Injuries Involving the Epiphyseal Plate

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An Instructional Course Lecture, The American Academy of Orthopaedic Surgeons

Injuries involving the epiphyseal plate present special problems in diagnosis and management. The dread complication of serious disturbance of growth is usually predictable and, in certain circumstances, can be prevented. Thus, knowledge of the prognosis for a given injury to the epiphyseal plate in a particular child is of considerable importance to the surgeon, who has the dual responsibility of treating the child and advising the parents. The purpose of this presentation is to discuss epiphyseal-plate injuries from both the clinical and the experimental points of view.

APPLIED ANATOMY AND HISTOLOGY

Each epiphysis has its own plate through which skeletal growth occurs; it is important that a distinction be made between the epiphysis and the epiphyseal plate.

Type of Epiphyses

Two types of epiphyses exist in the extremities, namely, pressure epiphyses and traction epiphyses (Fig. 1); there are significant differences between the two.

Pressure epiphyses: A pressure epiphysis, situated at the end of a long bone, is subjected to pressures transmitted through the joint into which it enters. In this sense it may be considered an articular epiphysis; furthermore, its epiphyseal plate provides longitudinal growth of the long bone. Pressure epiphyses may be divided into two types depending on whether their nutrient vessels enter the epiphyses directly (lower femoral epiphysis) or indirectly (upper femoral epiphysis). The significance of these two types of blood supply will be discussed in a subsequent section.

Traction epiphyses: A traction epiphysis is the site of origin or insertion of major muscles or muscle groups and is therefore subjected to traction rather than to pressure. Since it does not enter into the formation of a joint, it is non-articular, and it does not contribute to longitudinal growth of the long bone. Examples of traction epiphyses are the lesser trochanter of the femur and the medial epicondyle of the humerus.

Applied Histology of the Epiphyseal Plate

A knowledge of the microscopic features of the normal epiphyseal plate is pivotal in understanding the problems associated with the various injuries to which it may be subjected. The three main types of injuries are separation of the epiphysis through its epiphyseal plate, fractures that cross the epiphyseal plate, and crushing injuries of the plate itself.

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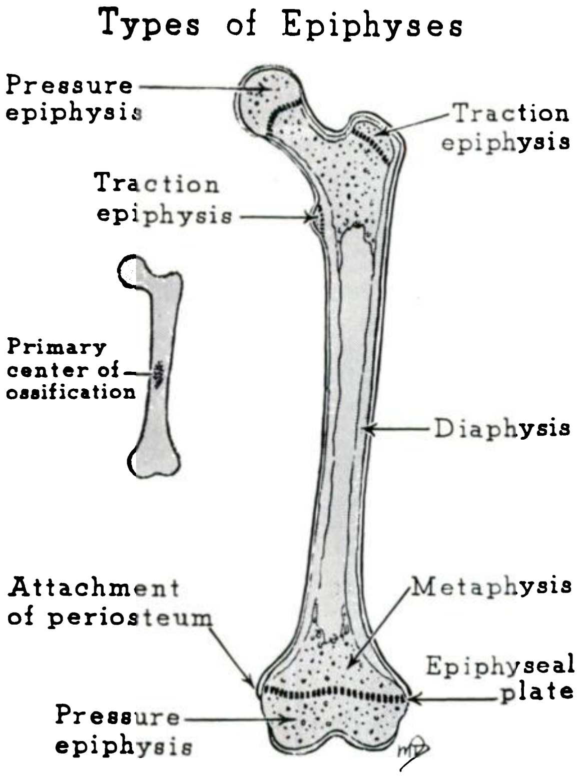


FIG. 1

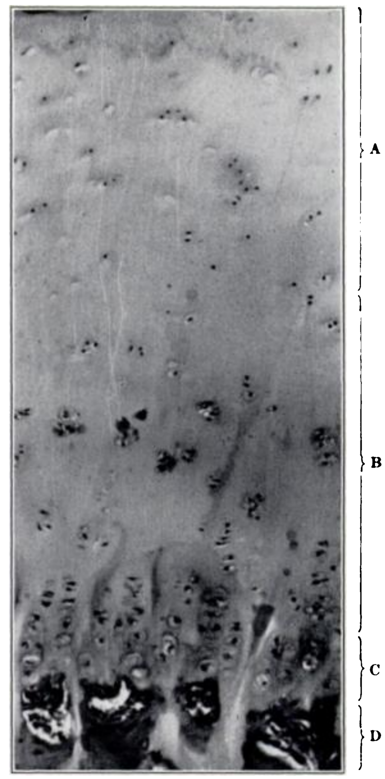


FIG. 2

Fig. 1: Types of epiphyses.
Fig. 2: Normal human epiphyseal plate showing the various layers. *A*, resting cells; *B*, proliferating cells; *C*, hypertrophying cells; and *D*, endochondral cells (metaphysis).

As seen in longitudinal section, the normal epiphyseal plate consists of four distinct layers (Fig. 2): (1) resting cells, (2) proliferating cells, (3) hypertrophying cells, and (4) endochondal ossification. The space between the cells is filled with cartilage matrix or intercellular substance. This intercellular substance, not the cells, provides the strength of the epiphyseal plate, particularly its resistance to shear. In common with the intercellular substance of other sorts of connective tissues, that of cartilage is made up of collagen fibers embedded in an amorphous cement substance containing chondroitin sulphuric acid. Because the refractive indices of these two components are the same, the collagen fibers cannot be identified in ordinary preparations, but they can be seen by special techniques, such as phase-contrast microscopy.

In the matrix of the epiphyseal plate, the collagen fibers are arranged longitudinally and no doubt play a role similar to that of steel rods in reinforced concrete. In the first two layers of the plate, the matrix is abundant and the plate is strong. In the third layer (hypertrophied cells), the matrix is scanty and the plate is weak. On the metaphyseal side of this layer, however, the matrix is calcified, forming the so-called zone of provisional calcification. The addition of calcification seems to reinforce this part of the third layer, since the plane of cleavage after separation lies in the third layer at approximately the junction of the calcified and uncalcified parts.

It seems logical, then, that the constancy of the plane of cleavage is the direct result of the structural details of the normal plate. The great significance of the constant location of the plane of cleavage following complete epiphyseal separation

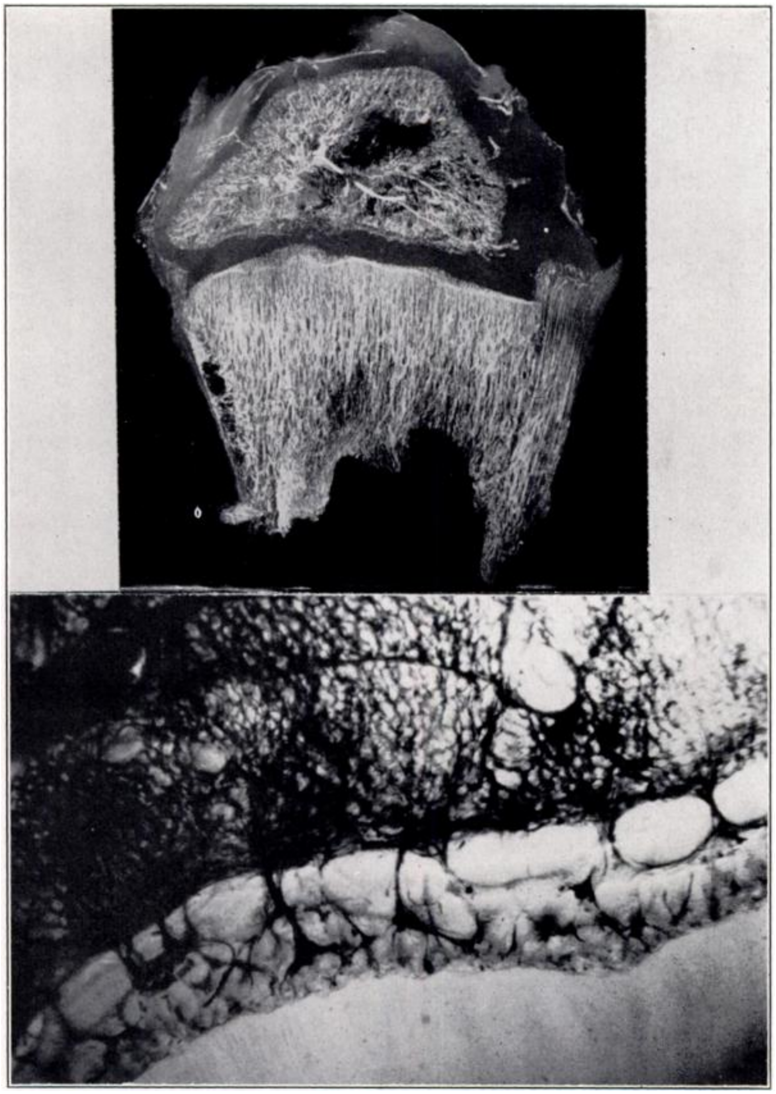


FIG. 3

Distal radial epiphysis in the rabbit. Top: Low-power microangiogram, showing the general pattern of epiphyseal and metaphyseal vessels. Bottom: High-power view (Spalteholz India-ink technique) showing the anastomosing network of vessels arising from the epiphysis and penetrating its cortical bone plate to terminate in vascular tufts in the resting layer of the epiphyseal plate.

is that the growing cells remain attached to the epiphysis. Thus, if the nutrition of these cells is not damaged by the separation, there is no reason why normal growth should not continue. The crux of the problem, then, is not the mechanical damage to the plate, but whether the separation interferes with the blood supply of the epiphysis.

Fractures that cross the epiphyseal plate and crushing injuries of the epiphyseal plate present additional problems that will be discussed later.

Mechanism of Nutrition in Epiphyseal Plates

Injection studies demonstrate two separate systems of blood vessels to the epiphyseal plate [19]. The epiphyseal system arises from vessels in the epiphysis that penetrate the bone plate of the epiphysis and end in capillary tufts or loops in the layer of resting cells of the plate (Fig. 3). The metaphyseal system arises in the

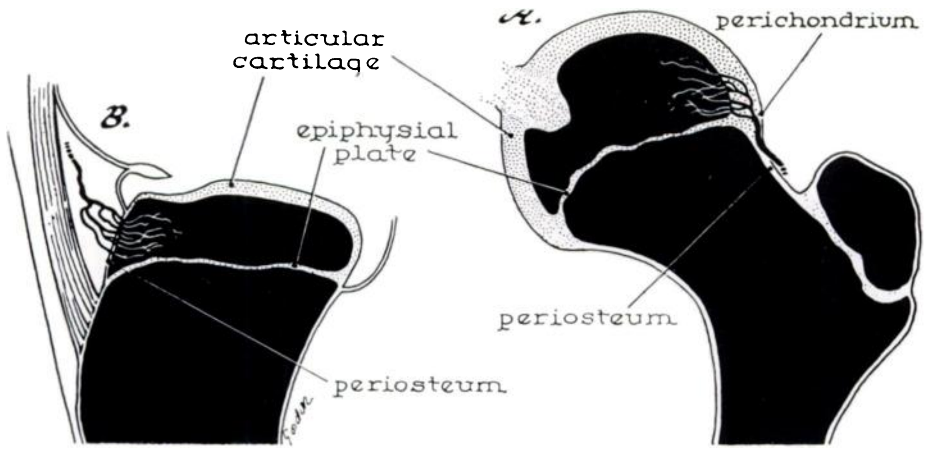


FIG. 4-A

The two methods by which blood vessels enter epiphyses.

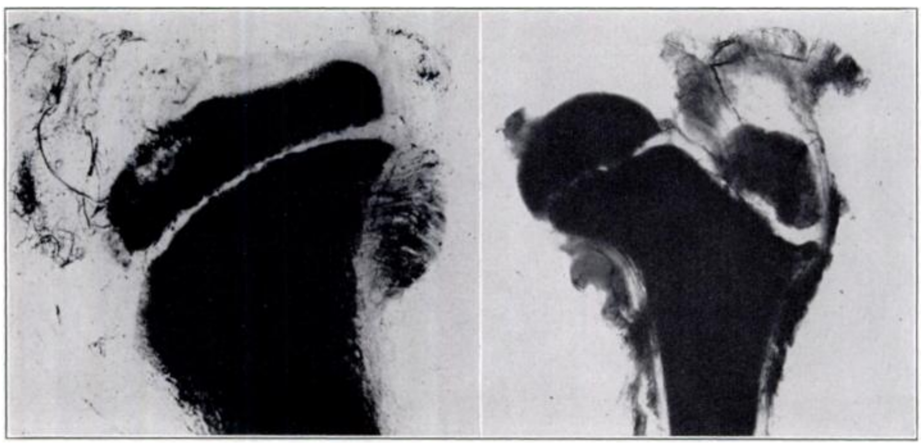


FIG. 4-B

Injected specimens from a monkey, showing nutrient vessels to the femoral head and upper tibial epiphysis. (Figs. 4-A and 4-B reprinted from Prognosis of Epiphyseal Separation by G. G. Dale and W. R. Harris. J. Bone and Joint Surg., 40-B: 117, Feb. 1958.)

marrow of the shaft, and ends in vascular loops in the layer of endochondral ossification. By selectively damaging one or other of these two systems, it can be shown that the former is responsible for the nutrition of the proliferating cells, while the latter is responsible for the nutrition of the cells involved in endochondral ossification [20].

The nutrient vessels of the epiphysis (from which the terminal vascular loops to the epiphyseal side of the plate are derived) enter in one of two ways (Figs. 4-A and 4-B)[12]. The first, and commoner, occurs when the sides of the epiphysis are covered with periosteum. The nutrient vessels penetrate the side of the epiphysis at a point remote from the epiphyseal plate. The second, decidedly less common, occurs when the entire epiphysis is intra-articular and, hence, covered with articular cartilage. The nutrient vessels then enter the epiphysis by traversing the rim of the epiphyseal plate. It is easy to see that the vessels to this type of epiphysis might be ruptured in the event of epiphyseal separation. The upper femoral epiphysis is the main example of this type; the upper radial epiphysis probably belongs to this group as well.

Relative Strength of the Epiphyseal Plate

The cartilaginous epiphyseal plate is obviously weaker than bone, and yet fractures through bone are much commoner in childhood than epiphyseal separations. The explanation for this apparent paradox probably is that only shearing forces and avulsion forces are capable of separating an epiphysis.

The epiphyseal plate is also weaker than normal tendons and ligaments in children. For this reason, injuries that may result in complete tear of a major ligament in the adult actually produce a separation of the epiphysis in the child. For example, an abduction injury of a child's knee results in epiphyseal separation rather than in rupture of the medial collateral ligament of the knee; abduction injury of the elbow avulses the medial epicondyle instead of rupturing the medial ligament of the elbow. Thus, tears or ruptures of major ligaments are very uncommon in childhood. Every child suspected of having torn a major ligament should have roentgenographic examination of the epiphyses of the area.

Similarly, the epiphyseal plate is not as strong as the fibrous joint capsule. Hence, traumatic dislocation of major joints, such as the shoulder, hip, and knee,

TABLE I

Major Long Bones: Percentage Contribution to Growth of the Epiphyses

Humerus		Femur	
Upper end	80%	Upper end	30%
Lower end	20%	Lower end	70%
Radius		Tibia	
Upper end	25%	Upper end	55%
Lower end	75%	Lower end	45%
Ulna		Fibula	
Upper end	20%	Upper end	60%
Lower end	80%	Lower end	40%

are decidedly less common in childhood than epiphyseal separations in these locations. For example, the injury that usually produces an anterior dislocation of the shoulder in an adult is likely to produce separation of the upper humeral epiphysis in a child.

Relative Growth at the Ends of Major Long Bones

In the lower extremity, longitudinal growth occurs more in the region of the knee than of the hip or ankle. By contrast, in the upper extremity there is more longitudinal growth at the shoulder and wrist than at the elbow. The approximate percentages of growth at the ends of major long bones, as determined by several workers, are shown in Table I.

INJURIES INVOLVING PRESSURE EPIPHYSES

Of all injuries to the long bones during childhood approximately 15 per cent involve the epiphyseal plate [6,11].

Age and Sex Incidence

Although injuries to the epiphyseal plates may occur at any age during childhood, they are somewhat commoner in periods of rapid skeletal growth, in the first year, and during the prepuberty growth spurt. These injuries—and others— are more frequent in boys than in girls, presumably because of the more active physical life of boys.

Site

In general, epiphyseal plates that provide the most growth are most commonly separated by injury. This is not true, however, of two types of epiphyseal injury—fractures that cross or crush the epiphyseal plate.

The lower radial epiphyseal plate is by far the one most frequently separated by injury; indeed, injuries to this epiphyseal plate are nearly as frequent as all other injuries to the epiphyseal plates combined [13]. In order of decreasing frequency, slipping is found in the lower ulnar, lower humeral (lateral condyle), upper radial (head), lower tibial, lower femoral, upper humeral, upper femoral (head), upper tibial, and phalangeal epiphyseal plates.

Etiology of Injuries to the Epiphyseal Plate

Trauma to an epiphyseal plate is usually one of four main types: shearing, avulsion, splitting, or crushing. Each mechanism tends to produce a characteristic type of lesion. The injury may be either closed or open. Open injury, although rare, is more likely to be associated with disturbance of growth.

Certain diseases, such as scurvy, rickets, osteomyelitis, and endocrine imbalance, make the epiphyseal plate more vulnerable to injury and therefore predispose to pathological separation of the epiphysis.

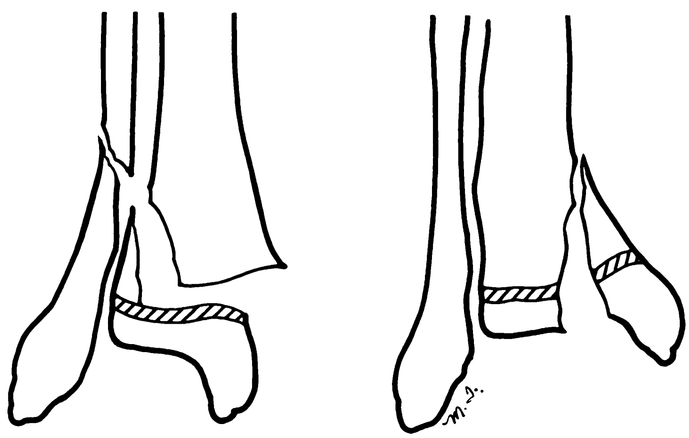


FIG. 5

Diagram to show the two basic types of epiphyseal injury: left, separation of the epiphysis; right, fracture at right angles to the diameter of the plate. (Reprinted from Epiphyseal Injuries by W. R. Harris. Instructional Course Lectures, The American Academy of Orthopaedic Surgeons, Vol. 15, p. 206. Ann Arbor, J. W. Edwards, 1958.)

Iatrogenic damage to epiphyseal plates is preventable. Such damage may occur during overzealous manipulation of deformities or during such operative procedures as removal of a tibial-bone graft, curettage of a metaphyseal bone cyst, excision of metaphyseal tumors (exostoses), and injudicious use of metal fixation across epiphyseal plates.

Experimental Epiphyseal Injuries

Experimental epiphyseal injuries are easy to produce. Study of such experimental injuries provides the basis of determining both clinical treatment and prognosis. Experimental epiphyseal injuries will be discussed under two headings: (1) separation of all or part of the epiphysis from the shaft, and (2) a fracture that crosses the epiphyseal plate (Fig. 5). In general, the former has a good prognosis; the latter, a bad one.

EPIPHYSEAL SEPARATION

Gross Appearance

Epiphyseal separation can be produced in a growing animal by closed manipu-

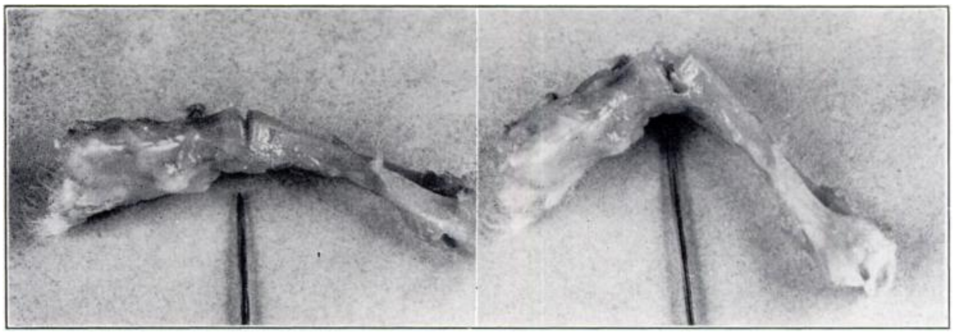


FIG. 6

Fig. 6: Separation of the distal radial epiphysis in the rabbit, showing the hinge effect of the intact periosteum.

Fig. 7: Separation of the distal radial epiphysis in the rabbit; the plane of cleavage almost always occurs through the layer of hypertrophied cells.

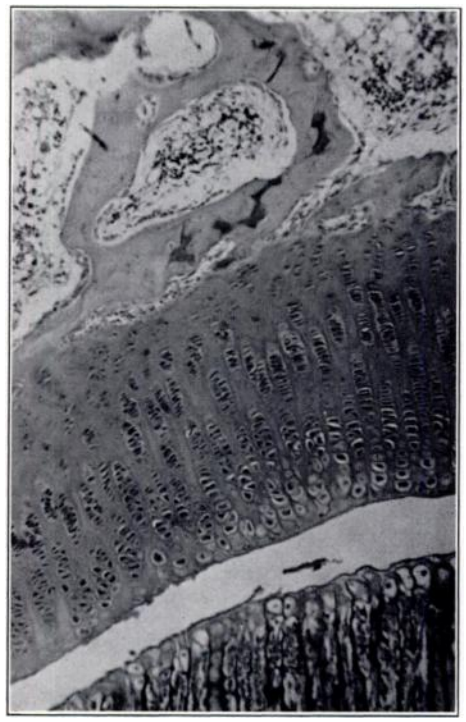


FIG. 7

lation, for example, by manual hyperextension of the forepaw. Study of the dissected specimen reveals that the periosteum on the "convex" side of the epiphyseal-plate displacement is ruptured, while on the "concave" side the periosteum is intact and acts as a hinge (Fig. 6). The hinge, which is slack when the epiphysis is in the displaced position, becomes taut when the epiphysis is reduced. This prevents overreduction and also makes the reduction stable, so that the simplest form of external fixation keeps the epiphysis correctly reduced.

Microscopic Appearance

The most striking microscopic feature of experimental separation is the constancy of the plane of cleavage. This cleavage is almost invariably on the diaphyseal side of the epiphyseal plate through the area of hypertrophied cartilage cells (Fig. 7). The fracture line occasionally deviates into the shaft, leaving a triangular fragment of the metaphysis attached to the epiphysis.

Healing after Experimental Epiphyseal Separation

Epiphyses Partly Covered with Articular Cartilage

When the distal radial epiphysis is separated from its shaft, at first there is a remarkable increase in thickness of the proliferating layer of the epiphyseal plate (Fig. 8). This is because the separation temporarily interferes with endochondral ossification, and the hypertrophied cartilaginous cells are not reabsorbed in the usual way. This increased thickness reaches its peak in about ten days. Thereafter, endochondral ossification resumes, and very rapidly the histological features return to normal. After three weeks, healing is complete, and it is difficult to recognize that anything has happened to the plate [12].

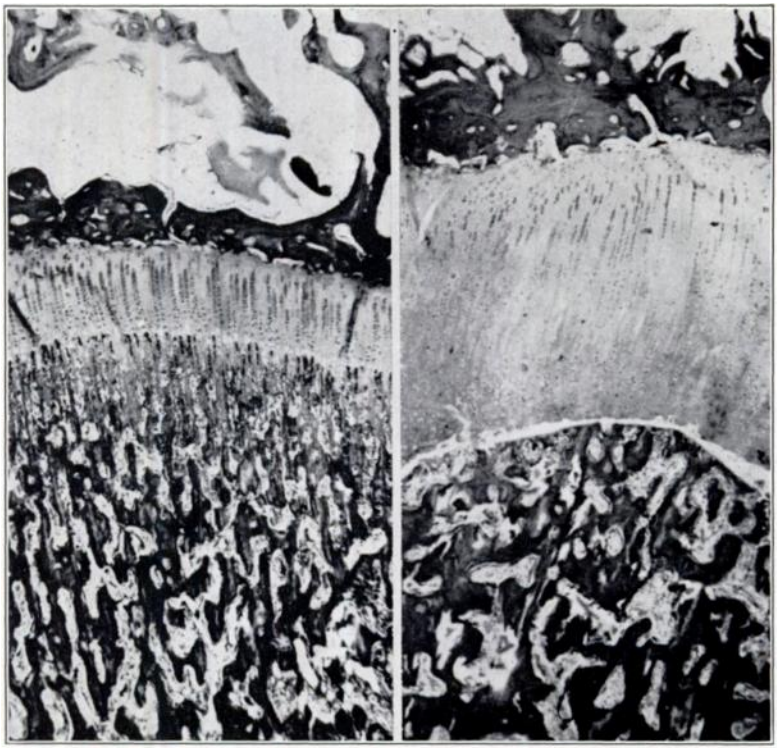


FIG. 8

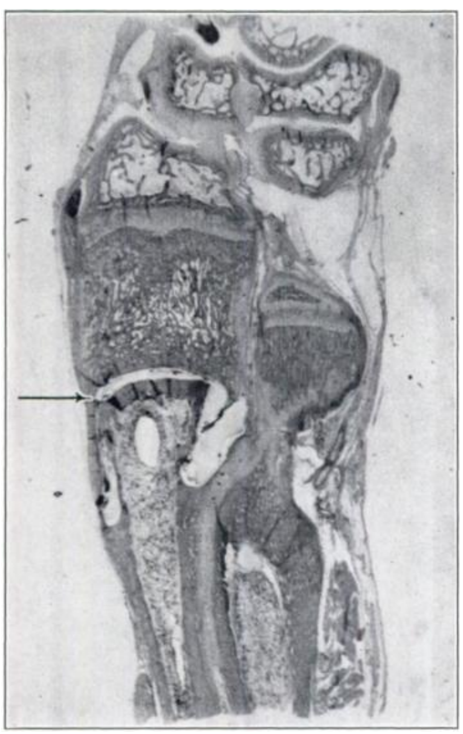


FIG. 9

Fig. 8: Ten days after separation of the distal radial epiphysis in a rabbit. Note the enormous thickening of the separated plate (right) in comparison with the untreated side (left).

Fig. 9: Continued growth on the distal radial epiphysis three weeks after a sheet of teflon had been interposed between the separated epiphysis and the shaft. Arrow indicates site of teflon.

The remarkable capacity of this sort of epiphysis for continued growth after separation can be shown even more dramatically when an impermeable membrane, such as teflon, is interposed between the separated epiphysis and shaft [14]. After three weeks, the epiphysis has grown away from the teflon membrane and normal endochondral ossification has resumed, leaving a pseudarthrosis in the shaft at the site of the separation (Fig. 9).

Epiphyses Entirely Covered with Articular Cartilage

When the upper femoral epiphysis is separated in young animals healing follows quite a different course [15]. Within three to five days avascular necrosis of the epiphysis can be recognized both by the empty bone lacunae and by atrophy of the marrow. At the same time growth in the epiphyseal plate ceases, as is shown by marked narrowing of the cartilaginous plate and atrophy and irregular arrangement of the cells (Fig. 10). New bone growing up from the femoral neck unites

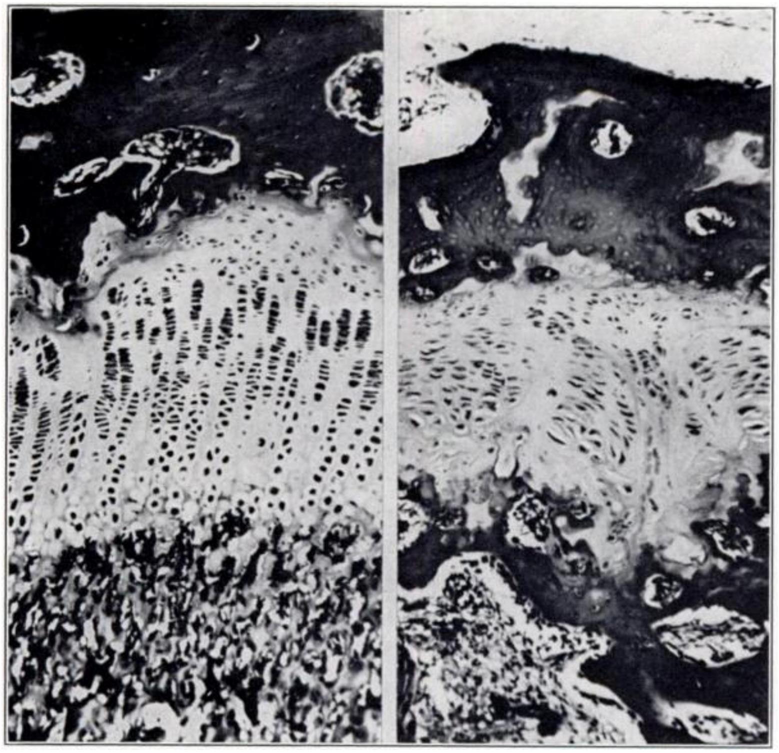


FIG. 10

Marked narrowing and disorganization of the upper femoral epiphyseal plate in a rabbit ten days after separation; note also the avascular necrosis of the bone in the epiphysis (normal control on left).

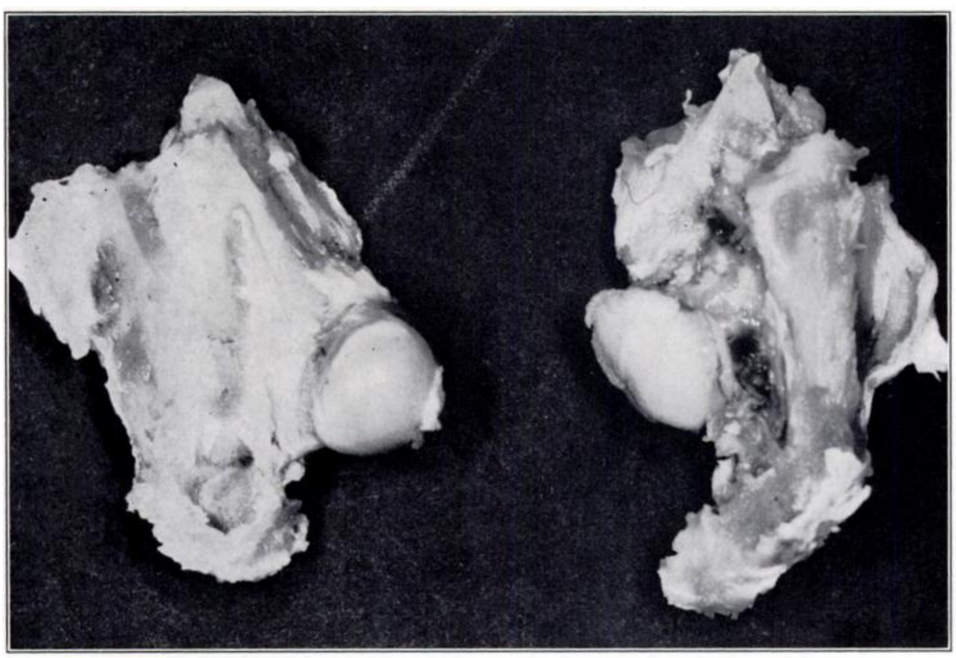


FIG. 11

Avascular collapse of the proximal femoral epiphysis (left) in a rabbit six weeks after separation with normal side for comparison (right). (Figs. 10 and 11 are reprinted from Histological Changes in Experimentally Displaced Upper Femoral Epiphysis in Rabbits by W. R. Harris and K. W. Hobson. J. Bone and Joint Surg., 38-B: 915, 918, Nov. 1956.)

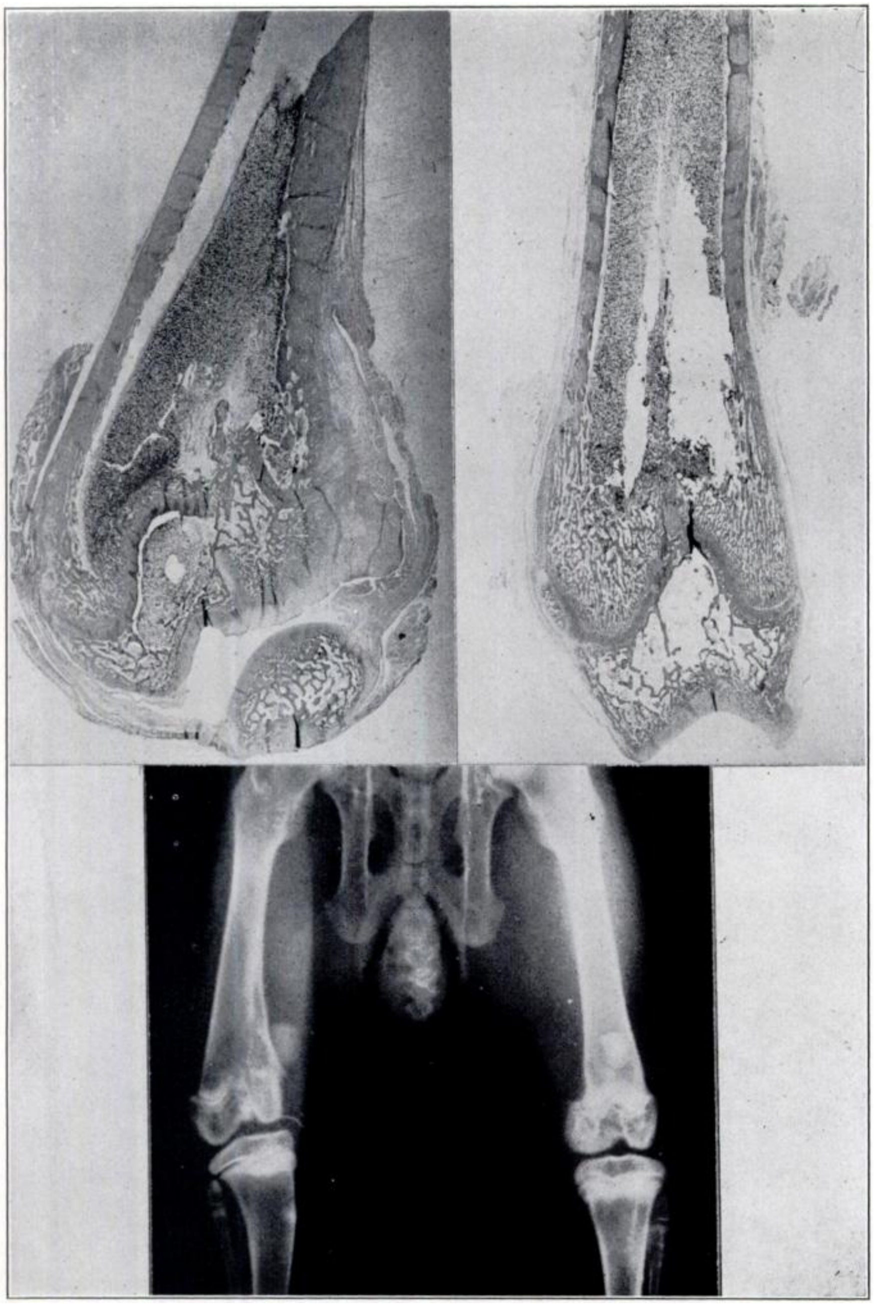


FIG. 12-A

Top: Distal femoral epiphyses of a rabbit six weeks after an experimental fracture traversing the left epiphyseal plate. Bottom: Roentgenogram of the same epiphysis.

the neck with the head, eventually penetrates the remnants of the epiphyseal plate, and reossifies the epiphysis which by then is totally necrotic. Generally, this process is so time-consuming that the typical features of avascular collapse occur (Fig. 11).

In studying such material, one notes that the remnants of the epiphyseal plate seem to act as a barrier to successful reossification of the epiphysis and that if this barrier were removed, reossification would be more rapid and more nearly complete. The experiment was repeated in exactly the same manner as before,

FIG. 12-B

Top: Distal femoral epiphyses in a rabbit six weeks after experimental fracture and accurate open reduction of the left epiphysis. Bottom: Roentgenogram of the same epiphysis. (The screw was placed in the epiphysis for technical convenience. In clinical cases, it is advisable to place the screw across the metaphysis if the fragments are big enough.)

except that the remnants of the epiphyseal plate were deliberately excised before reducing the separation. Although the head again underwent avascular necrosis, it was very rapidly reossified, so that avascular collapse of the epiphysis did not occur [15].

These observations indicate that the prognosis concerning future growth after complete epiphyseal separation ultimately depends on the fate of the nutrient vessels to the epiphysis.

FRACTURES THAT CROSS THE EPIPHYSEAL PLATE

These injuries present a completely different problem, because the injury causes mechanical interference with the growth of the epiphyseal plate without necessarily damaging its blood supply. This injury can be produced experimentally by exposing an epiphysis surgically, and, with a small osteotome, creating a vertical fracture extending from the epiphysis across the epiphyseal plate into the diaphysis. Microscopically, this procedure creates a gap in the epiphyseal plate. This gap then fills with bone, so the epiphysis is fused to the metaphysis in this area.

If there is no longitudinal displacement of the fragments, the epiphyseal plate in each continues to grow for a surprising length of time, but finally premature closure of each piece occurs, and the extremity ends up shorter than its fellow, but without deformity. However, if there is longitudinal displacement of one fragment in relation to the other, fusion occurs between the epiphysis of one fragment and the metaphysis of the other. When this happens, premature fusion of the plate occurs first (and sometimes only) in the displaced fragment, thus producing an increasing deformity of the end of the bone.

The tendency to produce deformity can be prevented by accurate reduction of the experimental separation and by holding the fragments in position with some form of internal fixation, such as a transverse screw, between the two fragments of metaphysis. While the gap in the epiphyseal plate never completely heals, if it has been closed sufficiently bone does not seem to grow across it. In an experimental series in which accurate reduction was maintained, there was no deformity and little, if any, decrease in the length of this limb compared with the other side at the conclusion of growth (Figs. 12-A and 12-B).

SOME CLINICAL APPLICATIONS

Epiphyseal Separations

In this injury the growing cells remain in the epiphysis, and the prognosis is good unless the injury simultaneously damages the nutrient vessels to the epiphysis. Vascular damage occurs most readily in epiphyses that are entirely covered by articular cartilage. This accounts for the high incidence of avascular necrosis of the femoral head in slipped femoral epiphysis. When the blood supply to an epiphysis appears to be destroyed, avascular collapse can be prevented by deliberately removing the remnants of the plate from the epiphysis, thus facilitating more rapid reossification.

Healing of the epiphyseal separations when there is no vascular damage is very rapid and is complete in three weeks. Thus, there seems to be little indication for continuing external immobilization beyond this interval, particularly as the hinge effect of the periosteum makes the reduction stable.

Fractures That Cross the Epiphyseal Plate

In this type of injury the gap created in the epiphyseal plate fills with bone. Premature closure of the plate and a shortened extremity result. If there has been longitudinal displacement of the fragments, the limb will be deformed as well. Both shortening and deformity can be prevented, at least experimentally, by accurate reduction with internal fixation. It thus seems worth while to perform reduction in clinical cases, particularly if the child is young and considerable

FIG. 13

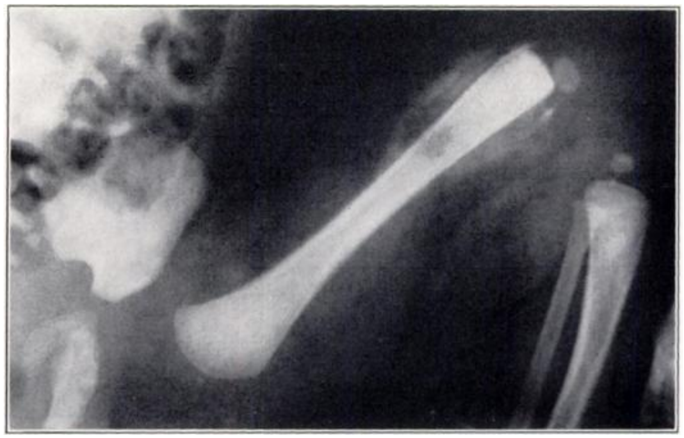


FIG. 14-A

Fig. 13: Type I epiphyseal-plate injury: separation of the epiphysis.

Fig. 14-A: Birth injury, lower femoral epiphysis (Type I). Roentgenogram made ten days after birth shows slight posterior displacement of the epiphysis and considerable subperiosteal formation of new bone.

FIG. 14-B

Roentgenogram made one year after birth injury shows virtually no deformity.

growth is anticipated. Because of the disastrous outcome when the blood supply to the epiphysis is damaged, such open procedures should be carefully performed, and if internal fixation is used it should be in the metaphysis rather than the epiphysis.

DIAGNOSIS OF EPIPHYSEAL-PLATE INJURIES

Clinical Diagnosis

While the accurate diagnosis of epiphyseal-plate injuries depends on roentgenographic examination, such an injury should be suspected clinically in any child who shows evidence of fracture near the end of a long bone, dislocation, ligamentous rupture, or even severe sprain of a joint. It must be remembered that an epiphysis may be displaced at the moment of injury and then return to its normal position, in which case clinical examination is likely to be of considerable importance in recognizing the nature of the injury. The history of the mechanism of injury, while often inadequate, may lead one to suspect a crushing type of epiphyseal-plate injury which is difficult to detect roentgenographically.

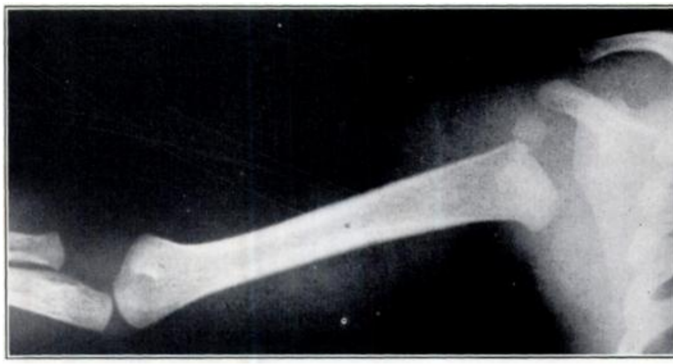


FIG. 15-A FIG. 15-B

Fig. 15-A: Type I injury of the upper right humeral epiphysis in early childhood. Humeral epiphysis remains in normal relationship with glenoid cavity but not with metaphysis.
Fig. 15-B: After reduction, normal relationship between epiphysis and metaphysis is restored.

FIG. 15-C

Ten days after reduction subperiosteal new-bone formation is apparent. No subsequent disturbance of growth.

Roentgenographic Diagnosis

Accurate interpretation of the roentgenograms of bones and joints in children necessitates a knowledge of the normal appearance of epiphyses and epiphyseal plates at various ages. Two views at right angles to each other are essential, and if doubt still exists it is prudent to obtain comparable views of the opposite uninjured extremity. The diagnosis of separation of an epiphysis before its ossification center has appeared is very difficult, but such a separation can be suspected if there is displacement of the metaphysis and roentgenographic evidence of associated soft-tissue swelling.

Possible Effects on Growth of Injury Involving the Epiphyseal Plate

Fortunately, most epiphyseal-plate injuries are not associated with any disturbance of growth. After separation of an epiphysis through its epiphyseal plate there may be a slight and transient acceleration of growth, in which case no significant deformity ensues.

The clinical problem associated with premature cessation of growth depends

FIG. 16-A

FIG. 16-B

Fig. 16-A: Type I pathological separations of both lower femoral and tibial epiphyses. Note roentgenographic evidence of scurvy.

Fig. 16-B: Two weeks after administration of vitamin C. Note ossification of subperiosteal hematomata. No subsequent disturbance of growth.

on several factors including the bone involved, the extent of involvement of the epiphyseal plate, and the amount of remaining growth normally expected in the involved epiphyseal plate.

If the entire epiphyseal plate ceases to grow, the result is progressive shortening without angulation. However, if the involved bone is one of a parallel pair (such as tibia and fibula or radius and ulna), progressive shortening of the one bone will produce progressive deformity in the neighboring joint. If growth in one part of the epiphyseal plate ceases but continues in the rest of the plate, progressive angulatory deformity occurs.

Cessation of growth does not necessarily occur immediately after injury to the epiphyseal plate, and, indeed, growth arrest may be delayed for six months or even longer. Furthermore, there may be a period of retardation before growth ceases completely.

CLASSIFICATION OF EPIPHYSEAL-PLATE INJURIES

Epiphyseal-plate injuries have been classified both generally and specifically (for a given epiphysis) by several authors [1-5,9,16]. The following classification is based on the mechanism of injury and the relationship of the fracture line to the growing cells of the epiphyseal plate. The classification is also correlated with the prognosis concerning disturbance of growth.

Type I (Fig. 13)

There is complete separation of the epiphysis from the metaphysis without any bone fracture. The growing cells of the epiphyseal plate remain with the epiphysis.

This type, the result of a shearing or avulsion force, is more common in birth

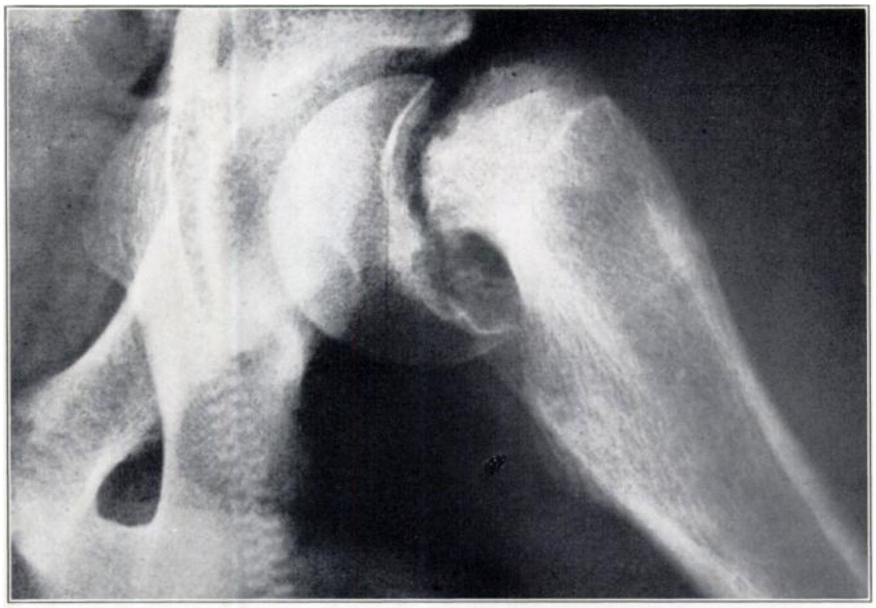


FIG. 17

Type I pathological separation of upper femoral epiphysis associated with endocrine imbalance.

FIG. 18-A

FIG. 18-B

Fig. 18-A: Obvious multiple fractures of the pelvis. Less obvious is the Type I traumatic separation of the right upper femoral epiphysis.

Fig. 18-B: Two months later, the right femoral head is dense, indicating avascular necrosis.

injuries (Figs. 14-A and 14-B) and in early childhood when the epiphyseal plate is relatively thick (Figs. 15-A, 15-B, and 15-C). It is also seen in pathological separations of the epiphysis associated with scurvy (Figs. 16-A and 16-B), rickets, osteomyelitis, and endocrine imbalance (Fig. 17). Wide displacement is uncommon because the periosteal attachment is usually intact.

Reduction is not difficult, and the prognosis for future growth is excellent unless the epiphysis involved is entirely covered by cartilage (for example, upper end of femur). In this case, the blood supply frequently is damaged with consequent premature closure of the epiphyseal plate (Figs. 18-A through 18-D).

Type II (Fig. 19)

In this commonest type of epiphyseal-plate injury, the line of separation

FIG. 18-C

Ten years after injury, there is marked shortening of femoral neck and coxa vara.

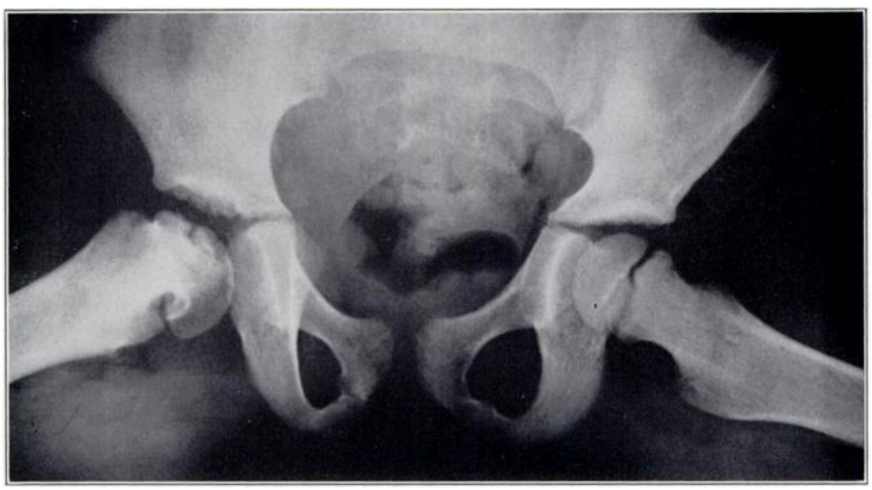


FIG. 18-D

Ten years after injury, there is residual coxa plana and marked shortening of femoral neck.

extends along the epiphyseal plate to a variable distance and then out through a portion of the metaphysis, thus producing the familiar triangular-shaped metaphyseal fragment sometimes referred to as Thurston Holland's sign. This injury usually occurs in children more than ten years old and is the result of either shearing injury or an avulsion force. The periosteum is torn on the convex side of the angulation but is intact on the concave side—the side on which the metaphyseal fragment is seen.

Reduction is relatively easy to obtain and maintain; because of the intact periosteal hinge and the metaphyseal fragment, overreduction cannot occur. The growing cartilage cells of the epiphyseal plate remain with the epiphysis; thus the prognosis for growth is excellent if the circulation to the epiphysis is intact, as it nearly always is (Figs. 20-A through 21-B).

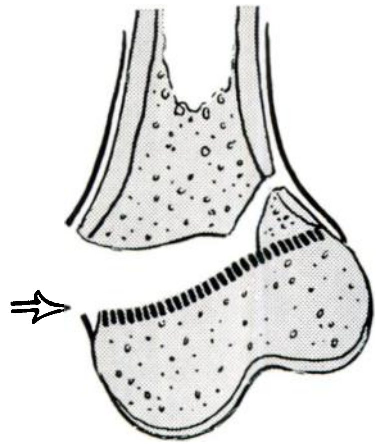


FIG. 19

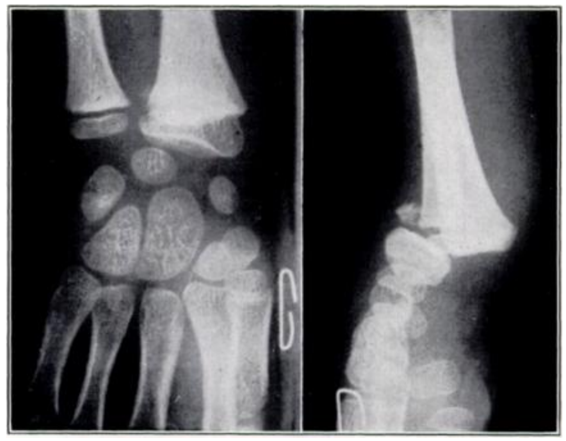


FIG. 20-A

Fig. 19: Type II epiphyseal-plate injury: fracture-separation of the epiphysis.
Fig. 20-A: Type II injury left lower radial epiphysis. Note the triangular metaphyseal fragment in lateral view.

FIG. 20-B

Type II injury right lower radial epiphysis in same patient with associated fracture lower end of ulna.

Type III (Fig. 22)

The fracture, which is intra-articular, extends from the joint surface to the weak zone of the epiphyseal plate and then extends along the plate to its periphery. This injury is uncommon, but when it does occur it is usually in either the upper or lower tibial epiphysis and is due to an intra-articular shearing force.

Accurate reduction is essential, not so much for the epiphyseal plate as for the restoration of a smooth joint surface. Open operation may be necessary to obtain such reduction (Figs. 23-A, 23-B, and 23-C). As in Type I and Type II injuries, the prognosis is good providing the blood supply to the separated portion of the epiphysis is intact (Figs. 24-A and 24-B).

Type IV (Fig. 25)

The fracture, which is intra-articular, extends from the joint surface through

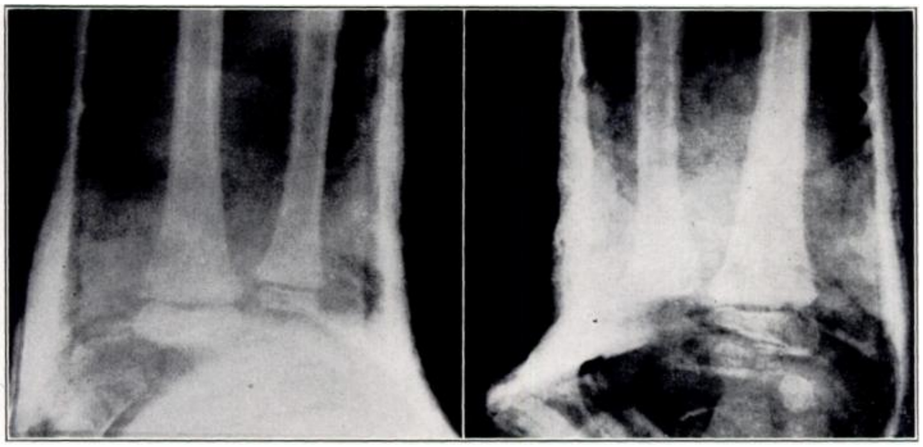


FIG. 20-C
Anteroposterior view of both wrists after closed reduction.

FIG. 20-D
Lateral view of both wrists after reduction. No subsequent growth disturbance.

FIG. 21-A
Type II injury lower tibial epiphysis. Note the large metaphyseal fragment.

the epiphysis, across the full thickness of the epiphyseal plate, and through a portion of the metaphysis, thereby producing a complete split. The commonest example of this type of injury is fracture of the lateral condyle of the humerus (Figs. 26-A and 26-B). Perfect reduction of a Type IV injury to the epiphyseal

FIG. 21-B
Position obtained by closed reduction. No subsequent disturbance of growth.

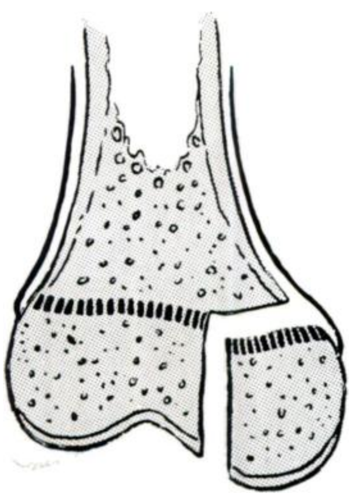


FIG. 22

FIG. 23-A

Fig. 22. Type III epiphyseal-plate injury: fracture of part of the epiphysis.
Fig. 23-A: Type III injury of anterolateral corner of the left lower tibial epiphysis, anteroposterior view.

plate is essential, for the sake not only of the epiphyseal plate but also of a smooth joint surface. Unless the fracture is undisplaced, open reduction is always necessary. The epiphyseal plate must be accurately realigned in order to prevent bone union across the plate with resultant local premature cessation of growth (Figs. 27-A and 27-B). If metal fixation is required to obtain stability, preferably it is placed across the metaphysis, although fine, smooth Kirschner wires which traverse the plate for a few weeks do not interfere with subsequent growth.

Type V (Fig. 28)

This relatively uncommon injury results from a very severe crushing force

Fig. 23-B

Fig. 23-C

Fig. 23-B: Lateral view.
Fig. 23-C: After open reduction. No internal fixation was necessary. (Wire is continuous intradermal wire suture in operative wound.) No subsequent disturbance of growth.

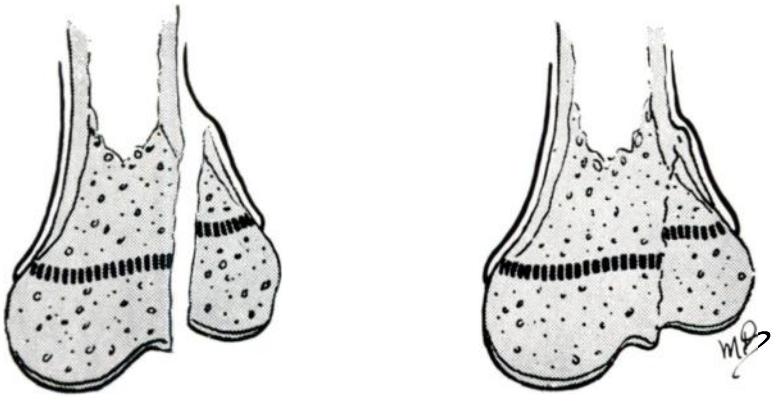
Fig. 24-A

Fig. 24-B

Fig. 24-A: Type III injury of the medial portion of the right lower tibial epiphysis.
Fig. 24-B: Three months after closed reduction. Joint surface has been restored. No subsequent disturbance of growth.

applied through the epiphysis to one area of the epiphyseal plate. It occurs in joints which move in one plane only, such as the ankle or the knee. A severe abduction or adduction injury to a joint that normally only flexes or extends is likely to produce crushing of the epiphyseal plate, which may separate. Displacement of the epiphysis is unusual under these circumstances, and the first roentgenogram gives little indication of the seriousness of the injury; indeed, the injury may be dismissed as a sprain [17].

One must suspect crushing of the epiphyseal plate when such an injury is



A FIG. 25 B

Type IV epiphyseal-plate injury: *A*, fracture of the epiphysis and epiphyseal plate; *B*, bone union and premature closure.

FIG. 26-A FIG. 26-B

Fig. 26-A: Type IV injury right lateral condyle of humerus (capitellum). Injury should have been treated by open reduction.

Fig. 26-B: Premature closure of the epiphyseal plate of the lateral condyle (left) five years later.

sustained. Weight-bearing must be avoided for three weeks in the hope of preventing the almost inevitable premature cessation of growth. The prognosis in Type V epiphyseal-plate injuries is decidedly poor (Figs. 29 and 30).

PROGNOSIS CONCERNING DISTURBANCE OF GROWTH

Significant disturbance of growth follows approximately 10 per cent of epiphyseal-plate injuries, and minor growth disturbances are seen after a higher percentage of injuries [6]. Although it is not possible to make a prognosis in a given child with a particular epiphyseal-plate injury with absolute accuracy, several factors help considerably in the estimate.

Factors in Prognosis

Type of epiphyseal-plate injury: The type of injury described anatomically in the authors' classification is important prognostically. In general, Types I, II, and III injuries have a good prognosis for growth provided the blood supply of the epiphysis is intact. For instance, the blood supply is particularly vulnerable to injury in the head of the femur and the head of the radius. Type IV epiphyseal

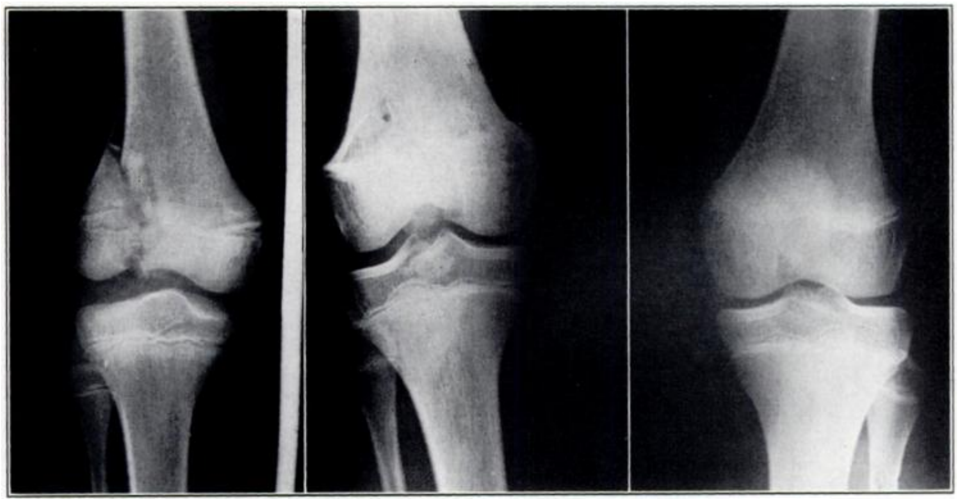
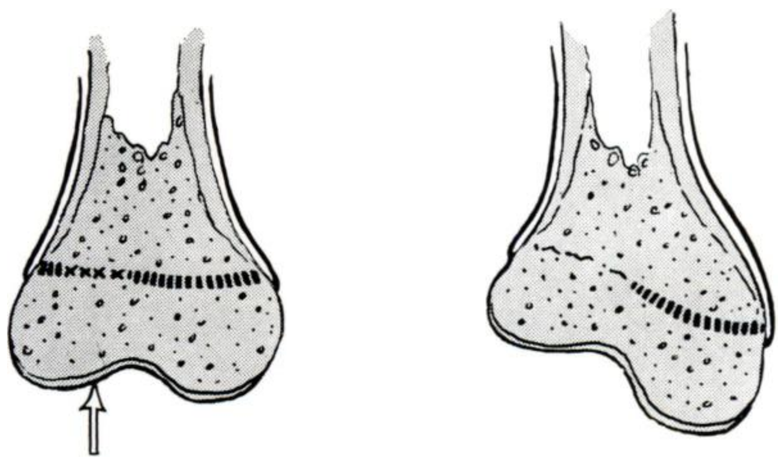


FIG. 27-A FIG. 27-B

Fig. 27-A: Type IV injury of lateral condyle of right femur. Injury should have been treated by open reduction to obtain completely accurate realignment of the epiphyseal plate and of the joint surface.

Fig. 27-B: Premature closure of the lower femoral epiphyseal plate with resultant shortening three years later.



A FIG. 28 B

Type V epiphyseal-plate injury: *A*, crushing of the epiphyseal plate; *B*, premature closure.

injuries carry a bad prognosis unless the epiphyseal plate is completely realigned. Type V injuries associated with actual crushing of the cartilaginous plate have the worst prognosis.

Age of the child at the time of injury: The age of the child is an indication of the amount of growth normally expected in the particular epiphyseal plate during the remaining years of growth. Obviously, the younger the child at the time of injury the more serious any growth disturbance will be, whereas even a serious injury incurred during the last year of growth will not produce a significant deformity since there is so little normal growth potential remaining.

Blood supply to the epiphysis: As we mentioned earlier, the epiphyseal plate is nourished by blood vessels of the epiphysis, and if this blood supply is destroyed the epiphyseal plate degenerates and growth ceases. Thus, interference with the blood supply to the epiphysis (a common complication of epiphyseal injuries of the femoral head and radial head) is associated with a poor prognosis.

Method of reduction: Unduly forceful manipulation of an epiphysis may injure

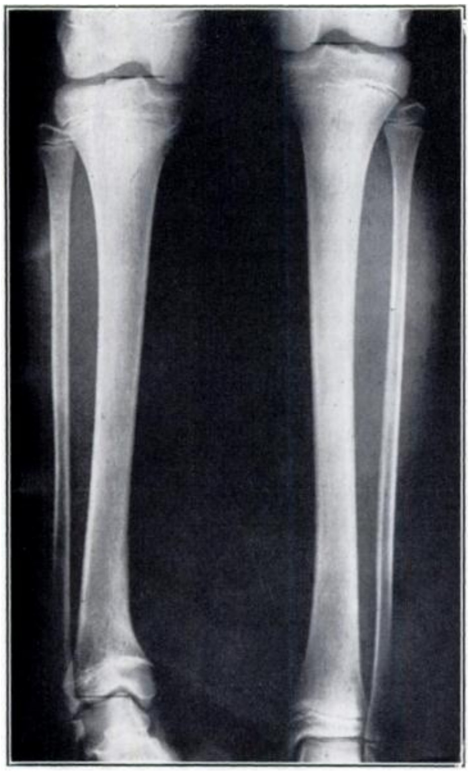


FIG. 29

FIG. 30

Fig. 29: Two years after Type V injury involving medial portion of right lower tibial epiphyseal plate. Note varus deformity of the right ankle and the discrepancy in leg length.

Fig. 30: Four years after Type V injury involving medial portion of the left upper tibial epiphyseal plate.

FIG. 31

Type II injury proximal phalanx of left ring finger. Note considerable rotational deformity at the fracture site.

the epiphyseal plate; this is particularly true if the manipulation is carried out after the tenth day following injury [13]. Likewise, the use of instruments to pry on an epiphyseal plate at time of open operation is deleterious to the plate. Screw nails or threaded wires which traverse the epiphyseal plate also increase the chances of premature cessation of growth.

Open or closed injury: Open injuries of the epiphyseal plate are uncommon. However, they have a poorer prognosis than closed injuries do because of the added factor of contamination and possible infection. If infection develops at the site of an epiphyseal-plate injury, the cartilaginous epiphyseal plate is usually destroyed by chondrolysis, and the prognosis is very poor indeed.

PRINCIPLES OF TREATMENT OF EPIPHYSEAL-PLATE INJURIES

Gentleness of reduction: In epiphyseal-plate injuries of Types I, II, and III, in contrast to fractures through bone, one of the fracture surfaces is composed of delicate, vulnerable cartilage of the epiphyseal plate. Consequently, unduly forceful manipulation of such an injury is to be avoided in order to prevent damage to the plate. This principle applies as well to surgical methods of reducing a displaced epiphysis at the time of open operation. No instrument should be used to pry a displaced epiphysis back into place.

Time of reduction: The best time to reduce an epiphyseal-plate injury is the day of the injury, since reduction becomes progressively more difficult with each day [10]. Indeed, after about ten days, the fragments, particularly in Type I and Type II, are difficult to shift without using excessive force. Under these circumstances, forceful manipulation may cause further damage to the cartilaginous plate and should be avoided; at this stage, therefore, it is wiser to accept an imperfect reduction than to risk the danger of either forceful manipulation or open operation. Corrective osteotomy can be performed later if necessary. In Type III and Type IV injuries, however, delayed reduction, although not desirable, is preferable to leaving the intra-articular fragment displaced.

Method of reduction—closed or open: The vast majority of Type I and Type II epiphyseal-plate injuries are readily reduced by closed means, and furthermore the reduction is easily maintained. Type III injuries may require open reduction to obtain a smooth joint surface, and displaced Type IV injuries nearly always require open reduction. When internal fixation is deemed necessary, it is preferable to place such fixation through the metaphysis rather than through the epiphysis. Although screws or threaded wires should never be inserted across the epiphyseal plate, fine, smooth Kirschner wires which cross the plate at right angles may be used safely, but they should be removed when the injury has healed [8]. Great care must be taken to avoid damage to the blood supply of the epiphysis.

Acceptable position of reduction: The contour of the epiphyseal plate is such that perfect reduction of Type I and Type II injuries is usually possible. If, however, there should be residual moderate displacement (anterior, posterior, medial, or lateral) or slight angulation, repeat manipulation is not necessary, since remodeling of the bone from the periosteum is adequate. The criteria for acceptable position are less rigid in the region of a multiplane joint, such as the shoulder, than in the region of a single plane joint, such as the knee or ankle. Type III and Type IV injuries must be perfectly reduced for reasons already mentioned.

Period of immobilization: Experience has shown that the three variations of epiphyseal separation (Types I, II, and III injuries) unite in approximately one-half the time required for union of a fracture through the metaphysis of the same bone in the same age group; therefore, the period of immobilization may be reduced correspondingly. This interesting phenomenon that has already been described in the experimental investigation is due to the unique process of healing in these injuries. Type IV injuries, by contrast, and because of their location, require the same period for union as metaphyseal fractures.

Indication of prognosis to the parents: In a given epiphyseal-plate injury, the prognosis concerning growth disturbance should be considered, at least in general terms, as described earlier. Part of the surgeon's responsibility in the treatment of these injuries is to provide the parents with some indication of the prognosis without causing them undue anxiety. The importance of follow-up examination needs to be stressed.

Follow-up observation: The need for regular follow-up observation of epiphyseal-plate injuries is obvious; just how long a period of observation is required is not always obvious. Since growth disturbance may be delayed, at least in its manifestations, for as long as one year, this period of observation is the minimum [11]. Six months after injury the injured bone and its opposite number in the normal uninjured extremity should be examined roentgenographically. If little growth has occurred in the normal, uninjured bone during this six-month period, a further six-month period must elapse before one can say with certainty that there is no disturbance of growth.

MANAGEMENT OF DEFORMITY DUE TO PREMATURE CESSATION OF GROWTH

After an epiphyseal-plate injury, local growth may either cease immediately or it may continue at a retarded rate for a variable period before complete cessation. Furthermore, the growth disturbance may involve either the entire epiphyseal plate or only one part of it. The resultant deformity is progressive until the end of the child's growing period. Thus, the gravity of the clinical problem depends on several factors, including the site of growth disturbance, the extent of involvement of the epiphyseal plate, and the expected amount of growth remaining in the involved plate. The main types of deformity that may develop are progressive angulation, progressive shortening, and a combination of both. Considerable judgment is required in planning the most effective management of these progressive deformities.

Progressive angulation: Retardation or cessation of growth in one area of the epiphyseal plate with continuation of growth in the remainder produces gradually increasing angulation. In this circumstance, growth in the remainder of the plate eventually ceases prematurely. Thus, the problem of shortening is added to that of angulation. It is usually preferable to deal with progressive angulation by open wedge osteotomy in order to preserve the growing potential of the undamaged portion of the epiphyseal plate and to gain some length in the extremity. Unless the entire epiphyseal plate has ceased growing, the osteotomy should overcorrect the deformity so that its inevitable recurrence may be delayed. When progressive angulation exists in a young child, it may be necessary to perform osteotomy more than once. Epiphyseal arrest by stapling may help to correct increasing angulation but only if the damaged area of the epiphyseal plate is still growing. However, this method has the disadvantage of producing further shortening of the involved extremity.

Progressive shortening: If one of two paired bones (radius or ulna, tibia or fibula) is the site of premature cessation of growth, the resultant discrepancy in length between the two bones will produce a progressive deformity (varus or valgus) of the nearest joint. For example, premature cessation of growth at the lower radial epiphyseal plate in the presence of continued growth at the lower ulnar epiphysis will produce an increasing valgus deformity or radial deviation of the hand. Therefore, it may be necessary either to lengthen the shorter bone surgically or to shorten the longer bone, and at the same time to arrest the growing epiphysis to prevent recurrence of deformity. When a single bone (femur or humerus) is the site of increasing shortening the problem is of discrepancy of limb length which is significant only in the lower extremity. Discussion of the various indications and methods for equalization of limb length is beyond the scope of this presentation.

SPECIFIC EPIPHYSEAL-PLATE INJURIES

A general knowledge of injuries to the epiphyseal plate is applicable to each specific site of injury. Nevertheless, since the specific epiphyses and their plates have various anatomical features, and since the forces applied to them differ, a few practical points concerning specific injuries merit mention.

Upper Extremity

Phalangeal Epiphyses

The epiphysis of the distal phalanx may be separated by sudden flexion injury in childhood. Clinically, the child's finger resembles a mallet or baseball finger since the flexor digitorum profundus tendon flexes the metaphysis into which it is inserted while the extensor tendon, being inserted into the epiphysis, maintains the epiphysis in the extended position. A lateral roentgenogram of the finger is needed to differentiate this type of epiphyseal-plate injury from a ruptured extensor tendon; the latter is uncommon in childhood, since the epiphyseal plate is weaker than the tendon. The epiphyseal displacement is readily reduced, and the reduction is easily maintained by a plaster splint for three weeks.

Epiphyseal-plate injury at the base of the proximal or middle phalanx is uncommon, but when it occurs it may be associated with considerable rotation at the line of separation (Fig. 31). The rotational deformity must be accurately reduced so the involved finger will be in proper relationship with its neighbors in both the flexed and extended positions.

Lower Radial Epiphysis

The lower end of the radius is by far the commonest site of epiphyseal-plate injury. The injury, almost invariably Type II, usually occurs in children more than ten years old and is comparable to the common Colles fracture in adults. In the epiphyseal-plate injury, however, there is little fracture hematoma, and local anesthesia is unsatisfactory. Reduction should be performed using general anesthesia. Reduction is readily obtained, the intact hinge of periosteum on the dorsal aspect of the radius preventing overcorrection (Figs. 20-A through 20-D). The plaster cast should extend above the elbow and be well molded, with the forearm pronated and the wrist ulnar deviated and slightly flexed. Immobilization for three weeks is adequate.

Prognosis is good, even if there is slight residual angulation, because remodeling at this site is very satisfactory; late osteotomy is seldom indicated [1]. In more severe injuries of the wrist the lower ulnar epiphyseal plate also may be separated.

Upper Radial Epiphysis

The common type of injury at this site is Type II, produced by a valgus force on the elbow, with resultant angulation of the radial head (Figs. 32-A, 32-B, and 32-C). Unless the angulation is extreme, reduction usually can be obtained by holding the extended elbow in varus and pressing directly over the radial head. If there is more than 15 degrees residual angulation after closed reduction, the radiohumeral joint will not function smoothly, and permanent limitation of supi-

FIG. 32-A

FIG. 32-B

Fig. 32-A: Type II injury left upper radial epiphysis from an abduction injury. Note the valgus deformity at the fracture site.
Fig. 32-B: Position obtained by closed reduction.

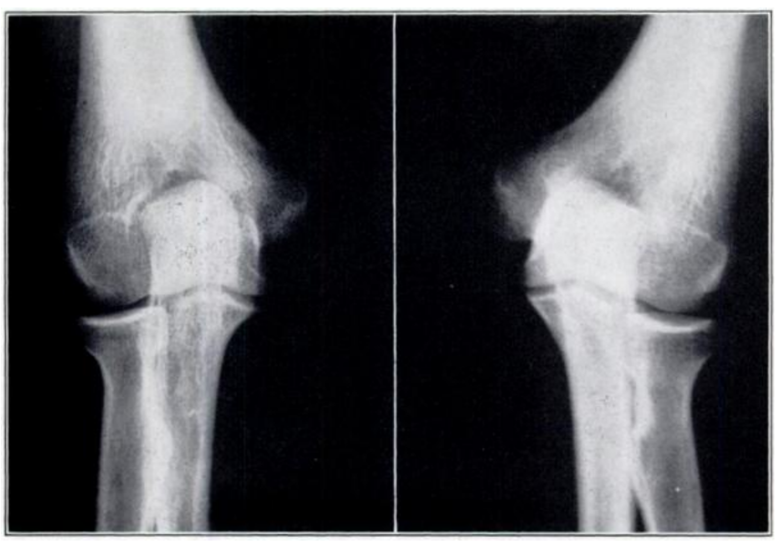


FIG. 32-C
Ten years later, there is no disturbance of growth.

nation and pronation may result. With this much angulation after manipulation, open reduction is indicated. The radial head should never be excised in children because the resultant loss of growth in the radius inevitably will produce progressive radial deviation at the wrist joint and progressive valgus deformity at the elbow.

A less common, but more serious, injury of the upper radial epiphysis is complete separation of the radial head with wide displacement and associated dislocation of the elbow joint. Open reduction is indicated, but even though the radial head is devoid of soft-tissue attachment — and therefore devoid of blood supply— it should be replaced. Premature closure of the epiphyseal plate is inevitable because of interference with blood supply, but since this type of injury usually occurs in an older child significant deformity is rare.

Lower Humeral Epiphysis (Lateral Condyle)

Fracture of the lateral condyle of the humerus (capitellum) is a Type IV injury of the epiphyseal plate, and as such it is a serious injury with potential problems related to union and growth [7]. Even when the initial displacement of the capitellum is slight, it tends to increase during the ensuing period of immobilization; weekly roentgenographic examinations are necessary to be sure that progressive displacement does not occur.

When the fracture is displaced, open reduction is clearly indicated, not only to restore a smooth joint surface but also to realign the epiphyseal plate (Fig. 33). Internal fixation may be obtained either by multiple sutures in the periosteum or

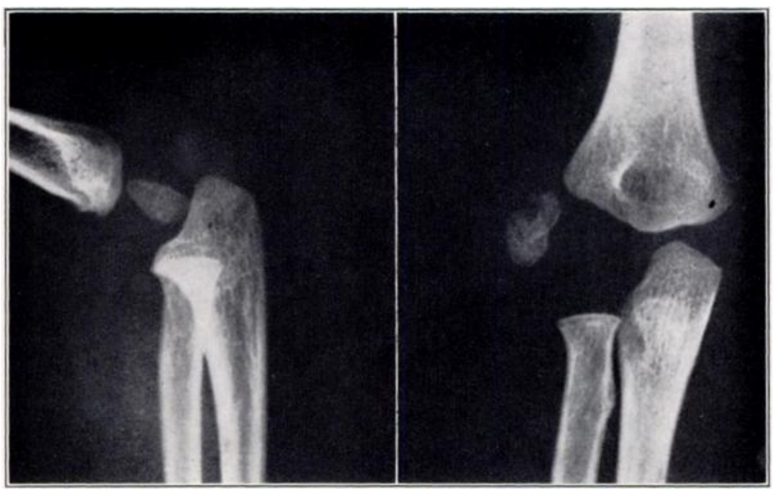


FIG. 33

Type IV injury of lateral condyle (capitellum) of right humerus with rotation and angulation of fragment. This injury must be treated by open operation.

by two fine removable Kirschner wires. The elbow should be immobilized for three weeks at 90 degrees; a more flexed position tends to displace the capitellum laterally. Failure to obtain or maintain accurate reduction of the fractured lateral condyle inevitably results either in delayed union, in non-union with secondary overgrowth of the radial head, or in premature cessation of growth with progressive valgus deformity of the elbow and tardy ulnar-nerve paralysis (Fig. 26).

Upper Humeral Epiphysis

Epiphyseal-plate injuries at the upper end of the humerus are either Type I, in young children, or Type II, in children more than ten years old (Fig. 34-A and 34-B). The wide range of circumduction at the shoulder joint probably explains the absence of Types III, IV, and V injuries at this site. Reduction may be difficult because of inability to control the mobile head of the humerus, but traction on the humerus with the arm in the overhead position usually will reduce the displacement. Perfect reduction is not necessary, since remodeling of the upper end of the humerus from the periosteal tube is very satisfactory [7]. Open reduction is almost

FIG. 34-A

FIG. 34-B

Fig. 34-A: Type II injury of left upper humeral epiphysis, demonstrated by supero-inferior roentgenogram with arm abducted.

Fig. 34-B: Position obtained and maintained by closed reduction. No subsequent disturbance of growth.

FIG. 35-A

FIG. 35-B

Fig. 35-A: Type V injury involving right lower tibial epiphysis with associated fracture of the fibula. Note the relatively slight displacement of the tibial epiphysis.

Fig. 35-B: One year later, there is varus deformity of the ankle owing to premature closure of the medial portion of the lower tibial epiphyseal plate. The lateral portion of the epiphyseal plate is almost closed and fibular overgrowth is already apparent.

never necessary, except on rare occasions when the long head of the biceps becomes trapped in the fracture site [16]. After reduction, the shoulder should be immobilized for three weeks in the "salute position" in a full shoulder spica cast and protected by a sling for a further week.

Lower Extremity

Lower Tibial Epiphysis

The lower tibial epiphyseal plate is subjected to a variety of injuries, because, in contrast to the shoulder, the ankle joint moves in only one plane and is very stable in all other planes [9]. Type II injuries of the lower tibial epiphysis usually can be managed by closed reduction (Figs. 21-A and 21-B). Type III injuries, which occur more frequently at this site than elsewhere, require perfect reduction in order to restore a smooth joint surface; open operation thus may be necessary (Figs. 23-A, 23-B, and 23-C). The lower tibial epiphysis is also the commonest site of the crushing Type V injury, which in the ankle is usually the result of a severe varus force. This kind of injury consistently carries a poor prognosis for growth (Figs. 29, 35-A, and 35-B). Since there may be little or no displacement of the epiphysis in the Type V injury, the child may be considered to have simply a severe sprain of the ankle [17]; the true nature of the injury may not be suspected until premature cessation of growth is established.

Upper Tibial Epiphysis

The epiphyseal plate of the upper tibial epiphysis is quite irregular and includes the long anterior tongue of the tibial tubercle; hence, epiphyseal separa-

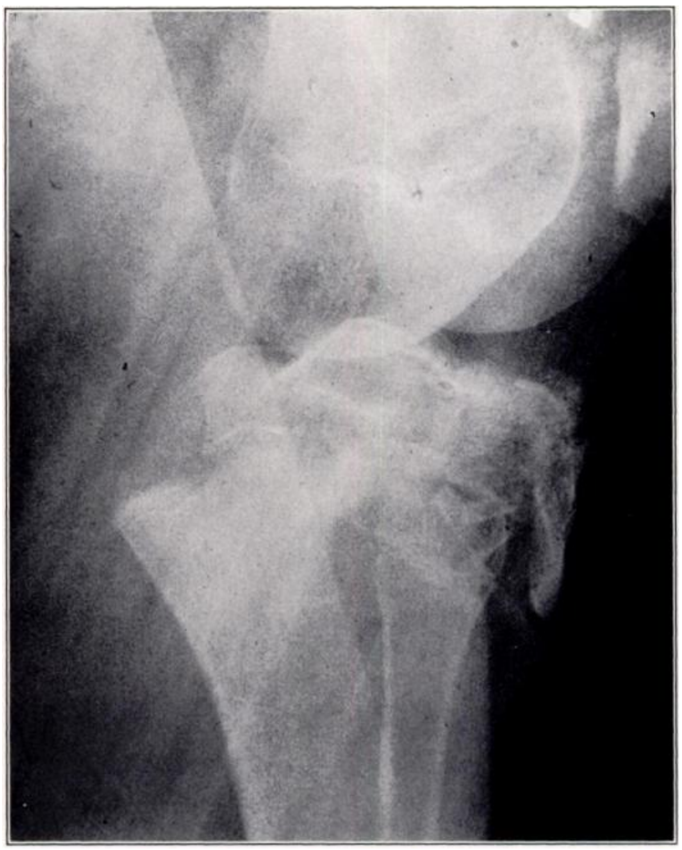


FIG. 36

Type II injury of the upper tibial epiphysis resulting from a severe automobile accident. This injury was complicated by serious damage to the popliteal artery.

tions at this site are uncommon and occur only as a result of very severe injury (Fig. 36). The popliteal vessels may be seriously damaged particularly with a hyperextension injury. Reduction sometimes can be obtained by closed means, but any coexistent major vascular injury necessitates open operation. A Type V injury of the upper tibial epiphysis may result from a severe abduction or adduction injury (Fig. 30).

Lower Femoral Epiphysis

The lower femoral epiphysis is the largest of the pressure epiphyses, and it is

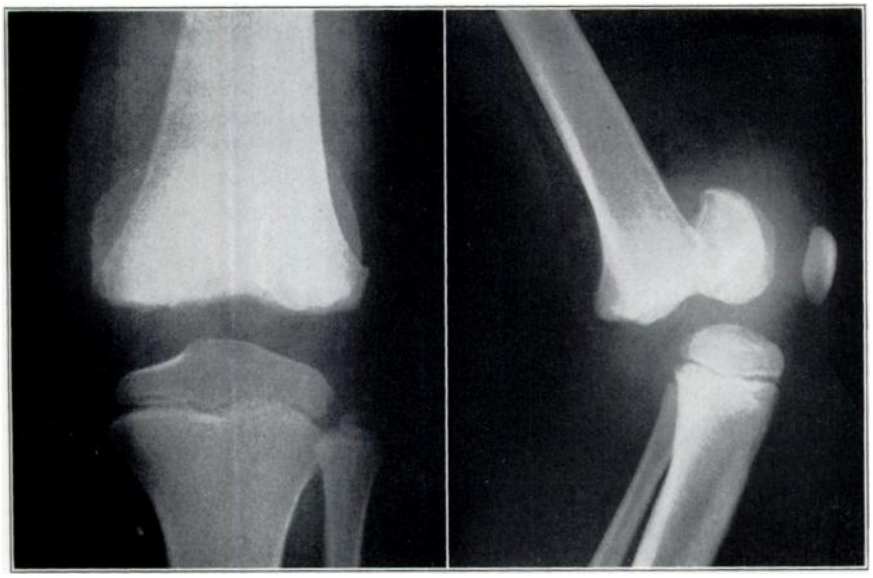


Fig. 37-A

Hyperextension Type II injury of left lower femoral epiphysis. Note the forward displacement of the femoral epiphysis.

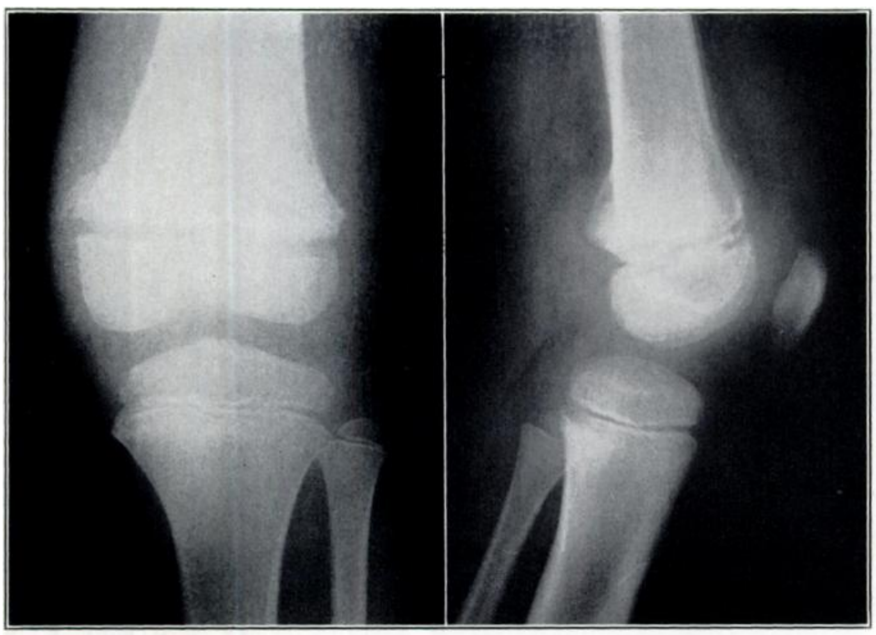


Fig. 37-B

Position obtained and maintained by closed reduction. No subsequent disturbance of growth.

the only one that exhibits an ossification center at birth [5]. Birth injuries of this epiphysis are usually associated with difficult delivery with extended breech presentation. Because this is a Type I injury there is a good prognosis (Figs. 14-A and 14-B). The lower femoral-epiphyseal plate, being a site of rapid skeletal growth, is frequently the site of Type I separation in scurvy (Figs. 16-A and 16-B).

In older children, a severe injury that would rupture a major ligament of an adult knee produces a Type II injury of the epiphyseal plate, since the plate is weaker than the ligaments. For example, the child who appears to have suffered a complete tear of the medial collateral ligament is more likely to have separation of the lower femoral epiphysis. If doubt exists and the initial roentgenogram is not helpful, a roentgenogram of the knee made in a valgus position will reveal the site of abnormal movement.

A serious injury of the lower femoral epiphysis is the hyperextension type with forward displacement of the epiphysis [18] (Figs. 37-A and 37-B). The posterior corner of the metaphysis is driven backward against the popliteal vessels. Sufficiently serious vascular injury may result that surgical exploration is indicated. This hyperextension injury is comparable in many ways to the hyperextension type of supracondylar fracture of the humerus. Reduction of the displacement is most readily obtained by placing the patient face down, applying traction on the semibent knee, pushing the proximal fragment forward, and then flexing the knee. The reduction is most stable with the knee flexed to at least 90 degrees but the circulation of the leg must be watched very closely. The flexion at the knee may be reduced after ten days. In any case, the total period of immobilization should not exceed three weeks, since flexion contracture of the knee associated with longer periods of immobilization may be very resistant to treatment.

The lower femoral epiphysis may also be the site of the serious Type IV injury which carries a poor prognosis unless perfect reduction is obtained. The joint surfaces and the epiphyseal plate must be accurately realigned in order to avoid both degenerative joint disease and premature cessation of growth; open operation and temporary internal fixation are usually required.

Upper Femoral Epiphysis

Epiphyseal-plate injuries at this site are always Type I. Traumatic separation of the femoral head may result from a birth injury, in which case the diagnosis is difficult, since at this time the entire head, being cartilaginous, is radiolucent. The clinical picture and the roentgenograms may suggest congenital dislocation of the hip, but the presence of slight crepitus indicates that epiphyseal separation has occurred. Within a week of the injury, the roentgenogram reveals new-bone formation which establishes the diagnosis with certainty.

The prognosis is poor in traumatic separation of the upper femoral epiphysis because of the frequently associated disruption of its blood supply and resultant avascular necrosis [7]. Since the epiphyseal plate receives its nutrition from the epiphyseal side, avascular necrosis of the femoral head results in death of the epiphyseal plate and consequent premature cessation of growth. Thus, the problem of progressive coxa vara is superimposed upon that of avascular necrosis of the femoral head (Figs. 18-A through 18-D). The displacement can usually be reduced by closed means. Reduction is best maintained by the insertion of removable threaded wires that pass through the neck and traverse the epiphyseal plate.

Pathological separation of the upper femoral epiphysis (slipped upper femoral epiphysis), either gradual or acute, is not within the scope of this presentation.

INJURIES INVOLVING TRACTION EPIPHYSES

The tendinous attachment of muscle origins or insertions into bone via Sharpey's fibers is so secure that when a sudden traction force is applied to the tendon it does not pull out of bone; instead, the force avulses a fragment of bone. During childhood, the weakest point at the insertion or origin of a muscle is the epiphyseal plate of the traction epiphysis; therefore, a sudden and severe traction force avulses the traction epiphysis through its plate.

Since a traction epiphysis does not contribute to longitudinal growth of the bone to which it is attached, any growth disturbance of its epiphyseal plate is not associated with deformity. If the epiphysis is accurately replaced, the epiphyseal plate becomes united to the shaft of the bone as it does after injuries to a pressure epiphysis; however, if the epiphysis remains displaced it becomes attached to the parent bone by fibrous union.

Certain of the traction epiphyses are particularly vulnerable to avulsion injuries and these will be discussed briefly.

Medial Epicondyle of the Humerus

The medial epicondyle of the humerus, being the site of origin of the common flexor muscles of the forearm, may be avulsed by a severe valgus or abduction injury of the elbow (Fig. 38). When the injury is not severe, the resultant displacement of the medial epicondyle is slight, and the elbow joint remains stable. Clinically, the diagnosis is suggested by the presence of swelling and tenderness over the medial aspect of the elbow. If the roentgenographic diagnosis is doubtful

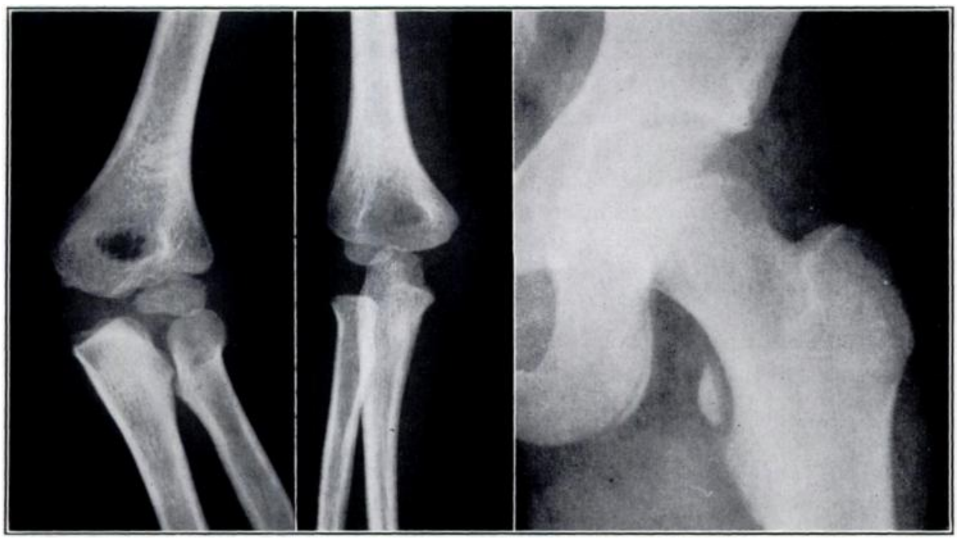


FIG. 38 FIG. 39 FIG. 40

Fig. 38: Traumatic separation (avulsion) of medial epicondyle of left humerus—a traction epiphysis.

Fig. 39: Traumatic separation of medial epicondyle of right humerus in a three-year-old child. The ossification center of the medial epicondyle has not yet appeared. Only roentgenographic evidence of injury is an increased soft-tissue shadow on the medial aspect of the elbow. The diagnosis was readily made by physical examination.

Fig. 40: Traumatic separation of the lesser trochanter of the left femur. The residual soft-tissue attachment of the iliopsoas muscle to the femur prevents marked displacement of the lesser trochanter.

a comparable view of the opposite elbow is very helpful. When this injury occurs in a child less than four years old, that is, before the cartilage of the medial epicondyle is ossified, the diagnosis must be made on clinical grounds alone (Fig. 39).

The extent of the injury, as indicated by the degree of instability of the elbow, is best determined by applying a valgus or abduction force to the extended elbow with the child under general anesthesia. If the elbow joint is stable, conservative treatment consisting of three weeks' immobilization with the elbow at slightly less than 90 degrees of flexion is indicated. In more severe injuries, the elbow joint is dislocated, and the medial epicondyle is widely displaced.

Occasionally the elbow joint will snap back into place and trap the medial epicondyle in the joint. Under these circumstances, the epicondyle can usually be pulled out of the joint by abducting the elbow joint, at the same time applying traction on the common flexor muscle origin by supinating the forearm and extending the wrist, while the child is under anesthesia. The more severe traction injuries of the medial epicondyle are associated with lateral instability of the elbow joint which is readily detectable in an anesthetized child. In marked instability, best results are obtained by open operation in which the epicondyle is either sutured securely into place by its periosteal attachments or is held in place by a removable Kirschner wire. Severe injuries frequently are associated with a traction injury of the ulnar nerve, which usually recovers completely.

Tibial Tubercle

During childhood, the downward, tongue-like projection of the upper tibial epiphysis constitutes the tibial tubercle and represents the traction epiphysis of the quadriceps muscle. Sudden contraction of the quadriceps against resistance may avulse a varying amount of this projection. When a large portion of the tibial tubercle is widely separated, open operation is indicated. More commonly, the separation is slight and immobilization of the knee in extension is adequate. Minor degrees of separation of the tibial tubercle probably account for the clinical condition commonly referred to as Osgood-Schlatter disease.

Lesser Trochanter of the Femur

The powerful iliopsoas muscle is inserted into the femur primarily via its traction epiphysis, the lesser trochanter, but it also gains attachment by an extension of the tendon into the periosteum of the shaft. Sudden abduction and extension of the hip may result in avulsion of the lesser trochanter, but the remaining periosteal attachment prevents marked displacement (Fig. 40). Clinically, relatively little disturbance is associated with this injury, and the only treatment indicated is rest in bed with the hip flexed until discomfort subsides, after which the patient may be allowed to resume activities.

Traction Epiphyses of the Pelvis

A sudden powerful contraction of the hamstring muscle group, for instance, during strenuous athletic activities, may avulse their site of origin, the epiphysis of the ischium. The displacement is seldom great, and the injury usually heals with abundant formation of bone. Weight-bearing should be avoided for three weeks.

The anterior superior spine, which is the traction epiphysis of the sartorius muscle, and the anterior inferior spine, which is the traction epiphysis of the rectus femoris muscle, may be avulsed by sudden contraction of the attached muscle. In either case, symptomatic treatment consisting in local rest for three weeks with the hip in flexion is sufficient.

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