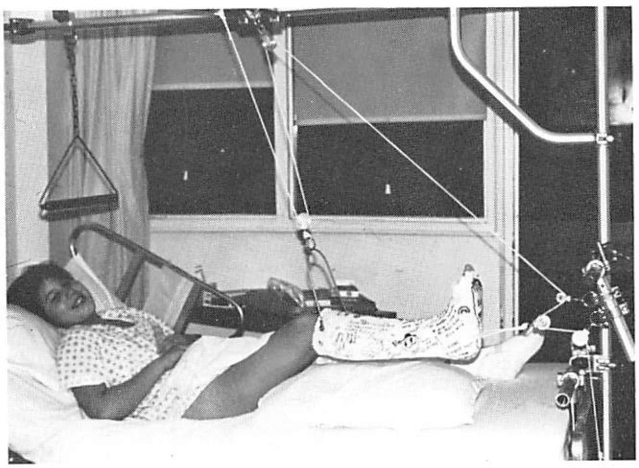


Figure 23. Skeletal Hamilton-Russell traction. Upward and distal traction is applied through a single upper tibial threaded Steinmann pin. The below-the-knee cast is attached to the pin and is used to maintain the foot plantigrade and also anchors cords tied to the pin proximally and to a pulley beyond the end of the foot. A stirrup connects the pin through another pulley for the vertical pull. A single cord utilizes both these pulleys, thus doubling the effective upward and distal pull that can be obtained by a single weight. Correct placement of the pin prevents external rotation of the femur, and very considerable traction can be applied to the femur by using this technique. It is ideal for reduction of acute slips of the upper femoral epiphysis (type I fractures) and intertrochanteric fractures of the neck of the femur.

Russell traction, in which the mechanical advantage of a pulley system in an upward direction and a second in a distal direction linked by a single cord and weight effectively multiplies the pull down of the shaft of the femur, requires frequent adjustment. It is best used as a skeletal rather than skin traction device, employing a proximal tibial pin with both upward and distal traction through that point (Fig. 23). Substantial traction can be applied, and it is then extremely effective in controlling rotation and position in fractures and injuries around the neck of the femur and hip joint.

Internal Fixation

As a general rule, fractures in children do not require open surgery. The specific exceptions may be intraarticular fractures involving the epiphysis and fractures transgressing the growth plate, namely the Salter-Harris types III and IV injuries, in which an anatomic reduction is imperative. Fixation, however, is usually simple and may be no more than a suture in the periosteum. At most, Kirschner wires may be used, and where possible, these should not transgress the growth plate. If they must do so, the pin should be smooth and cross the plate centrally rather than peripherally. Fractures of the neck of the femur, where the vascularity of the femoral head is in jeopardy, are often best treated by accurate reduction and internal fixation. Occasionally, when manipulative techniques fail in an important area, open reduction, but not always internal fixation beyond a suture, is called for. Examples are both bones of the forearm, the Monteggia and Galeazzi fracture dislocations of the forearm, displaced fractures of the distal radial metaphysis, and sometimes a supracondylar fracture.

External Fixation Devices

The potential value of fixing two fragments of long bones by pins transgressing the cortices at right angles and passing through skin and soft tissues to an external clamping device has been appreciated as long as leg-lengthening apparatus has been used. External fixation devices have found a very valuable application when there is significant soft tissue injury, because they can provide rigid fixation of the fracture with total exposure of the limb. They have little place in the management of closed fractures, however. Although they can hold accurate alignment, delayed union and pin tract infection in adults are a problem.[13] In children, external fixation is indicated only for severe open fractures and occasionally in fractures associated with head injuries.

Several systems are commercially available. The popular Hoffmann apparatus uses in each fragment three parallel-threaded pins that pass completely across the limb. A special rig is required to keep the pins parallel. Clamps link the pins to rods that control length, angulation, and rotation (Fig. 24). The Roger Anderson system uses stout, threaded half pins that cross both cortices but protrude on one side of the limb only. Universally jointed clamps attach the pins to linking rods, so that the pins need not be parallel. These features make this system very useful in children.

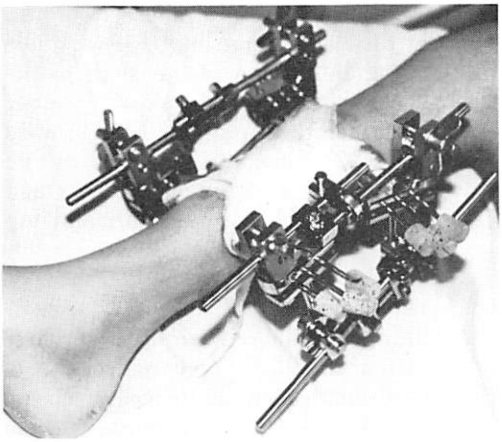


Figure 24. The Hoffmann external fixation device held a difficult open fractured tibia anatomically reduced in this boy who also had a severe head injury.

MANAGEMENT OF SELECTED FRACTURES

Fractures in the limbs that are important or illustrate the principles outlined will be discussed.

Fractures Around the Elbow

These form an important group of injuries. The humerus is flattened fore and aft at the trochlear notch; the trochlea is largely cartilaginous in young children and therefore radiolucent. Fractures of the distal humerus may thus be occult and also carry the danger of vascular and neurologic problems. As with all fractures, thorough examination for peripheral weakness, for sensory loss, or for signs of vascular impairment is mandatory.

Supracondylar Fractures. Assessment of possible ischemia and nerve palsies are more important in this fracture than perhaps any other in the body. Neurologic involvement may be of the radial, ulnar, and median nerves. They may be subtle, involving perhaps loss of flexion of the distal interphalangeal joint of the index finger and tip of the thumb. Transient nerve palsies may be seen in as frequently as 14 per cent of supracondylar fractures.[25] The majority of these fractures are displaced posteriorly (Fig. 25). The intact periosteal hinge causes a rotary deformity, and there is invariably a sideways shift. Occasionally, the distal humeral fragment may displace anteriorly, and reduction may only be achieved by extension.

There is considerable controversy about the management of the normal posteriorly displaced supracondylar fracture. As a general rule, closed reduction under a general anesthetic, a half cast, and a high collar and cuff sling is preferable. Prolonged longitudinal traction to achieve relaxation, followed by correction of the more common medial or occasional lateral shift, must precede flexion. As the forearm is flexed, thumb pressure over the point of the olecranon will help reduce the fracture. When there has been medial shift, forearm pronation helps tighten the medial periosteal hinge, and for lateral shifts, with the lateral periosteal hinge intact, supination will help close the fracture gap for the same reason.

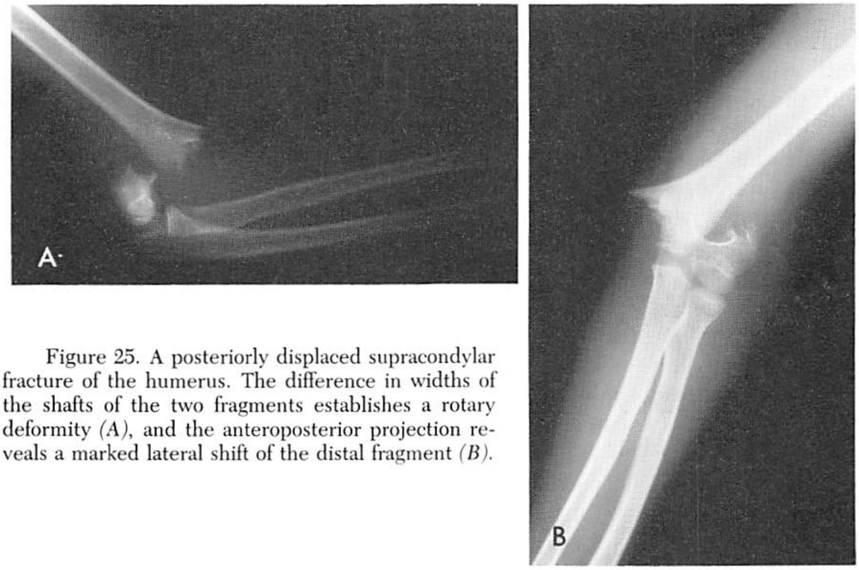


Figure 25. A posteriorly displaced supracondylar fracture of the humerus. The difference in widths of the shafts of the two fragments establishes a rotary deformity *(A)*, and the anteroposterior projection reveals a marked lateral shift of the distal fragment *(B)*.

The key to assessing reduction is the ability to flex the elbow freely to the point where the hematoma provides a spongy resistance. Do not accept less than a virtually anatomic reduction in a supracondylar fracture. Residual varus or valgus angulation cannot be assessed for months until full extension of the elbow is subsequently achieved. When there is doubt, a transverse olecranon pin, angled so as to hold the fracture in the position of reduction, and overhead traction are preferable (see Fig. 19). Manipulative reduction is usually needed a few days later. Sometimes, a supracondylar fracture can be reduced but not easily held. Percutaneous pins may then be used to advantage. Many surgeons will insert two pins from the lateral side only, but the addition of a medial pin, placed with due regard to the position of the ulnar nerve, provides stability (Fig. 26). When there is vascular damage,

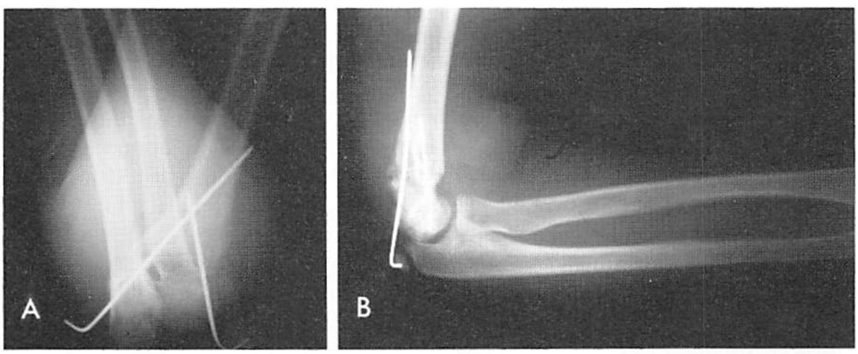


Figure 26. The supracondylar fracture in Figure 25 was easily reduced but unstable. On that account, it was held by two Kirschner wires passed percutaneously through both medial and lateral condyles (*A* and *B*). Particular care was taken to avoid the ulnar nerve on the medial side.

and in the occasional irreducible situation, open reduction and internal pin fixation may be warranted. Immobilization in acute flexion should be limited to three weeks, followed by a further two or three weeks in a simple sling with the arm at a right angle.

Full flexion that keeps the fracture stable may be accompanied by loss of the radial pulse. The forearm may then be extended slightly until a pulse is felt or may be heard with a Doppler apparatus. The arm is further flexed in a few days when the swelling subsides. If much extension is necessary to maintain a safe blood supply, then traction is probably the better route to follow.

Fractures of the Medial Epicondyle. These fractures are avulsive and follow a vigorous pull of the common flexor origin. Their significance is that they are often associated with subluxation or even dislocation of the elbow that reduces spontaneously. Under these circumstances, the epicondyle may be trapped in the elbow joint and, in the very young, will only show on a radiograph as a slight widening of the joint, because no bone has yet formed in the cartilaginous epiphysis. Comparative radiographs of both sides are then essential. The epicondyle must be removed from the joint, almost always by open surgery, and sutured back in place. When only slightly displaced, the medial epicondyle will heal by fibrous union, and the flexor attachment will be stable. By and large, however, it is preferable to attach properly the epicondyle by using periosteal sutures or percutaneous Kirschner wires.

Fractures of the Lateral Humeral Condyle. This Salter-Harris type IV fracture (see Fig. 13) commences laterally in the humerus and moves towards the articular surface by transgressing the growth plate. Occasionally, the articular surface is actually spared, and the capitellum hinges away from the humerus as the elbow subluxes. The line of the fracture is usually more medially situated than the edge of the capitellum, passing in fact through the lateral aspect or even through the middle of the trochlea. The whole lateral mass may displace significantly, often rotating through 90° in two planes, probably because of the pull of the common extensor forearm muscles. The radiographic diagnosis in a very young child may be difficult because the center of ossification in the capitellum is so small that the rotation and displacement may not be appreciated. Comparative elbow views should always be taken.

These fractures require accurate reduction. Poor treatment may result in stiffness, cubitus valgus, and tardy ulna nerve palsy. A good reduction rarely results in any growth disturbance. Very few of these injuries are amenable to closed manipulation and immobilization, and an open reduction through a lateral approach that permits visualization of the anterior aspect of the joint and the fracture line is needed. Two parallel Kirschner wires will hold reduction once achieved.

Olecranon Fractures. As intraarticular injuries, accurate apposition is called for. More distal fractures will also transgress an epiphysis and growth plate, and reduction with pin fixation, either by closed percutaneous methods or open operation, is called for (Fig. 27).

Fractures of the Neck of the Radius. Unlike an adult whose fall on an outstretched arm may fracture the radial head, a child will sustain a Salter-Harris type II fracture at the head of the radius (see Fig. 10). Angulation

Figure 27. A displaced fracture of the olecranon that disrupts a major portion of the articular surface. Anatomic reduction and internal fixation are indicated.

may be extreme and the appearance disturbing, but if it is 10° or less,[2] no treatment beyond joint aspiration is called for, as remolding will occur. Wadsworth[34] will accept an angulation of 45° in a child under the age of ten years. When the fracture is more tilted, manipulative reduction to reduce the angle to an acceptable degree is usually all that is required. Never excise the head of the radius before growth is complete, or severe radial shortening, with disruption of the wrist joint, will occur.

The Pulled Elbow, or Nursemaid's Elbow. Although not a fracture, this injury is very common and warrants description. A jerk on the arm of the child aged one to four years produces a characteristic clinical picture. The child will hold that arm in a position of flexion and pronation. The mechanism appears to be a subluxation of the radial head out of the annular ligament with the traction, and when this is released, part of that ligament becomes trapped between the head of the radius and capitellum.[30] Reduction is easily achieved by sharply supinating the slightly flexed forearm. Often a click will be heard, and the child will immediately begin to move the arm, which should be rested in a sling for a few days. Occasionally, reduction by supination will fail, and under those circumstances, the child's arm should be placed in a plaster of Paris backslab with the elbow at 90° and the forearm fully supinated for a period of a week or so. Normal function returns rapidly thereafter.

Special Note. Injuries around the elbow in children frequently result in prolonged stiffness, and parents should be warned that this is likely to be the case. Mobilization should be through active exercises only. Forcing extension or flexion will not hurry the process of mobilization and carries the risk of heterotopic bone formation.

Fractures of Both Bones of the Forearm

The majority of fractures of the shafts of the radius and ulna follow a fall on the outstretched hand when a violent supinating force is applied against the tensed, pronated limb. The apparent anterior angulation is really rotational (Fig. 28).[25] Fractures close to the distal epiphysis in a child with sufficient growth ahead can be expected to correct 30 to 40° of angulation. In the middiaphysis, however, union with angulation, rotation, or both will leave permanent loss of forearm rotation.

Figure 28. Fractures of the shafts of both bones of the forearm. The distal fragments have rotated markedly on the periosteal hinges, which aggravates the appearance of angulation.

Complete fractures of the diaphyses of both bones of the forearm therefore require accurate reduction. A cortex-to-cortex apposition may be acceptable if rotation is correct and angulation appropriate, so that there is no narrowing of the interosseous space. Much is made of the position of the forearm with regard to rotation when setting these features. Frequently, more distal fractures are stable in pronation, thus opposing the force of the injury, but this is not always the case, and the rule should be to immobilize the fracture in the position that holds the alignment correct and provides maximum stability. Casts may be wedged or rotated in two or three weeks when early union is commencing. Reduction is carried on by retracing the line of forces of the fracture and increasing deformity until the bones can be locked together. Next, correct angulation, and finally rotation. Casts should be well molded, and the principle of three-point fixation followed (see Fig. 17). All casts for forearm fractures must be extended above the elbow with that joint held at a right angle.

When adequate reduction cannot be achieved, open reduction may be the better alternative. However, internal fixation may be limited to an intramedullary Kirschner wire passed through an oblique hole drilled in the cortex a little distance away from the fracture site.

Fractures of the distal shaft of the radius, with dorsal displacement and shortening, especially when associated with a greenstick fracture of the

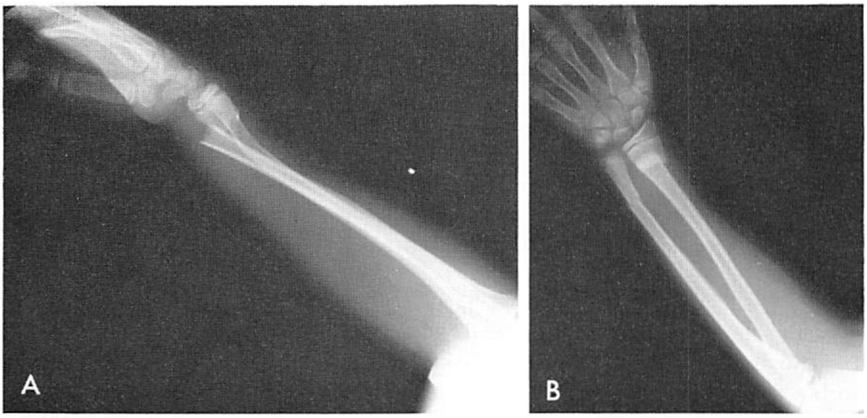


Figure 29. Fracture of the distal shaft of the radius with dorsal displacement *(A)*. The degree of shortening of the radius and the greenstick nature of the ulnar fracture are clearly visualized in the anteroposterior projection *(B)*.

ulna, present a challenge to the orthopedic surgeon. There is frequently some crushing of the dorsal cortex of the proximal fragment, and reduction by increasing the angulation and forced flexion may fail. Even when the distal fragment is hooked on the proximal one, the lack of supporting cortex may permit redisplacement. This is perhaps the commonest fracture in children when an open operation is performed for failure to achieve a satisfactory reduction (Fig. 29).

General Principles

In forearm fractures, angulation even up to 40° is acceptable close to the growing epiphysis, but almost none can be accepted in the midshaft. In neither area can malrotation be permitted to occur, and if closed manipulation fails to correct this, open reduction is indicated.

Fractures at the Hip Joint

A great deal of force is necessary to cause a fracture in the area of the hip joint in a child, unlike the situation in the elderly adult. Many have a bad prognosis because of avascular necrosis, and some midcervical and intertrochanteric fractures will heal in varus if inadequately treated. It has been suggested[12] that the hip joint should be aspirated to prevent tamponade and vascular occlusion in all these fractures.

Salter-Harris Type I Fractures. In younger children, great violence causes the fracture, and closed manipulation and hip spica immobilization with a close follow-up is indicated. In the adolescent, it may represent one end of the spectrum of slipped upper femoral epiphysis, and for these, skeletal Russell traction (see Fig. 23) for a few days to achieve reduction, followed by threaded pin fixation across the fracture site, is best.

Transcervical and Basal Fractures. When undisplaced, there is some inherent stability, and a hip spica is the treatment of choice.[25] When these fractures are displaced, however, malunion, particularly coxa vara, may be the sequel, and it is thought that accurate reduction also reduces the incidence of avascular necrosis.[26] Knowles threaded pins that stop short of the growth plate are better than the trifin nail, which may jam in the rather dense bone of the neck in a child and occasionally can displace the epiphyseal plate.

Intertrochanteric Fractures. Most will reduce satisfactorily on traction. The skeletal variety of Russell traction is most appropriate for this fracture (see Fig. 23). When callus is present, a hip spica can be safely applied. Avascular necrosis is rare in these fractures.

Femoral Shaft Fractures

In children, these are relatively easily treated and have a good prognosis. There are several satisfactory alternatives, but by and large initial traction followed by a hip spica is the most universally practiced.

Overhead skin traction of the Bryant's type is best for a child under the age of two years (see Fig. 18). The circumferential bandage holding the skin traction in place must be carefully applied to avoid pressure, and the feet must be watched for any ischemic changes. Beyond infancy, the use of a hip spica after callus forms at about two weeks may be necessary.

Skin traction on a balanced Thomas splint works well for a child over the age of two (Fig. 30). Where skin traction cannot be properly supervised, skeletal traction through the upper tibia is helpful and is always preferable in children with other injuries or restlessness after head trauma. More traction to overcome spasm is also then possible. Alignment of the femur can be readily achieved by the placement of suitable padding. If there is

Figure 30. Skin traction and a balanced Thomas splint are being used for a fractured shaft of the femur in a patient with osteogenesis imperfecta.

posterior angulation, this is inserted between the sling under the Thomas splint and the thigh. Similar pressure can be applied to an adducted fragment when the fracture is high and also to an anterior bowed fragment by medial and anterior pads held in palce by an Ace bandage applied around the Thomas splint and thigh.

In very high fractures, flexion of the proximal fragment may present a problem of management, and in children with these fractures, 90-90 traction through a supracondylar pin is most satisfactory. Apply the pin from the medial side and with the knee bent so that the tensor fascia lata is under correct tension, and the femoral artery is relaxed and thus easily avoided (Figs. 21 and 22).

In all these fractures, a hip spica can be applied as soon as there is sufficient callus to maintain stability. The spica can often be made unilateral, and weight bearing can be achieved by casting with some flexion at both hip and knee. Sitting is then also possible.

In a stable fracture, the immediate application of a hip spica extending either to the opposite knee or sufficiently high to maintain good stability of the pelvis is a good alternative to traction. The complications of immobilization do not occur in young children.

Fractures of the Distal Femur

A type II fracture is the usual injury (see Fig. 10). Sporting activities produce a varus or valgus strain, and clinically the fracture may resemble damage to the collateral ligaments. Reduction is usually stable and may be held in a plaster of Paris cylinder. The prognosis, however, must be guarded, since there is often a crushing element with damage to the growth plate, and the parents should be warned that there may be a growth disturbance that may cause shortening and angulation.

The type III and IV fractures of the distal femoral condyles, which are the equivalent to T-fractures in adults, transgress both the growth plate and articular surface and call for accurate reduction and suitable fixation. An open procedure is invariably necessary.

Avulsion Fractures of the Tibial Spine

As previously described, this is a pure epiphyseal fracture (see Fig. 5). There are three grades: the spine may be hinged up but be otherwise undisplaced, the whole spine may be avulsed, and in the most severe form, the avulsion may involve a portion of the surrounding articular surface of the tibia. Because this is a fracture of epiphyseal and articular cartilage and also because malunion may present a block to full extension at the knee, accurate reduction is necessary. In the simplest type, aspiration of the knee joint and extension of the knee may reduce the fragment. Immobilization in a plaster of Paris cylinder may suffice. When in doubt, an open operation to achieve reduction and fixation is required. Sometimes, a part of the meniscus may slip under the fragment, making open reduction imperative.

Tibial Shaft Fractures

In general terms, management of fractures of the tibial shaft in children is little different from that in adults. The danger of vascular compromise is always present in displaced fractures in the proximal area, whether these be epiphyseal or metaphyseal, because the anterior tibial artery passes over the proximal edge of the interosseous membrane into the anterior compartment and is therefore fixed in position and is relatively easily compressed, stretched, or torn.

Valgus Proximal Tibial Metaphyseal Greenstick Fractures. These apparently innocuous-looking fractures deserve special mention. The fibula is intact as is the lateral tibial cortex, and the valgus tilt is so slight that they are frequently accepted as undisplaced and treated in a cast without manipulation. When healed, there is often an unacceptable degree of knock-knee. The valgus may initially worsen, the tibia as a whole may overgrow, and spontaneous correction may occur but may not be complete. It was first described by Cozen in 1953.[10] Taylor[33] thought that the progressive valgus was due to the tibial overgrowth that follows fracture hyperemia, with the intact fibula acting as a tether. Ogden has evidence that the valgus deformity is the result of selective longitudinal overgrowth of the medial cortex.[22] Recently, Skak[32] suggested that there were radiologic signs of interposition of soft tissues medially in the fracture gap. He noted some late spontaneous compensation at the distal tibial metaphysis, which developed a degree of varus, resulting in a screw-shaped tibia. Rang[25] found that the tibia would grow straight when the fracture was fully corrected under anesthesia and subsequently held in a well-molded cast holding a position of varus. A corrective osteotomy may be required if a valgus deformity persists.

Fractures of the Ankle Joint

Generally, an injury that would cause a trimalleolar Pott's fracture in an adult will cause a type II fracture separation of the distal tibial epiphysis and fracture of the fibula, so that the ankle joint as a whole will shift but the talotibial relationship will be preserved (Fig. 31). For that reason, most fractures in children at the ankle joint are amenable to manipulation and cast reduction and have a good prognosis. The situation changes, however, as maturity is reached. Closure of the distal tibial growth plate commences on the medial side of the tibia. This irregular closure pattern sets the stage for the production of two unusual but noteworthy ankle joint fractures.

The Tillaux Fracture. This is a Salter-Harris type III fracture of the lateral and unclosed portion of the distal tibial epiphysis in adolescence. The fracture was drawn in rough by Paul Jules Tillaux before he died in 1904 and now carries his name. It was described in detail by Kleiger and Mankin in 1964.[14] The fragment is avulsed by a pull on the anterior tibiofibular ligament after an external rotation force. The fibula is usually sufficiently flexible to spring back into position, and often the tibial epiphyseal fragment is only minimally displaced. The fracture is difficult to see because it is obscured by the fibula in the anteroposterior view (see Fig. 12*A*). Growth disturbance is rare because the growth plate is closing. When displaced, these require internal fixation principally to realign correctly the articular surface (see Fig. 12*B*). Cast fixation may suffice for the occasional undisplaced fracture.

The Triplane Fracture. Whereas the Tillaux fracture is a Salter-Harris type III fracture of the distal tibial epiphysis, the triplane fracture in its usual form is a similar fracture but is of the Salter-Harris type IV variety,

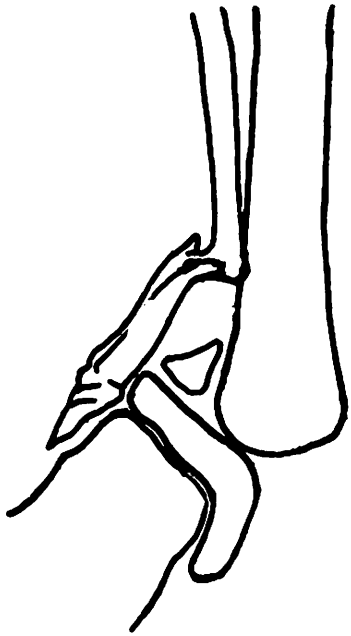


Figure 31. Diagram of a type II fracture of the distal tibial epiphysis and a greenstick fracture of the fibula, caused by a plantar flexion and eversion injury to the ankle. The ankle joint itself has remained intact, reduction can be easily achieved, and six weeks in a walking cast is all that is required.

in which a fragment of metaphysis fractures and displaces together with the epiphyseal segment.

SPECIAL FRACTURES

Birth Fractures

Limbs may be injured during difficult vaginal births, particularly during breech presentations when the shaft of the femur may be fractured, and the trailing upper limb may be injured. The upper limb is also in jeopardy with an impacted shoulder. Fractures of the clavicle and humeral shaft occur occasionally (Fig. 32), and particularly noteworthy is what appears to be a dislocation of the shoulder on x-ray film. These are invariably Salter type I fractures of the proximal humeral epiphysis with considerable shift of the humeral shaft away from the radiolucent head (see Fig. 9). When there is doubt, an arthrogram will establish the diagnosis (Fig. 33), or within a week or ten days, healing callus under the elevated periosteum will show the true nature of the injury. The most important aspect of these birth injuries is the possible association with traction nerve lesions, particularly in the upper limb. The "pseudoparalysis" of fracture may indeed be the result of a true brachial plexus injury. When the injury takes place with the arm by the side, these tend to be of the upper brachial plexus or Erb's variety, and when they occur with the arm elevated, the lower portion of the brachial plexus may be injured, producing the Klumpke type of lesion that affects primarily the hand.

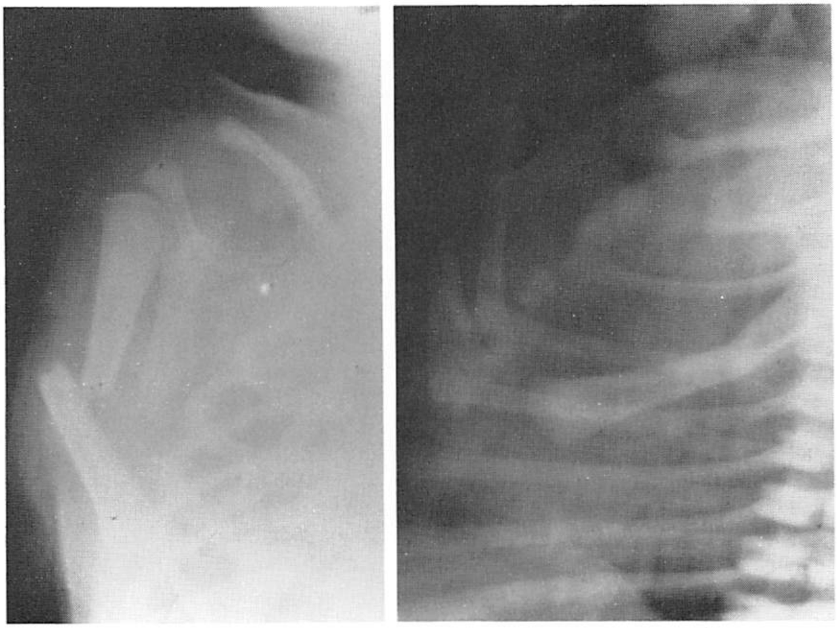


Figure 32. This fracture of the shaft of the humerus in a newborn infant occurred during a difficult delivery. This injury will heal rapidly with a simple body bandage. Always look for an associated brachial plexus palsy.

Figure 33. A type I fracture of the proximal humerus in a neonate was thought to be a dislocation of the shoulder. Two weeks later, an arthrogram into the joint confirmed the location of a cartilaginous head, and subperiosteal new bone provided further evidence of the true nature of the injury.

Birth fractures require minimum treatment. A week or ten days of simple traction for a femoral shaft fracture and a body bandage for a humeral shaft fracture suffice. The remolding capability of newborn children is considerable, and angulation of under 45° will correct very rapidly.

If there are multiple birth injuries, suspect an underlying cause such as osteogenesis imperfecta.

The Battered Child

More than one fracture in an infant, particularly when they are at different stages of healing, should alert the clinician to the possibility of battering. Subperiosteal elevation without an overt fracture, particularly when near an epiphysis, suggests a type I injury that has displaced and become repositioned (Fig. 34). A very careful history is called for. In particular, spiral fractures in children under the age of three should cause one to suspect that these children have literally had their arms twisted.[11]

Pathologic Fractures

Several causes of local weakness in bone may cause a spontaneous fracture.

Bone Cysts. Unicameral or simple bone cysts commonly occur in the proximal humerus and proximal femur, and attention is frequently drawn to them because of pain when an x-ray film is taken for the first time. The pain is due to a fracture through the thin cortex. In the neck of the femur, there may be deformity. The cyst does not prevent healing of the fracture. Since the area is weak, the cysts require treatment after the fracture has healed. Steroid injections into the cyst are a promising, relatively noninvasive form of treatment popular at the present time.[7] Should repeated

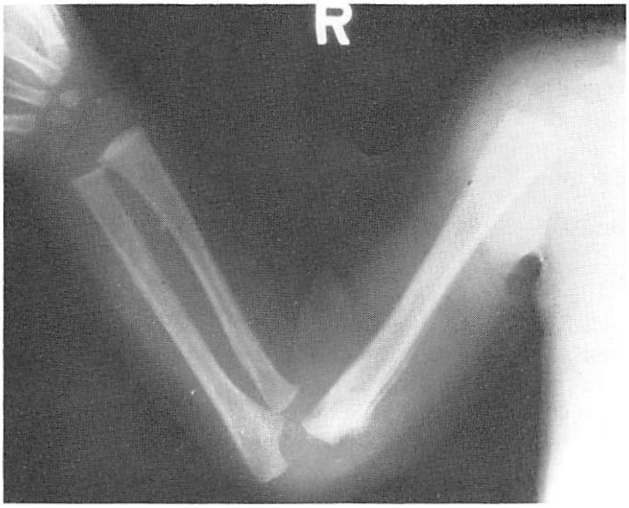


Figure 34. Subperiosteal new bone formation in the distal humerus and midshaft of the ulna may be the result of a twisting injury or even a spontaneously reduced type I fracture. Battering is the cause.

injections fail to heal the cysts, curettage and packing by bone chips may be necessary.

Fractures through an aneurysmal bone cyst require curettage and bone grafting to prevent refracture. A fracture may occasionally complicate a nonossifying fibroma. Besides management of the fracture, no treatment is necessary.

Paralyzing Conditions. Lesions of the lower motor neurons such as spina bifida and spinal cord injuries, poliomyelitis and muscular dystrophy, create osteoporosis partly because of poor or absent weight bearing, but more significantly because the stimulus of the pull of a muscle is lacking at attachment points. Spontaneous fractures are common in these patients. In particular, children with spina bifida who undergo surgery and postoperative immobilization are in significant danger of spontaneous fractures as soon as the casts are removed. Although these fractures may occur in the metaphysis and diaphysis, they more usually take the form of Salter-Harris type I epiphyseal fractures with displacement. The periosteum remains intact and is elevated by formation of hematoma. The gap between periosteum and bone fills rapidly with very exuberant callus. Clinically, the limb may have marked swelling and redness, but the child is usually in no discomfort and is systemically well. The lack of sensation may well contribute to spontaneous fractures in myelomeningocele. Immobilization of these fractures should be kept to a minimum, and early weight bearing encouraged.

Fractures in children with cerebral palsy are uncommon because the bones are usually kept strong because of spastic muscle pull. Fractures are occasionally a problem in bedridden patients.

Stress Fractures

These are seen usually in the upper tibia, lower femur, and metatarsals. The rib, pelvis, and humerus may also be involved. Sudden activity after periods of inactivity cause these transverse fractures that may not even appear on an x-ray film until subperiosteal callus is seen (Fig. 35). The periosteal elevation may resemble a bone neoplasm. A careful history and tomographic views will establish the diagnosis and prevent an unnecessary biopsy and, in one known instance, the amputation of a leg. Except in the neck of the femur, limitation of activity is all that is required.

General Bone Diseases

Osteogenesis Imperfecta and Osteopetrosis. Fractures in these conditions, particularly in the more severe forms of osteogenesis imperfecta, occur frequently. In both, however, healing is unimpaired, and splinting should be kept simple so that the children may be treated at home as soon as possible. In the recurring fractures of osteogenesis imperfecta, care must be taken to prevent angulation (Fig. 36). In the more severe variety, simple weight bearing may create small stress fractures that permit gradual bowing, and the use of orthoses, particularly pneumatic trouser splints,[20] during activity may be helpful.

Renal Osteodystrophy and Vitamin D–Resistant Rickets. Apart from an increased danger of fracture, a slow slip at growth plates sometimes occurs. This was observed in the distal radius on both sides in a child who

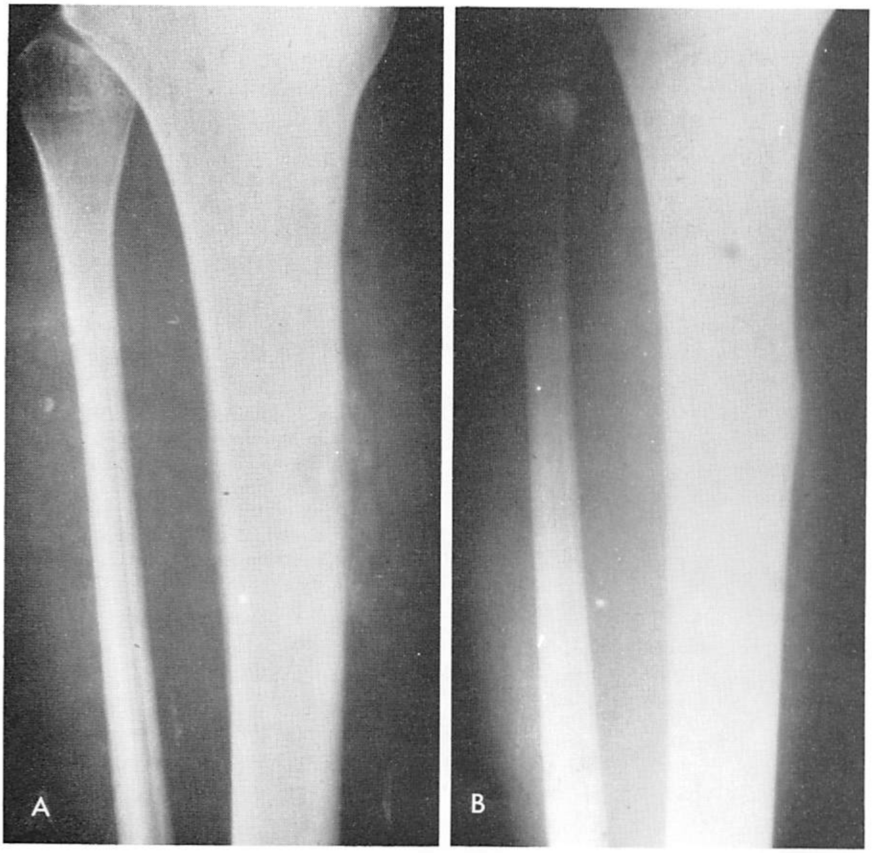


Figure 35. The fuzzy appearance under the periosteum on the medial side of this young athlete's upper tibia was observed two weeks after the commencement of the track season. The area was mildly red and swollen, and the patient had persistent pain. The radiographic appearance may suggest neoplasia *(A)*, but the cortex is intact. A biopsy specimen showed exuberant new bone formation and dividing cells. The patient's activities were limited, and the condition healed rapidly *(B)*. The diagnosis was a stress fracture, although this was never satisfactorily visualized by the x-ray film.

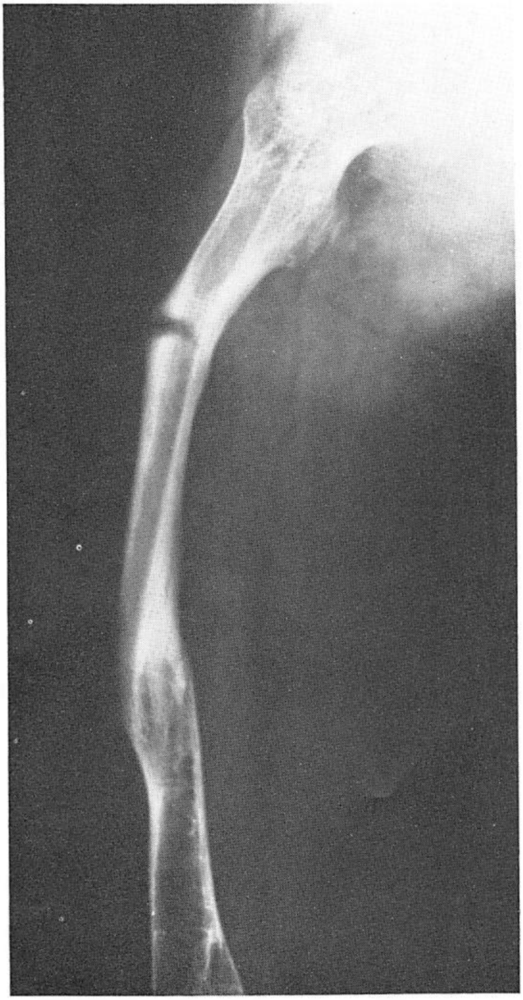


Figure 36. A recent fracture in the upper third of the shaft of the femur in a boy with osteogenesis imperfecta. Although only greenstick in nature, unless reduced, it will heal in varus, thus contributing to increasing deformity.

had the habit of falling on her outstretched hands in play. The femoral epiphyses may slip in these children at any age and should be pinned in situ as soon as it is noted.

CONCLUSIONS

A clear understanding of the specific features of children's fractures, in particular, the role of the growth plate and the epiphysis, the usefulness and limits of molding, the value of the thick periosteum, the speed of healing, and fractures that occur under special circumstances, is necessary to provide care of good quality. Add good human relations to competence. Take time to explain the fracture and treatment plan to the parents, and always take the child into your confidence. Eliminating the fear of the unknown helps your young patient face the situation and cooperate with your treatment plan.

REFERENCES

1. Aitken, A. P., and Magill, H. K.: Fractures involving the distal epiphyseal cartilage. J. Bone Joint Surg., *34A*:96, 1952.
2. Apley, A. G.: A System of Orthopaedics and Fractures. London, Butterworths, 1977.
3. Borden, S.: Roentgen recognition of acute plastic bowing of the forearm in children. A.J.R., *125*:524, 1975.
4. Bright, R. W.: Surgical correction of partial epiphyseal plate closure in dogs by bone bridge resection and use of silicone rubber implants. J. Bone Joint Surg., *54A*:1133, 1972.
5. Bright, R. W., and Elmore, S. M.: Physical properties of epiphyseal plate cartilage. Surg. Forum, *19*:463, 1968.
6. Brighton, C. T.: Structure and function of the growth plate. Nantucket Seminar, Resources for Basic Science Educators, American Academy of Orthopaedic Surgeons, Committee on Basic Sciences, 1977.
7. Campanacci, M., Dessessa, L., and Bellando-Randone, P.: Bone cysts: Review of 275 cases—results of surgical treatment and early results of treatment by methylprednisolone acetate injections. Chir. Organi. Mov., *62*:471, 1976.
8. Chamay, A.: Mechanical and morphological aspects of experimental overload and fatigue in bone. J. Biomech., *3*:263, 1970.
9. Charnley, J.: The Closed Treatment of Common Fractures. Edinburgh, Churchill Livingstone, 1961.
10. Cozen, L.: Fracture of the proxim portion of the tibia in children followed by valgus deformity. Surg. Gynecol. Obstet., *97*:183, 1953.
11. Herndon, W. A.: Personal communication, 1982.
12. Kay, S. P., and Hall, J. E.: Fracture of the femoral neck in children and its complications. Clin. Orthop., *80*:53, 1971.
13. Kimmel, R. B., and Neidre, A.: Results of treatment using the Hoffmann external fixator for fractures of the tibial diaphysis. Orthopaedic Transactions. J. Bone Joint Surg., 5:431, 1981.
14. Kleiger, B., and Mankin, H. J.: Fracture of the lateral portion of the distal tibial epiphysis. J. Bone Joint Surg., *46A*:25, 1964.
15. Langenskiöld, A.: The possibilities of eliminating premature closure of an epiphyseal plate caused by trauma or disease. Acta Orthop. Scand., *38*:267, 1967.
16. Langenskiöld, A.: An operation for partial closure of the epiphyseal plate in children and its experimental basis. J. Bone Joint Surg., *57B*:325, 1975.
17. Langenskiöld, A.: Surgical treatment of partial closure of the growth plate. J. Pediatr. Orthop., *1*:3, 1981.

18. Langenskiöld, A., and Österman, K.: Surgical treatment of partial closure of the epiphyseal plate. Reconstr. Surg. Traumatol., *17*:48, 1979.
19. Matsen, F. A., III, and Veith, R. G.: Compartmental syndromes in children. J. Pediatr. Orthop., *1*:33, 1981.
20. Morel, G., and Haughton, G. R.: Pneumatic trouser splints in the treatment of severe osteogenesis imperfecta. Acta Orthop., Scand., *53*:547, 1982.
21. Mubarek, S. J., Owen, C. A., Hargens, A. R., et al.: Acute compartment syndromes: Diagnosis and treatment with the aid of the wick catheter. J. Bone Joint Surg., *60A*:1091, 1978.
22. Ogden, J. A.: Skeletal Injury in the Child. Philadelphia, Lea & Febiger, 1982.
23. Peterson, H. A., and Burkhart, S. S.: Compression injury of the epiphyseal growth plate: Fact or fiction? J. Pediatr. Orthop., *1*:377, 1981.
24. Poland, J.: Traumatic Separation of the Epiphysis. London, Smith, Elder and Co., 1979.
25. Rang, M.: Children's Fractures. Philadelphia, J. B. Lippincott Co., 1974.
26. Ratcliff, A. H. C.: Fracture of the neck of the femur in children. J. Bone Joint Surg., *44B*:528, 1962.
27. Rigal, W. N.: Diaphyseal aclasis. *In* Rang, M. (ed.):: The Growth Plate. Edinburgh, E. & S. Livingstone, 1969.
28. Royoppy, S., and Karaharju, E. O.: Alteration of epiphyseal growth by an experimentally produced angular deformity. Acta Orthop. Scand., *45*:490, 1974.
29. Salter, R. B., and Harris, W. R.: Injuries involving the epiphyseal plate. J. Bone Joint Surg., *45A*:587, 1963.
30. Salter, R. B., and Zaltz, C.: Anatomic investigations of the mechanism of injury and pathologic anatomy of "pulled elbow" in young children. Clin. Orthop., 77:141, 1971.
31. Shapiro, F.: Epiphyseal growth plate fracture-separations. A pathophysiologic approach. Orthopedics, *5*:720, 1982.
32. Skak, S. V.: Valgus deformity following proximal tibial metaphyseal fracture in children. Acta Orthop. Scand., *53*:141, 1982.
33. Taylor, S. L.: Tibial overgrowth: A cause of genu valgum. J. Bone Joint Surg., *45A*:659, 1963.
34. Wadsworth, T. G., and Haddad, R. J.: Childhood trauma. *In* Wadsworth, T. G. (ed.): The Elbow. London, Churchill Livingstone, 1982.

Division of Pediatric Orthopaedic Surgery
Rhode Island Hospital
Providence, RI 02902