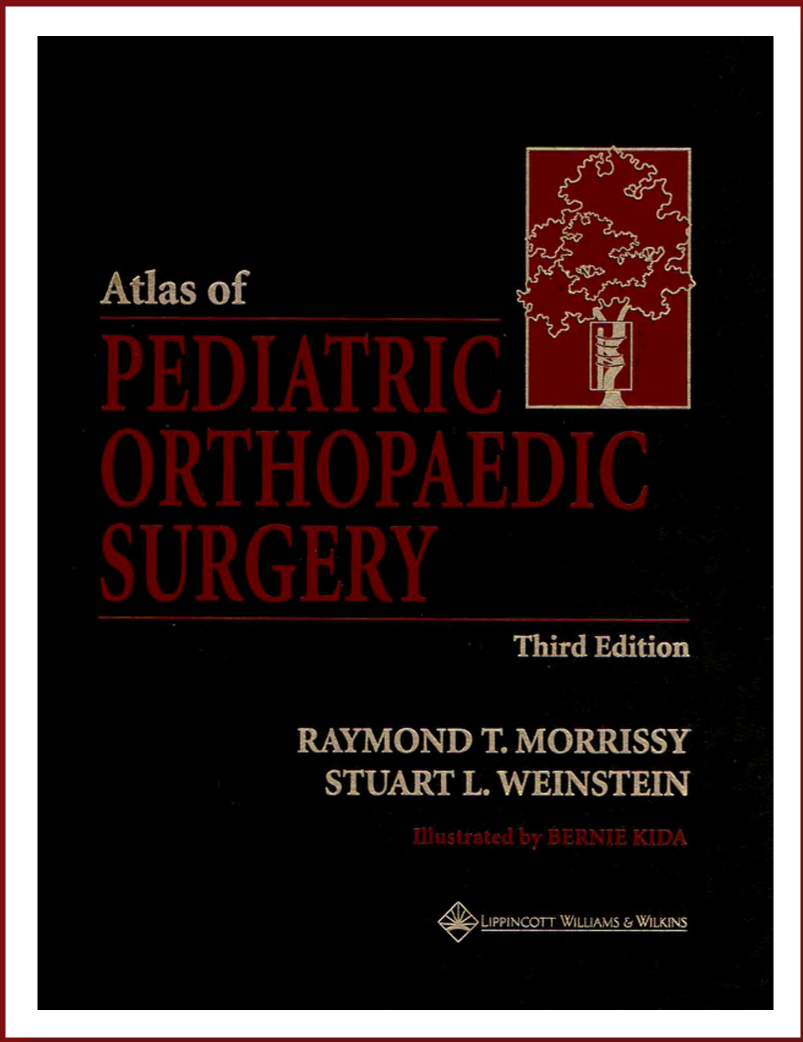
Atlas of Pediatric Orthopaedic Surgery

Third Edition



Raymond T. Morrissy
Stuart L. Weinstein

Illustrated by Bernie Kida

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THE UPPER EXTREMITY

1.1 WOODWARD REPAIR OF SPRENGEL DEFORMITY

Congenital high scapula, commonly known as *Sprengel deformity,* is not a common condition. It can be seen in all degrees of severity. We have seen numerous children as a result of the school screening programs with minor degrees of scapular elevation and smaller scapulae on one side. Minor degrees of high-riding scapulae need no treatment and are usually not associated with other developmental abnormalities around the shoulder. At the other end of the spectrum is the child diagnosed at birth or shortly thereafter. The physician recommending surgical correction and the parent making the decision should realize that the deformity usually becomes worse with growth. This can be difficult when the child is between 4 and 8 years of age, which is the ideal time for optimal correction.

The condition is the result of a problem during the 9th to 12th weeks of gestation; therefore, other organs may be affected as well as those structures around the shoulder girdle. An understanding of the pathologic anatomy is important to the correction of the deformity and the avoidance of complications. The scapula is shorter in its vertical height than the opposite normal scapula and is more concave anteriorly to fit the convex shape of the superior aspect of the thoracic cage. In addition, the supraspinous portion of the scapula is usually tilted forward, and its superior medial portion may be larger. The clavicle may also be higher and shorter, lacking its usual anterior convexity (1). In about one third of the cases, there is an omovertebral bone connecting the superior medial angle of the scapula to the posterior elements of the fourth and fifth cervical vertebra. This may actually be bone, cartilage, or fibrous tissue. Finally, the muscles of the shoulder girdle are usually affected, and hypoplasia of the trapezius and rhomboids is the most common problem.

Two operations for the correction of Sprengel deformity have stood the test of time and are the ones most commonly used. The Green procedure (2–5) detaches the muscles from the scapula, whereas the Woodward procedure (6,7) detaches the origins of the trapezius and rhomboids from the spinous processes. We have had experience with both procedures and find the Woodward procedure to be easier (but not easy) and to produce the same results with less hospitalization and morbidity.

One of the most important complications is radial nerve palsy resulting from compression of the brachial plexus between the clavicle and the first rib when the scapula is pulled down. Some authorities have advocated division or morcellation of the clavicle to prevent this complication (1,8). This is an effective measure, but it is important to determine which patients require it. Because the incidence of radial nerve palsy is low (2,6,9,10), especially in young children, this additional procedure may be reserved for affected children older than 8 years of age and those younger children who have an unusually severe deformity. When nerve palsy is noted after the Woodward procedure, division of the clavicle can be done (Figs 1-1 to 1-6).

FIGURE 1-1. The patient is positioned prone. The arm and the shoulder on the affected side should be draped free. It may be helpful if the entire posterior thorax is in the sterile field so that the level of the opposite scapula can be observed. It is also helpful if the head is positioned as if looking straight ahead. The incision should be in the midline and extend from the level of the upper cervical spine (C1 to C2) to the lower thoracic spine (T9 to T10).

The incision is deepened through the subcutaneous tissue and is undermined on the affected side. This dissection should be carried far enough laterally to identify the lateral border of the trapezius muscle in the inferior aspect of the wound and the lateral border of the scapula in the midportion and far enough to allow exposure of the medial half of the supraspinous portion of the spine of the scapula in the superior portion.

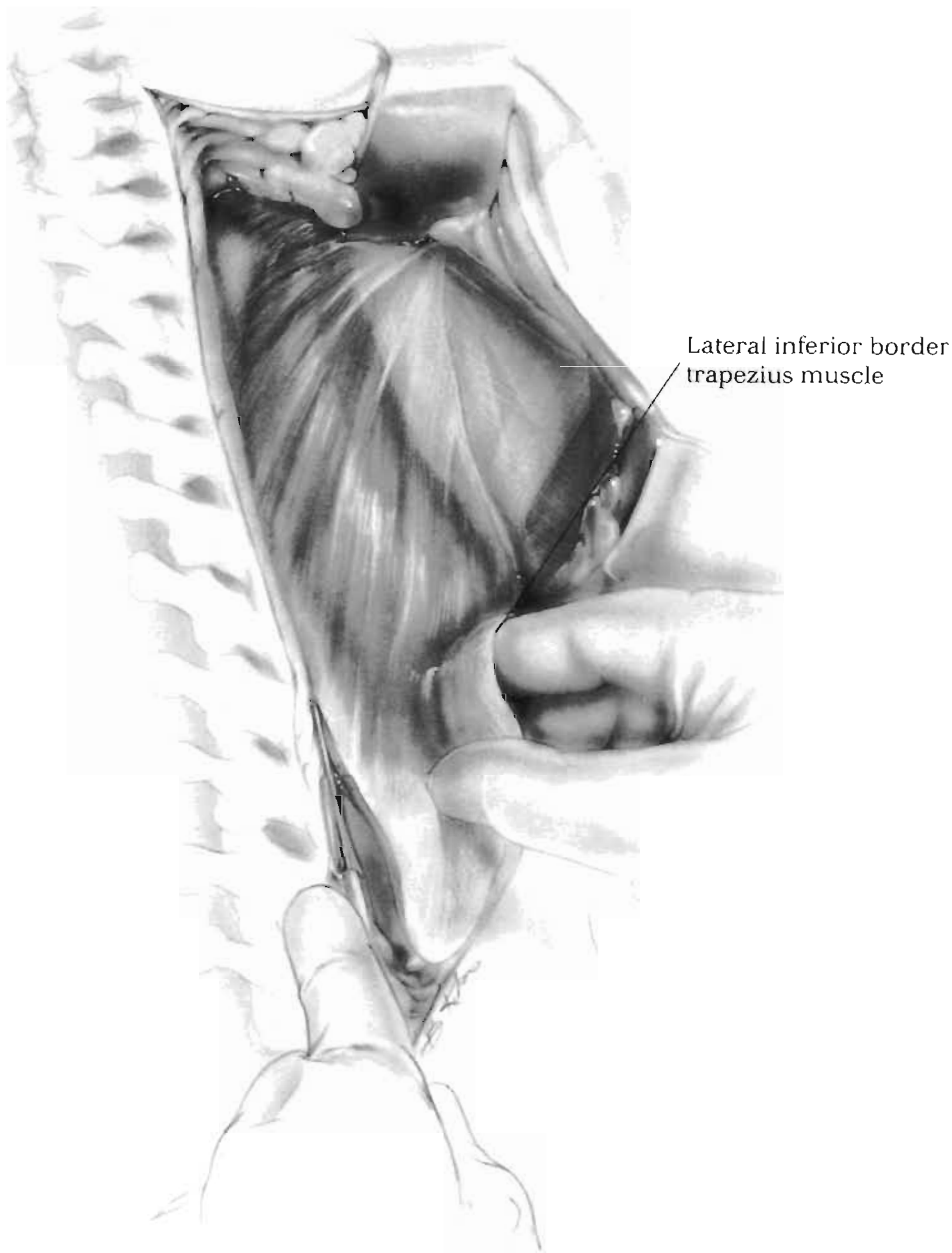


FIGURE 1-2. Although Woodward described detaching the trapezius and rhomboid muscles by directly detaching their origins from the midline, this is virtually impossible because they blend inseparably with all of the other muscle origins at the midline. First, identify the lateral border of the trapezius muscle in the inferior aspect of the wound, and by blunt finger dissection, separate it from the well-defined thoracolumbar fascia and the latissimus dorsi muscle, which covers the serratus and erector spinae muscles. The maneuver eases identification of its origin, which can be detached without cutting into the deeper muscle layers. This detachment of the trapezius is begun distally and extends to the level of the fourth cervical vertebra, where it can be cut transversely to complete its release. After the trapezius muscle is detached and reflected laterally, the rhomboid muscles attaching to the scapula are identified. Blunt finger dissection can be used to separate them from the underlying deep fascia, aiding in detaching them from their origins like the trapezius muscle.

Although this dissection is straightforward in an adult cadaver, it is much more difficult in a 4-year-old child with hypoplastic muscles and abnormal fibrous bands. Nevertheless, this step is the key to the exposure and the procedure.

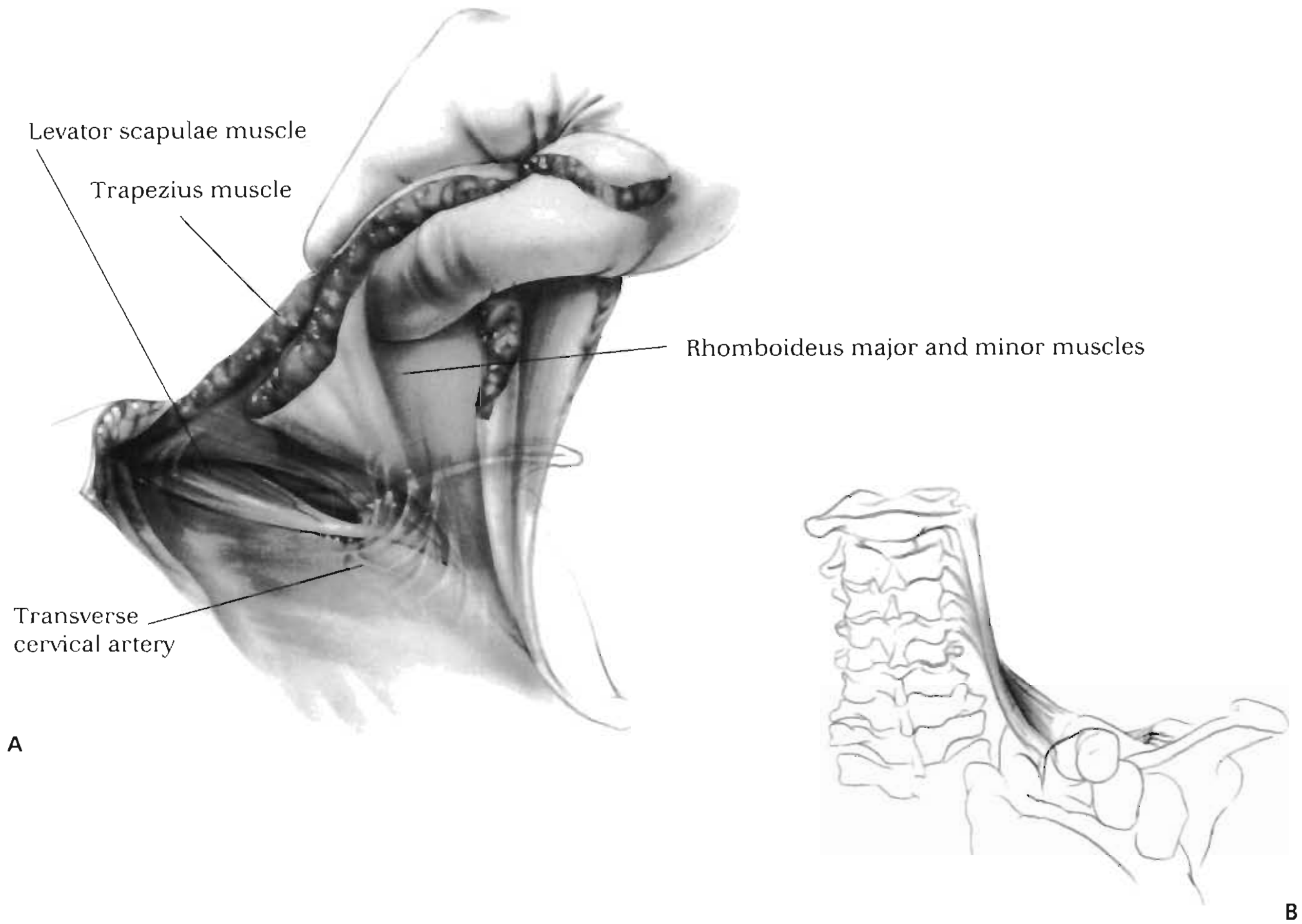


FIGURE 1-3. With the trapezius muscle retracted laterally **(A)**, the levator scapula muscle can be identified as that structure originating from the superior medial corner of the scapula and running toward the cervical spine. Although it lies in the same plane as the rhomboids muscles, it is difficult to identify as a distinct structure. In about one third of cases, an omovertebral bone (not illustrated here), consisting of actual bone, cartilage, or dense fibrous tissue, originates from this corner of the scapula, usually lying beneath the levator scapulae muscle. If present, it is rarely connected to the cervical spine by bone and can usually be detached by sharp dissection after the bone has been exposed by extraperiosteal dissection. It is essential to release all structures in this region because they will prevent downward displacement of the scapula. Fibrous bands, as well as the levator scapulae muscle, are most easily isolated and divided at the superior medial border of the scapula. Notice the transverse cervical artery running deep to the levator scapulae muscle. Care should be taken to avoid cutting it **(B)** by inserting a finger behind the muscle before dividing it.

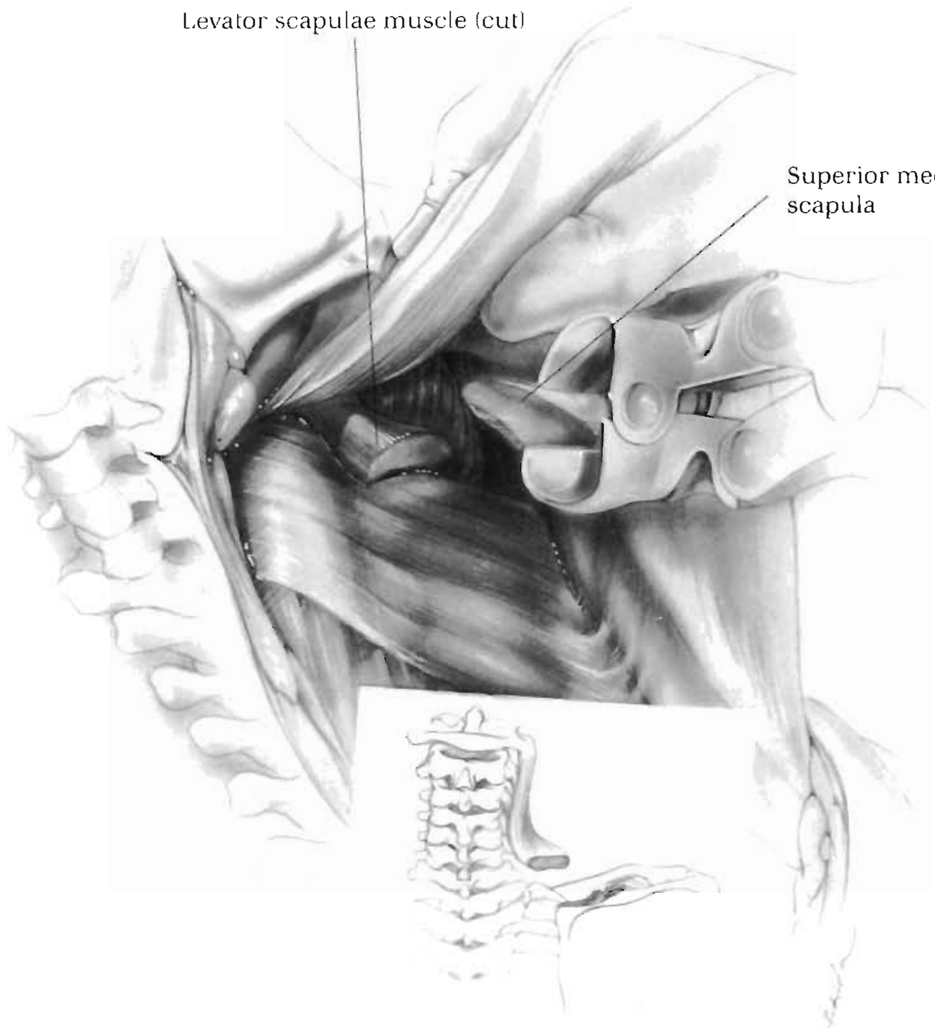


FIGURE 1-4. With the division of the structures originating from the superior medial border of the scapula, it becomes easier to appreciate the contribution that the large anterior-curving, medial supraspinous portion of the scapula makes to the deformity. This portion of the scapula should be exposed extraperiosteally and excised with a large bone-cutting forceps. The surgeon should proceed no farther laterally than the scapular notch to avoid causing injury to the suprascapular artery or nerve.

With this completed, the scapula can be everted. This usually reveals multiple fibrous adhesions between the scapula and the chest wall. This is especially true in cases with associated anomalies of the chest wall (e.g., missing ribs). These adhesions should be divided. The scapula can be pushed downward and observed for any other tight structures. In severe cases, it may be necessary to divide a portion of the serratus muscle insertion into the scapula.

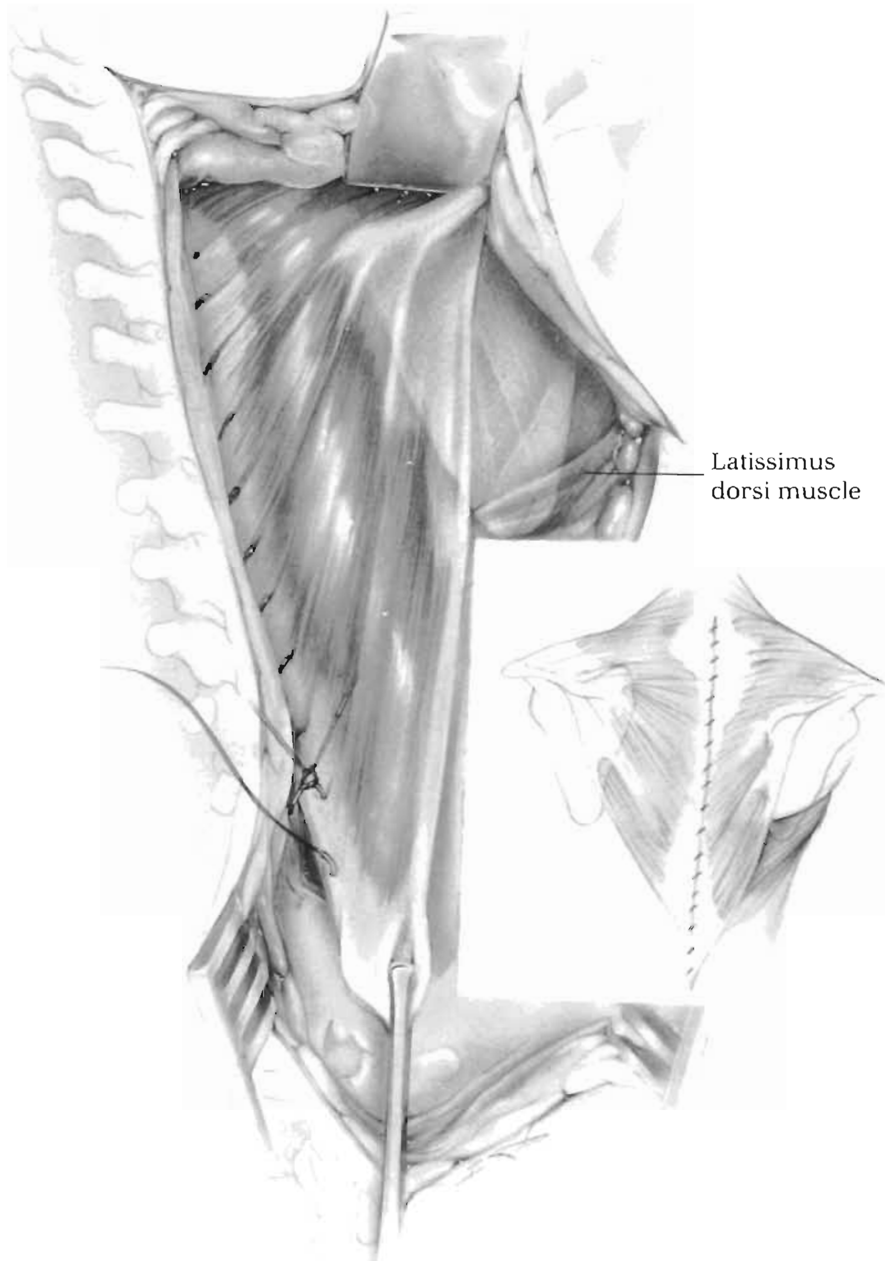
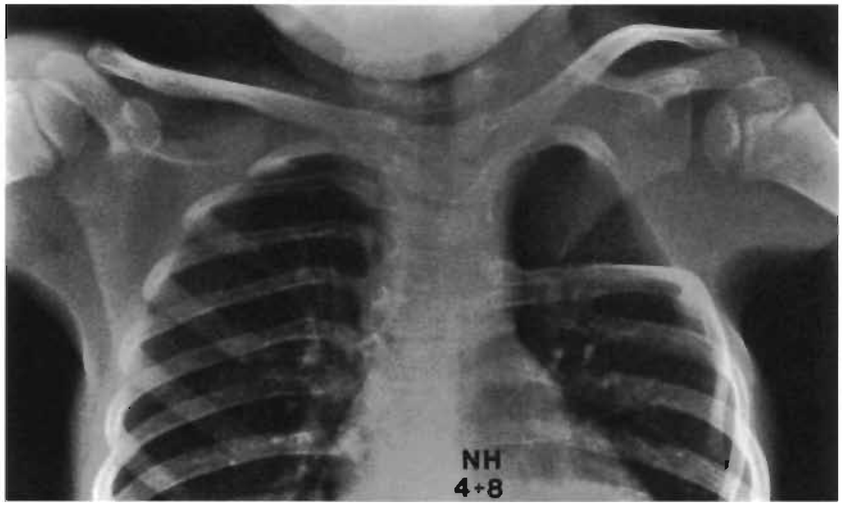


FIGURE 1-5. The latissimus dorsi muscle is elevated to allow the scapula to be displaced beneath it. The rhomboid and trapezius muscles are pulled downward, displacing the scapula to the desired level. The affected scapula is smaller than normal; therefore, displacing it so that its inferior border is level with the inferior border of the opposite normal scapula results in overdisplacement. Rather, it should be displaced so that the spines of the two scapulae lie on the same level.

The suprascapularis and subscapularis muscles can be repaired by suturing them together over the resected area of the superior medial border of the scapula. If the serratus muscles were detached, they can be resutured to the scapula in a more cephalad location. The rhomboid and trapezius muscles are reattached to their midline origin in a new, more caudal location. Because the most distal origin of the trapezius muscle (extending to T12) was left intact, there is a redundant segment of muscle and fascia distally. This can be excised. If desired, the tip of the scapula can be sutured to an underlying rib by an absorbable suture as a temporary means of fixation. We find this useful in maintaining proper rotation of the scapula. Finally, the latissimus dorsi muscle is reattached to the tip of the scapula, and the wound is closed.



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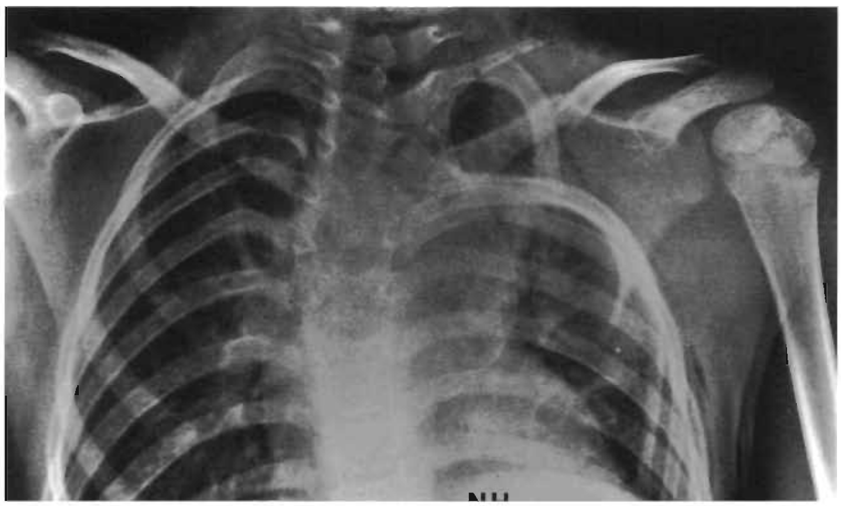

B

FIGURE 1-6. NH is a 4-year, 8-month-old girl who presented with her parents because of a high left shoulder and restricted motion, which they had observed in her shoulder. They had consulted an orthopaedic surgeon 2 years previously and were told that treatment would not be advisable because she would just be trading a slightly high shoulder for a very large scar. They were convinced the deformity was becoming worse, however.

A: A preoperative radiograph shows many of the skeletal anomalies seen in association with the congenital elevation of the scapula. The most obvious is that the scapula is high, but it is also smaller than the opposite scapula. There is a defect in the chest wall with missing and deformed ribs and mild scoliosis with a vertebral anomaly.

B: Postoperatively, the spine of the left scapula is on the same level as the normal scapula. Its smaller size is obvious and demonstrates that the affected scapula should not be brought so far inferior that the inferior angle is on the same level as the normal scapula.

POSTOPERATIVE CARE

The patient is placed in a Velpeau-type bandage to immobilize the arm for 4 weeks. The drain can usually be removed on the first or second postoperative day because it is not difficult to secure hemostasis. The patient is allowed to ambulate the day after surgery and is usually ready for discharge on the second or third postoperative day. After removal of the immobilization bandage at 4 weeks, the patient is started on physical therapy that emphasizes glenohumeral range of motion and active strengthening of the shoulder and scapular muscles.

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1.2 REPAIR OF CONGENITAL PSEUDARTHROSIS OF THE CLAVICLE

Congenital pseudarthrosis of the clavicle is an unusual condition of unknown etiology. Although the name often causes congenital pseudarthrosis of the clavicle to be confused with congenital pseudarthrosis of the tibia, there is no similarity in the etiology or natural history of these conditions. The pathology, unlike congenital pseudarthrosis of the tibia, is of two bone ends covered with cartilage and often encapsulated with synovial tissue and fluid. It is clear, however, that resection of the pseudarthrosis, bone graft, and internal fixation are necessary to obtain union (1–4).

Patients may present at any age with a painless lump in the clavicle. Although usually mild in terms of cosmetic deformity and typically asymptomatic in younger children, the deformity worsens with age. Dissatisfaction with the cosmetic appearance usually develops by adolescence, and discomfort, especially with throwing activities, may develop. For these reasons, surgical repair is usually recommended when noted at a young age. The ideal time to repair the pseudarthrosis is between 3 and 4 years of age, to take advantage of remodeling with growth. Repair, however, can be accomplished with improved cosmesis and elimination of discomfort at any age.

Several methods of repair have been recommended. Fixation with a Kirschner wire is difficult because of the shape of the clavicle. This method is less than ideal because the small flexible wire necessary to traverse this convoluted shape often breaks. A series of successful cases has been reported using only a suture to secure the bone ends (5). We believe that more rigid fixation is necessary and have used the technique described here with a small reconstruction plate (Figs. 1-7 to 1-11).

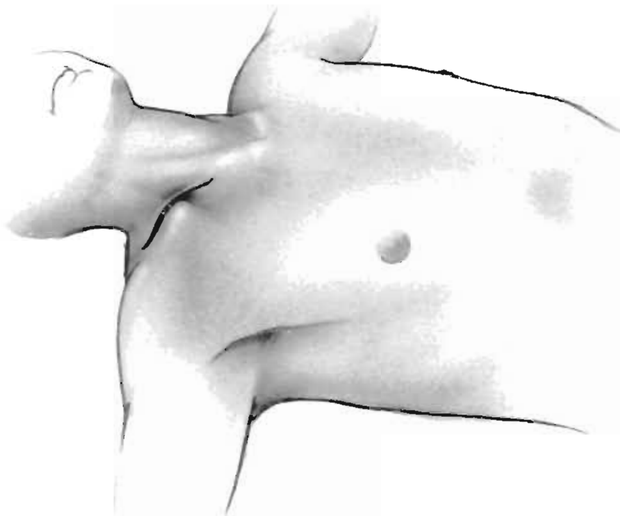


FIGURE 1-7. The patient is placed supine on the operating table with a sand bag under the upper thoracic spine to allow the head and shoulder to fall posteriorly and improve exposure of the clavicle. The arm, the shoulder, and the clavicle are draped free. The anterior iliac crest is also prepared for the bone graft, which will be necessary in the repair. The skin incision is placed along the cephalad edge of the clavicle. Its length depends on the size of the child, but because the skin in this region is so mobile, it does not need to be excessively long.

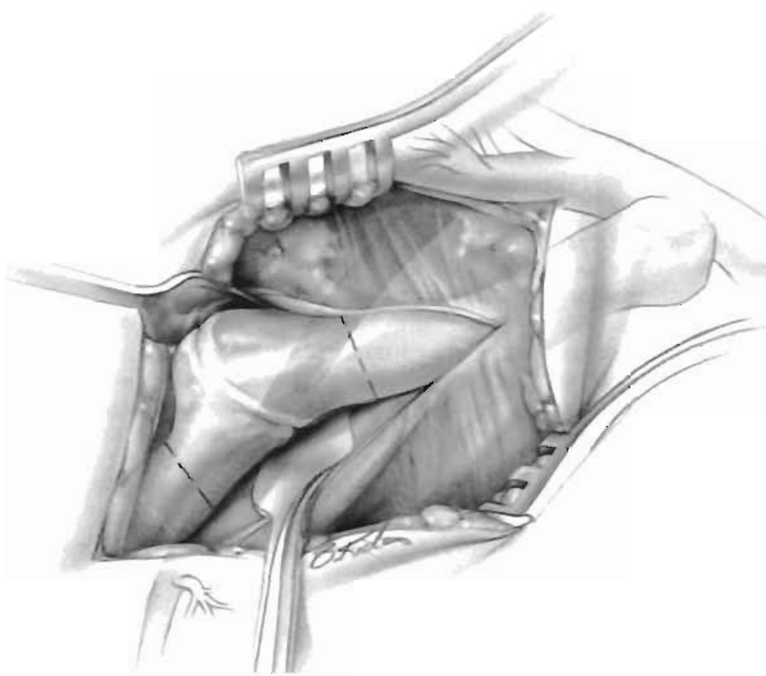


FIGURE 1-8. After dividing the skin, the periosteal surface of the clavicle is exposed below the platysma muscle. The normal clavicle and as much as possible of the bulbous ends of the pseudarthrosis should be exposed subperiosteally. In older children, the bulbous ends may be large, in which case it is impossible to remain subperiosteal. The surgeon must use great care during the dissection because of the proximity of the subclavian artery and vein and the apex of the pleural cavity. The pseudarthrosis is then excised with a rongeur. If the surgeon wishes to preserve the entire pseudarthrosis for histology, a Gigli saw or bone biter can be used provided that the circumferential dissection is sufficient.

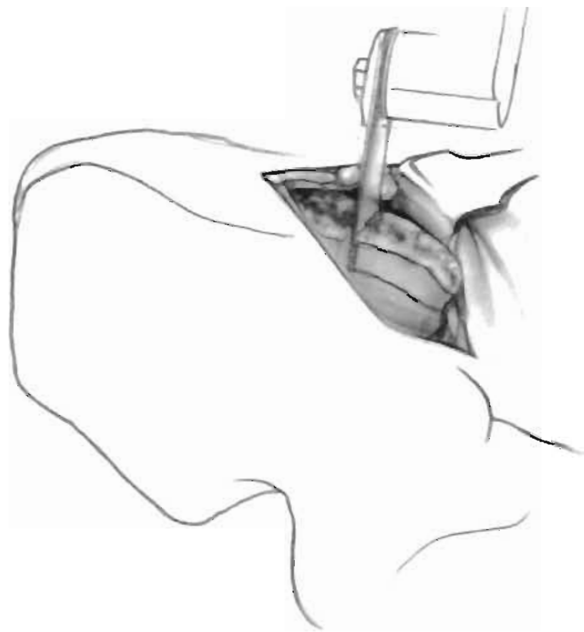


FIGURE 1-9. After resection of the pseudarthrosis, a bone graft may be necessary both to secure osteosynthesis and to maintain the length of the clavicle. A full-thickness (tricortical) piece of bone can be harvested from the anterior iliac crest just behind the anterosuperior iliac spine. The portion of bone just beneath the apophysis is thicker than the thin plates of bone that make up most of the iliac wing and provides a better fit with the two ends of the resected pseudarthrosis. A larger piece of bone than is judged necessary should be removed to allow it to be fashioned to the appropriate size and contour.

FIGURE 1-10. Various forms of fixation have been used, all more or less with success. Grogan and colleagues (5) recommend only a suture and no graft. If a graft is used, it is possible to use a Kirschner wire, which is drilled out laterally from the osteotomy site and then through the graft and the proximal fragment. If a Kirschner wire is used, it is necessary to leave the wire outside of the skin, bending it at 90 degrees to prevent its migration. It is best to remove this wire within 3 to 4 weeks to prevent infection. ▶

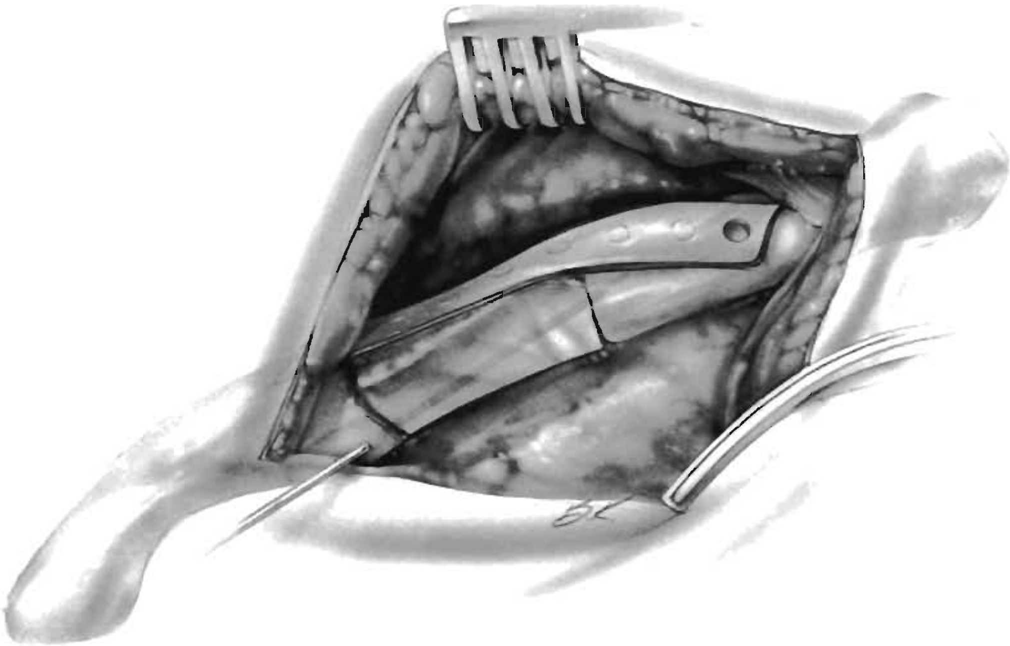
Because of the complex shape of the clavicle, it is impossible to keep a pin or wire of any strength within the medullary canal of the clavicle. A thin Kirschner wire that can be passed through the medullary canal of the bone provides little fixation and, unless left outside of the skin and bent, risks migration. The use of a pin or wire also risks migration. To avoid these potential problems, the surgeon can use the small reconstruction plates.

The plates come in two sizes, 2.7 mm and 3.5 mm. Their flexibility makes it possible to contour them exactly to the shape of the clavicle and graft. Because immobilization is required in an active child, regardless of the method of fixation, the plates are sufficiently strong.

A, B: With the graft held temporarily in place between the two resected ends of the clavicle by a small Kirschner wire, the appropriately sized reconstruction plate is contoured using the template provided.

C: When the proper shape has been achieved, the plate is attached by screws to both ends of the clavicle and the graft. Each end of the clavicle should be fixed with a minimum of two screws, and at least one screw should hold the graft.

The wound is irrigated, a small drain is placed adjacent to the clavicle and brought out through the skin lateral to the incision, and the wound is carefully closed in layers. In small children, a Velpeau dressing is applied and reinforced with a roll of plaster if deemed necessary. In older children, who may be more cooperative with the postoperative immobilization, a commercial sling with a strap that passes around the waist to hold the arm next to the trunk is sufficient.



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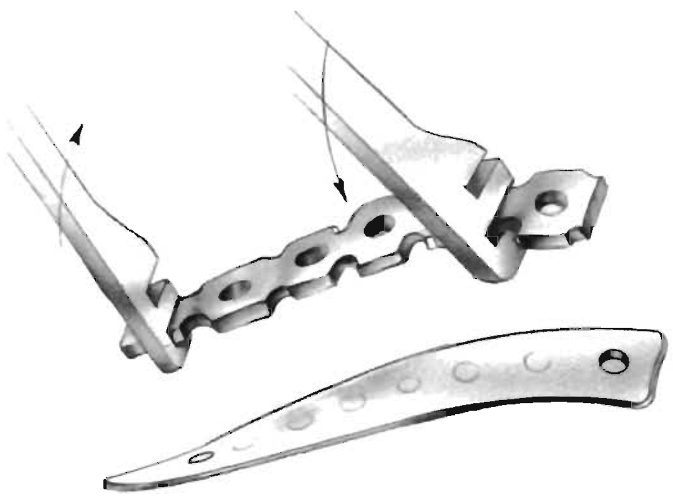

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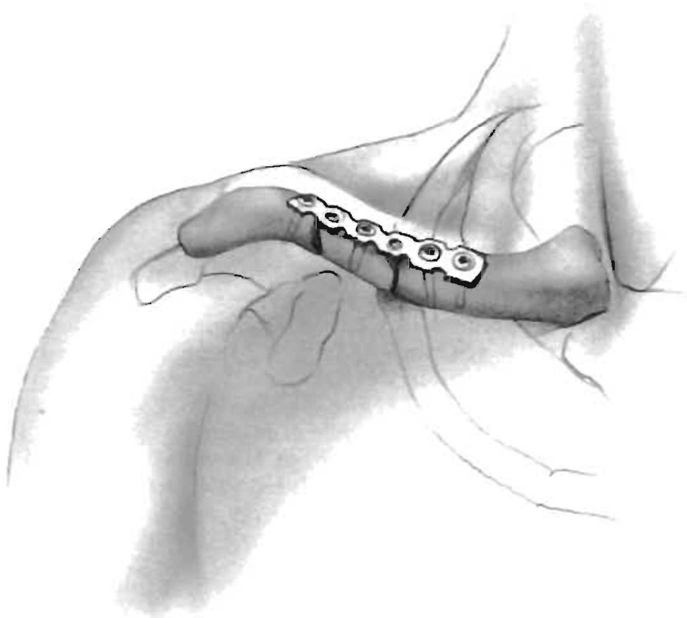

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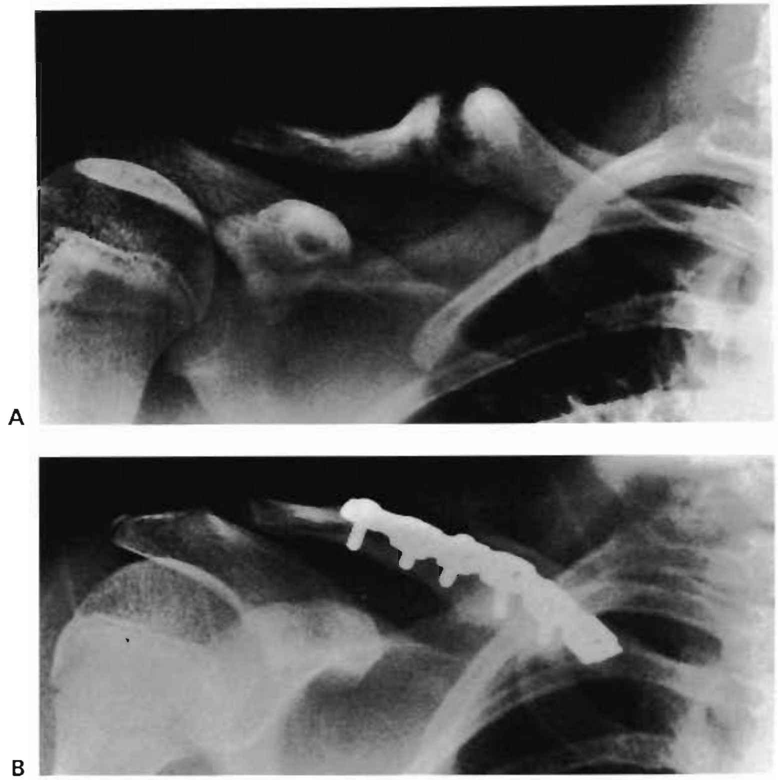

FIGURE 1-11. BC is a 10-year-old boy who noticed a lump on his collar bone and discomfort with throwing activities since an injury 3 years previously. At the time of the injury, he was told that he had fractured his clavicle; at the time of these radiographs, he was referred for a persistent nonunion. **A:** Radiographs demonstrate a typical congenital pseudarthrosis of the right clavicle. **B:** Results of excision, grafting, and plating are shown. Healing was prompt, and he returned to all activities without discomfort in 6 months.

POSTOPERATIVE CARE

The drain can be removed the day after surgery. The patient is usually ready for discharge the same day. Immobilization should be continued until radiographic evidence of union is seen. This is usually sufficient by 6 weeks. The plate can be removed electively 6 to 12 months later on an outpatient basis.

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1.3 RELEASE OF CONGENITAL CONSTRICTION BAND

Congenital constriction bands can occur in any location on a limb. In addition, they occur with varying degrees of severity, ranging from incomplete partial rings that may require no treatment to deep rings that completely encircle the part creating distal edema and cyanosis.

This ring of abnormal constriction has breadth as well as depth and consists of abnormal, dense, scar-like tissue. For this reason, the constriction band must be excised rather than merely incised. If not, the dense scar tissue is merely rotated into the flaps. In excising the constriction ring, especially in areas such as the fingers or when it appears to go down to the bone, great care must be taken not to divide vital structures that lie beneath. This is especially troublesome in the fingers. Further, no more than half the circumference of the constriction ring should be excised at one time to avoid complete disruption of the lymphatic and vascular drainage from the distal part. An interval of 2 to 3 months is usually adequate.

It is not acceptable simply to excise the ring, no matter how minor it appears, because attempts to repair the defect in a linear manner cause the resultant scar to contract, creating a cosmetic problem. Thus, the treatment of congenital constriction bands lies in the application of the principles of Z-plasty (Figs. 1-12 and 1-13).

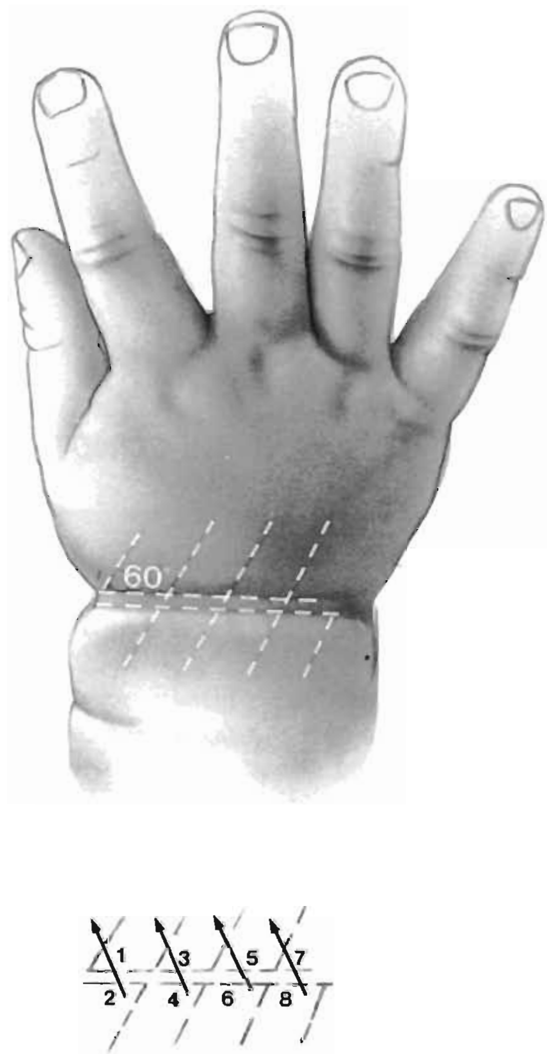


FIGURE 1-12. The excision of the constriction band can be marked, although it is usually so obvious that this is not necessary. The flaps of the Z-plasty are then planned. They should be as large as is feasible. The angle of 60 degrees is believed to provide the optimal balance between the vascular supply to the tip of the flap and the mobility of the base of the flap. Ideally, the length of the flap should be no more than two times the width of the base of the flap.

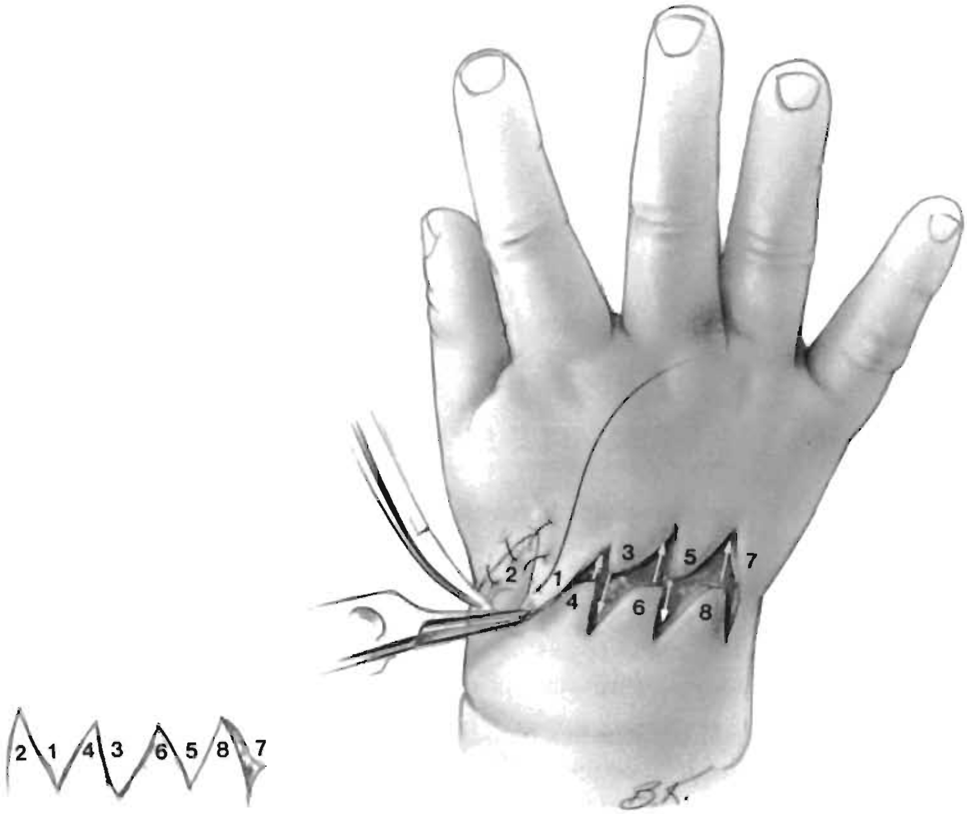


FIGURE 1-13. After the constriction band is excised and the flaps mobilized, they are transposed. In children, it is best to use fine absorbable suture to avoid the arduous task of suture removal. Great care should be exercised in handling the flap tips to avoid necrosis. When placing the corner stitches, the subcutaneous tissue, not the skin, should be grasped, in the flap tip region to avoid tip necrosis.

POSTOPERATIVE CARE

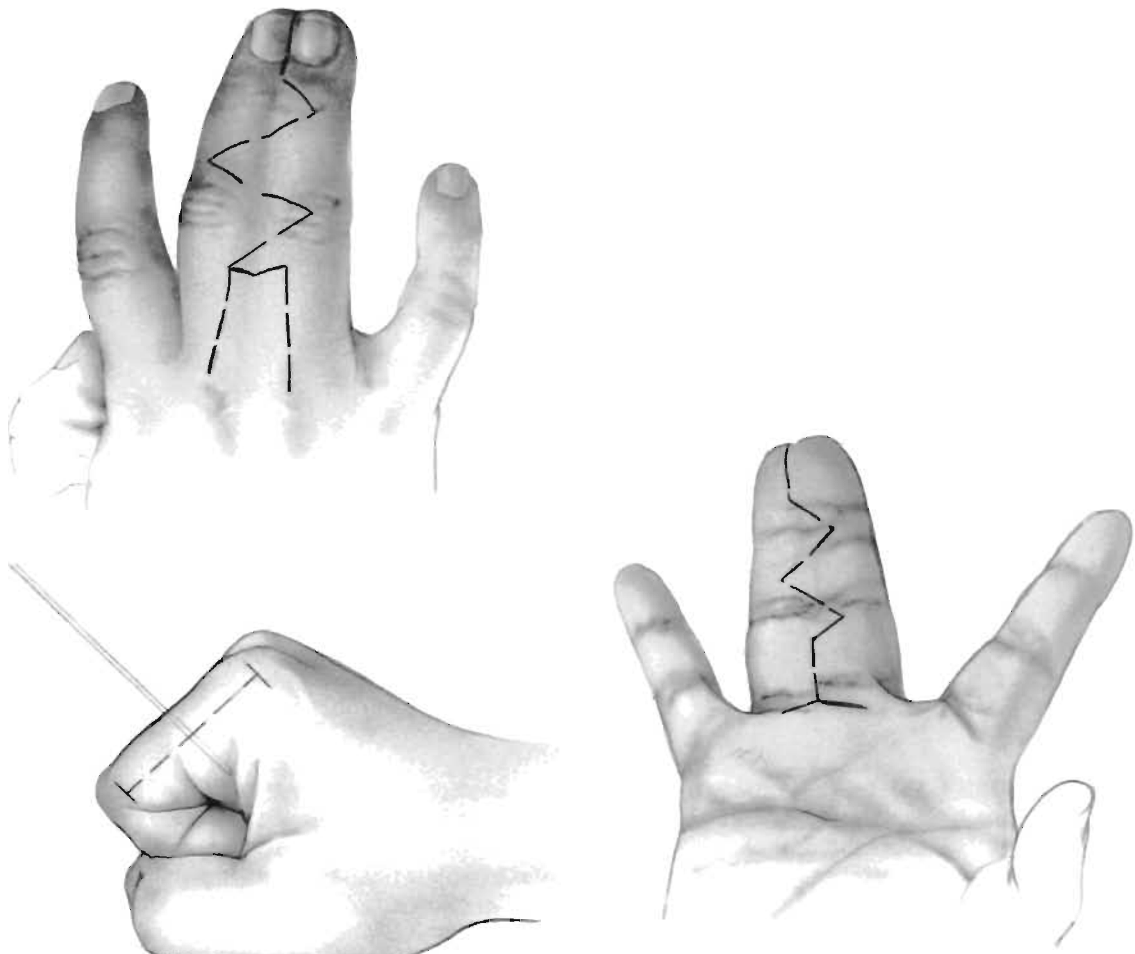
It is wise to provide maximum soft tissue immobilization during the initial period of healing. This is accomplished with a pressure dressing of fluffed gauze beneath a rigid plaster dressing. Adjacent joints should be immobilized as well. The dressing can usually be removed in 1 week and the second stage performed in 2 to 3 months.

1.4 RELEASE OF SIMPLE SYNDACTYLY

Syndactyly is the most common congenital anomaly of the hand, following polydactyly. Excellent discussions of this topic can be found in standard texts (1,2). Only separation of a simple syndactyly is described here (Figs. 1-14 to 1-16).

There is disagreement regarding the age at which each particular syndactyly should be separated as well as regarding which is the best method, but there is no disagreement about several important principles:

1. The surgery should be done in a bloodless field.
2. Loupe magnification is required.
3. The use of angled and zigzag incisions is necessary.
4. Additional skin in the form of either split- or full-thickness graft is required.
5. Local skin flap and not graft should be used to reconstruct the commissure.
6. Rigid and adequate postoperative dressings are needed to ensure healing of the skin.



A

B

C

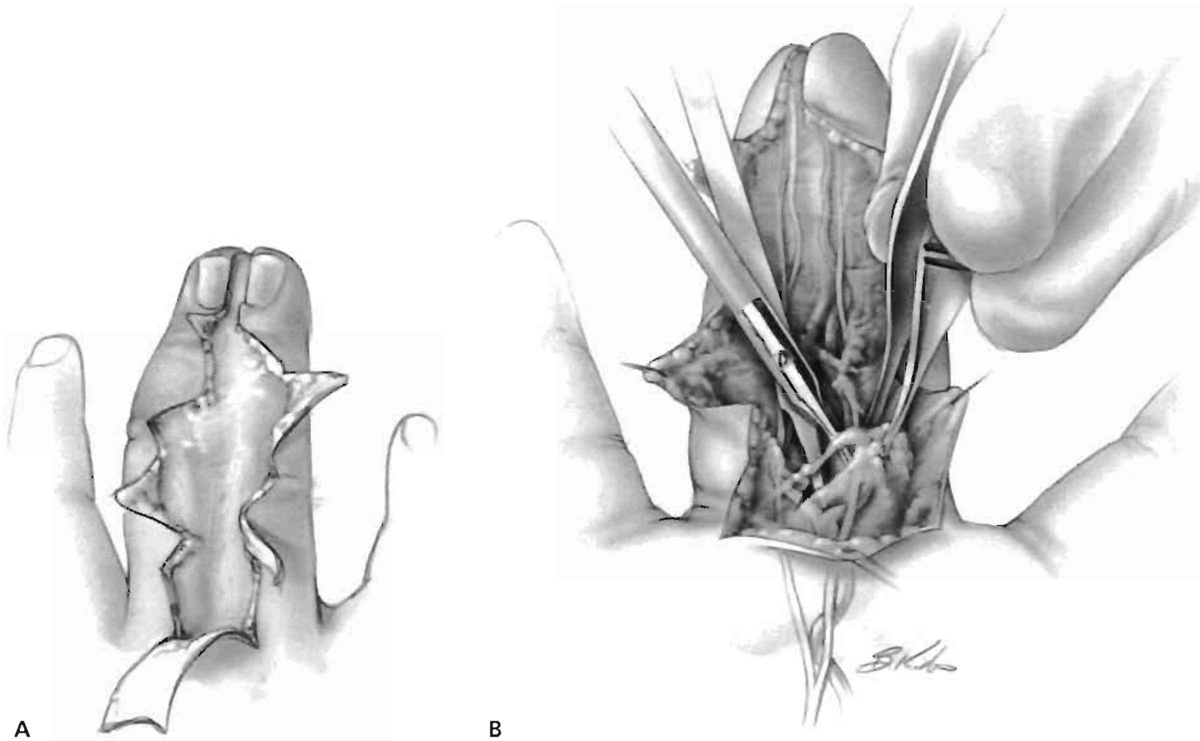
FIGURE 1-14. The first part of the operation is to plan the incisions. There are many different incisions that work well, and surgeons often prefer the one that they were taught. The planning begins with the flap that will be used to reconstruct a commissure. The broad dorsal flap, first described by Bauer and colleagues (3), has received wide acceptance and is described here. The flap begins at the metacarpophalangeal joint and extends about two thirds of the way to the proximal interphalangeal joint. It is about 1 cm in width and should taper slightly from the base to the tip **(A)**.

Before the volar incisions are made, it is first necessary to determine the location of the commissure on the volar surface. This can be done by examining the hand from the radial side in the clenched fist position. In the normal hand **(B)**, the commissure is about midway between the metacarpal head and the distal condyle of the proximal phalanx. This point can be marked by passing a small needle from the dorsal to the volar surface along this midway mark. At this point, a transverse incision can be made to provide the area where the dorsal flap will be sutured.

After this, dorsal and volar zigzag incisions are made out to the distal interphalangeal joint **(C)** in such a manner that the base of the triangle of the volar flap matches the tip of the dorsal flap, and vice versa. The planning of this interdigitation can be aided by passing a small 27-gauge needle through the dorsal and volar skin to mark the tips of the flaps.

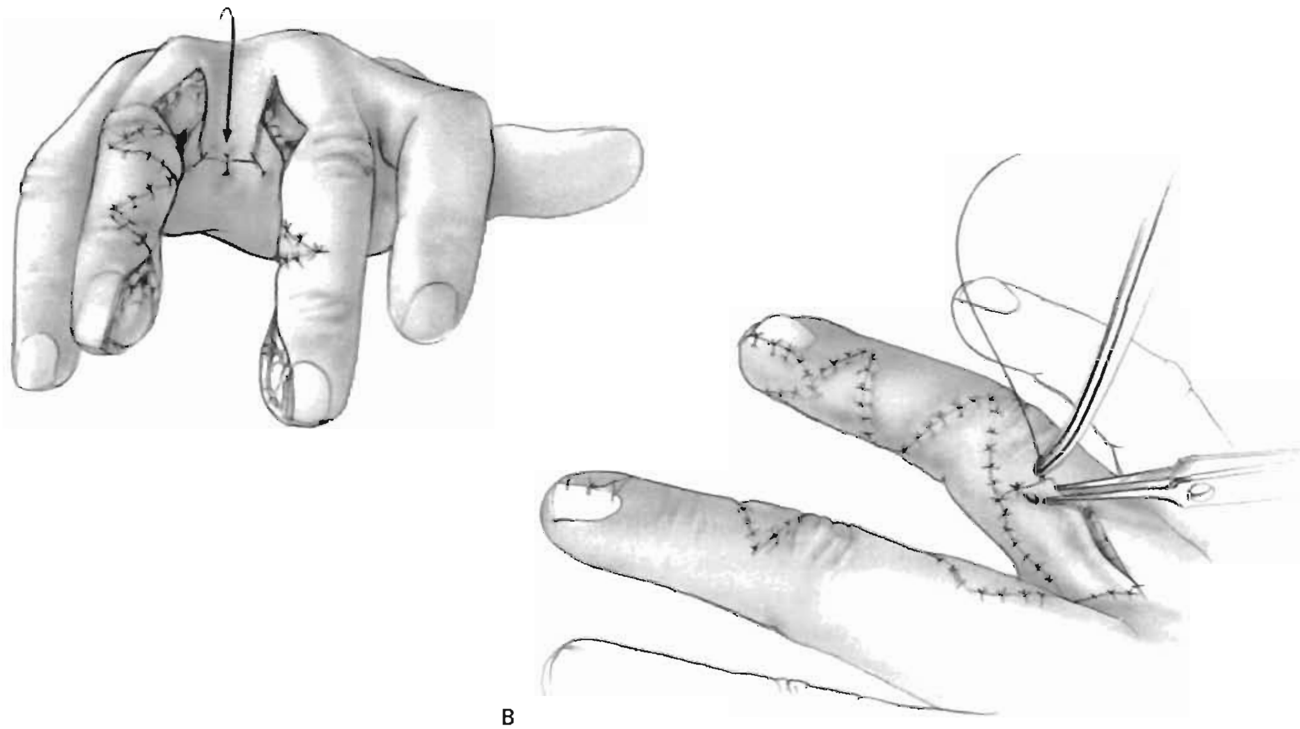
From the distal interphalangeal joint to the tip of the fingers, a straight longitudinal incision is made to complete the separation of the skin. Care should be taken not to damage the nail plate if it is joined by making one clean, sharp, decisive incision through it.

As these flaps are developed, it is extremely important that they are defatted. This increases their mobility and decreases the postoperative swelling.



A B

FIGURE 1-15. There is usually a clear line of separation between the two fingers in a simple syndactyly **(A)**, with little crossing of fibrous bands or blood vessels. In some cases, however, the digital vessels or nerves can divide more distally than usual. It is therefore necessary to isolate the neurovascular bundles. This should start distally **(B)**, following these structures proximally until their junction is found. If the nerve divides more distally than is desirable, it can be split. If the vessels divide more distally, the surgeon must decide whether to divide one of these to allow the commissure to be moved more proximally to the correct location. Some surgeons do not advocate this, but it is commonly done. If one vessel is divided, it should be recorded carefully in the operative note so that further surgical planning can account for the fact that only one artery supplies the digit. This is especially important when there is a syndactyly on the other side of the affected finger.



A

B

FIGURE 1-16. The flaps are now sutured into place, starting with the dorsal flap. Before this is done, it is important to be sure that the flaps are defatted. The flaps should be sutured with a fine, absorbable material **(A)** so that these sutures will not have to be removed.

This leaves two areas on each finger to be grafted: the most distal and most proximal portion of each finger. Thin, full-thickness skin **(B)** should be used for this coverage. It can be obtained most easily from the groin crease; however, the physician must be careful to stay far enough laterally to avoid skin that will later grow hair. This will have to be at least lateral to the femoral artery and preferably more lateral below and just medial to the anterosuperior iliac spine. The defect from which the graft is obtained is closed primarily, and the graft is sutured into the recipient areas.

A pressure dressing that applies gentle compression to the flaps and the skin grafts is essential. This should be covered with a rigid plaster that extends above the elbow to immobilize the child's arm.

POSTOPERATIVE CARE

The dressing is usually left in place for 10 to 14 days to allow good healing of the grafts and flaps. If deemed necessary, an additional dressing can be applied for 1 to 2 weeks to allow further stabilization of the grafts. After this, there is usually no need for further immobilization, and the patient is allowed full use of the hand.

References

1. Bayne LG, Costas BL. Malformations of the upper limb. In: Morrissy RT, ed. Lovell and Winter's pediatric orthopaedics, 3rd ed. Philadelphia: JB Lippincott, 1990:577.
2. Flatt AE. The care of congenital anomalies of the hand. St Louis: CV Mosby, 1977:170.
3. Bauer TB, Tondra JM, Trusler HM. Technical modification in repair of syndactylism. Plast Reconstr Surg 1956;17:385.

1.5 RELEASE OF CONGENITAL TRIGGER THUMB

Congenital trigger thumb is usually noted by the parent after birth. In some cases, it may be possible to extend the thumb, in which case a trial of nonoperative treatment is indicated (1). A course of observation is indicated in most circumstances because about 40% of the cases resolve, and full motion results after surgery if it is performed in the first 3 years of life (2) (Figs. 1-17 to 1-20).

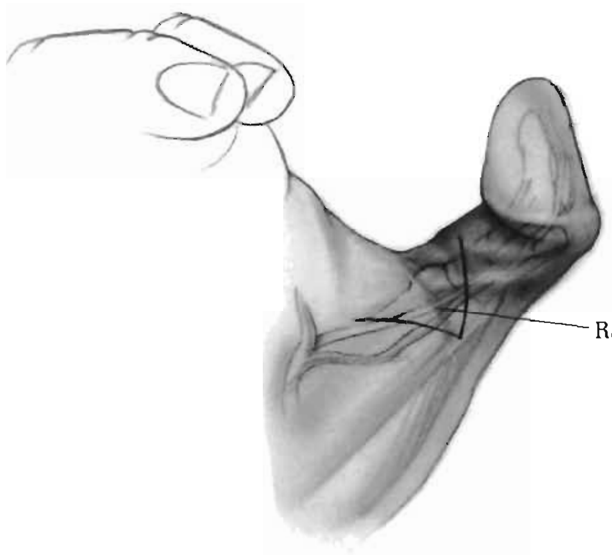


FIGURE 1-17. Although this release can be done through a simple transverse incision, an ulnar-based zigzag incision over the flexor crease of the metacarpophalangeal joint provides better exposure. The incision is perhaps the most difficult part of the operation because the radial digital nerve crosses the midline at exactly this point; and because it lies just beneath the skin, it can be divided easily while making the skin incision.

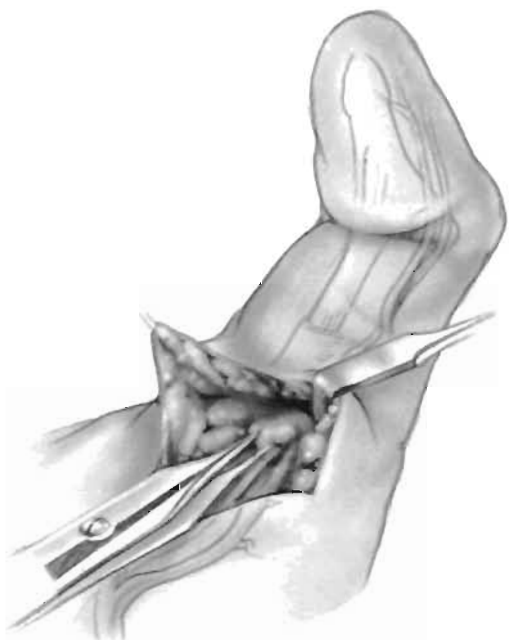


FIGURE 1-18. After the dermis is divided, a small, sharp scissors or hemostat is used to dissect out the radial digital nerve.

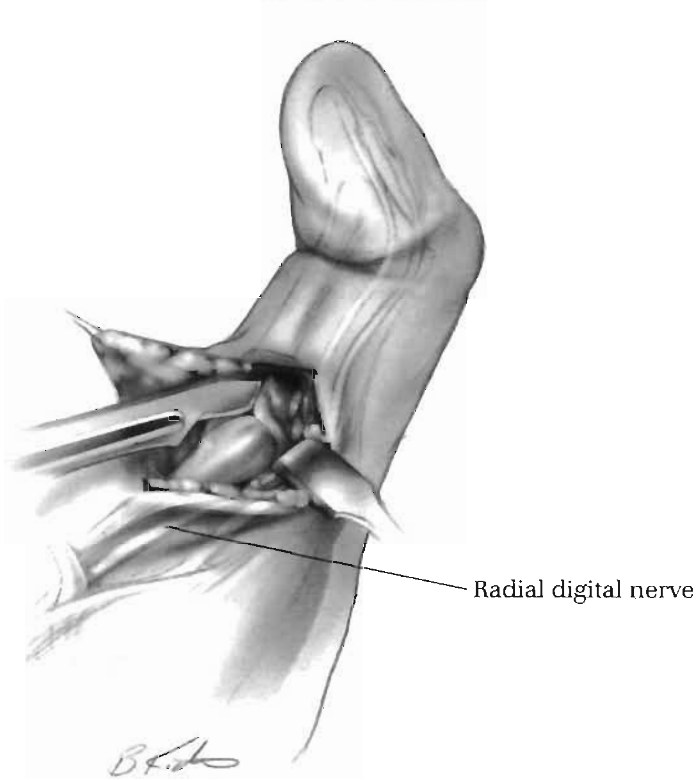


FIGURE 1-19. After it is safely retracted out of the way, the A-1 pulley is incised. It is usually not necessary to excise a portion of this pulley nor to shave the nodule, which will disappear after the release.

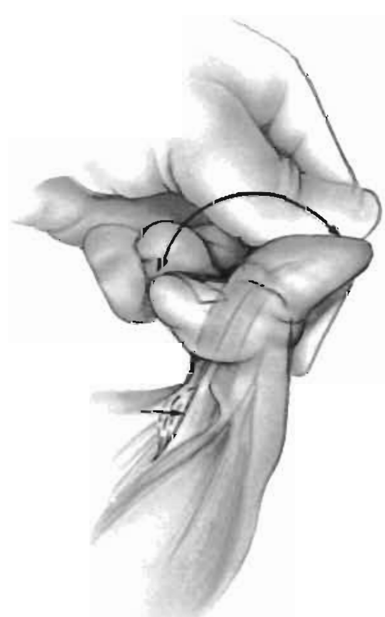


FIGURE 1-20. The thumb is extended fully to be certain that the release is complete. The release should not be extended too far distally so that bow stringing of the flexor pollicis longus tendon is avoided. Only the skin is closed.

POSTOPERATIVE CARE

The thumb is placed in a light (child-proof) dressing for 1 week and then removed to allow return to the usual activities. No further treatment is required.

References

1. Bayne LG, Costas BL. The upper limb. In: Morrissy RT, ed. Lovell and Winter's pediatric orthopaedics, 4th ed. Philadelphia: Lippincott-Raven, 1996:781.
2. Ger E, Kupcha P, Ger D. The management of trigger thumbs in children. J Hand Surg [Am] 1991;16:994.

1.6 EXCISION OF DUPLICATE THUMB

Duplication of the thumb, or preaxial polydactyly, is not common. Because polydactyly is the most common congenital anomaly of the hand, however, most orthopaedic surgeons encounter this anomaly. The treatment of this condition may hold a trap for the physician who is unaware of its unique anatomy. Because of the anatomic reasons discussed subsequently, simple excision of the smaller thumb rarely produces a satisfactory result (1).

Selecting which digit to remove may be difficult if both are of nearly the same size and function. Both function and cosmesis should be considered. In general, the radial digit is the smaller digit and is removed. This confers the advantage of leaving the ulnar collateral ligament intact for stability during pinch. Despite the fact that both thumbs have their own flexor and extensor motors, however, the thenar musculature attaches to the most radial digit. It is therefore necessary that these attachments be preserved and reattached to the remaining digit. If the ulnar digit is removed, it is necessary to preserve a periosteal and ligamentous flap from the radial border of this digit to reconstruct an ulnocollateral ligament for the remaining digit.

The wide variety of anomalies encountered under the term *duplicate thumb* makes careful assessment and planning imperative. Wassel (2) has classified these anomalies into seven types, whereas Marks and Bayne (3) have devised a more simple classification based on the level of duplication. These authors and others have discussed the principles involved as well as the results (4,5). The surgeon must plan an incision that will not leave a linear scar that will later contract, correct all rotational and angular deformity in the retained digit, carefully plan a reconstruction of the joint that will impart lasting stability, centralize the flexor and extensor tendons, and plan to keep the attachments of the thenar muscles on the retained digit.

These principles are illustrated on the most common type of thumb duplication: a Wassel type IV or a Marks and Bayne type I, in which there is complete duplication of the proximal phalanx (Figs. 1-21 to 1-26).

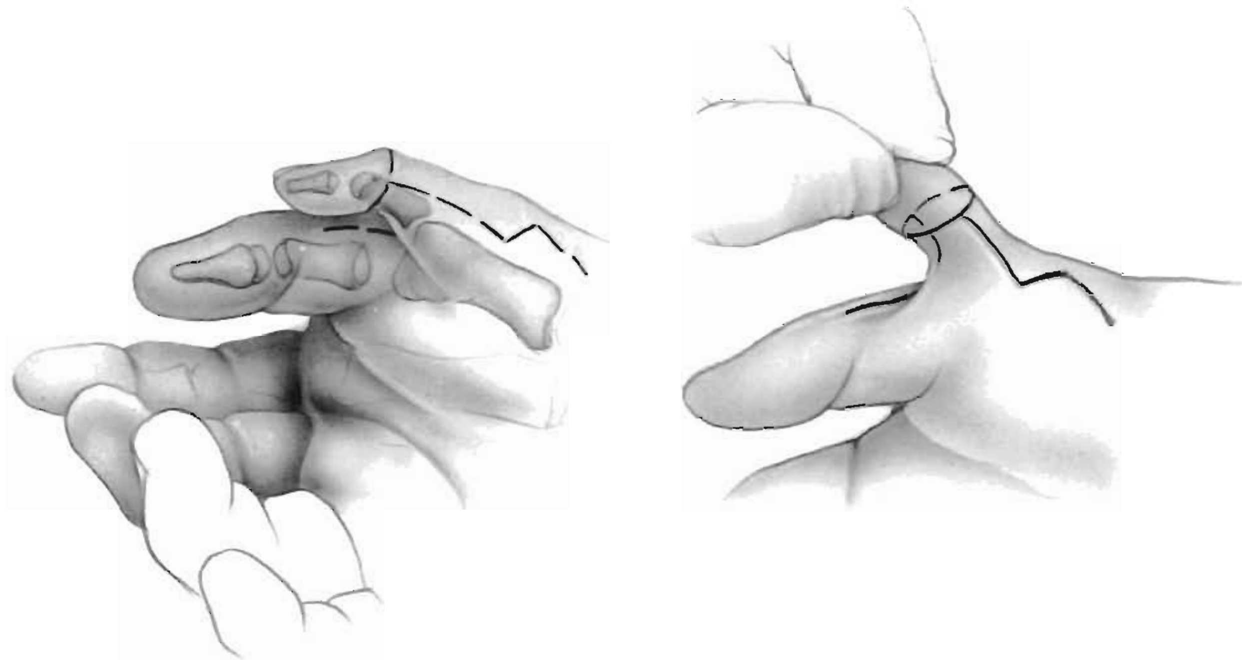


FIGURE 1-21. The incision is planned so that a straight scar is avoided. The incision illustrated has committed the surgeon to removal of the radial thumb. This incision permits exposure of all of the structures to both thumbs.

If the surgeon is uncertain at the beginning of the case about which thumb is to be retained, a different incision should be planned. This might occur if both digits were small or there was a question of the blood supply to the digit that might be retained.

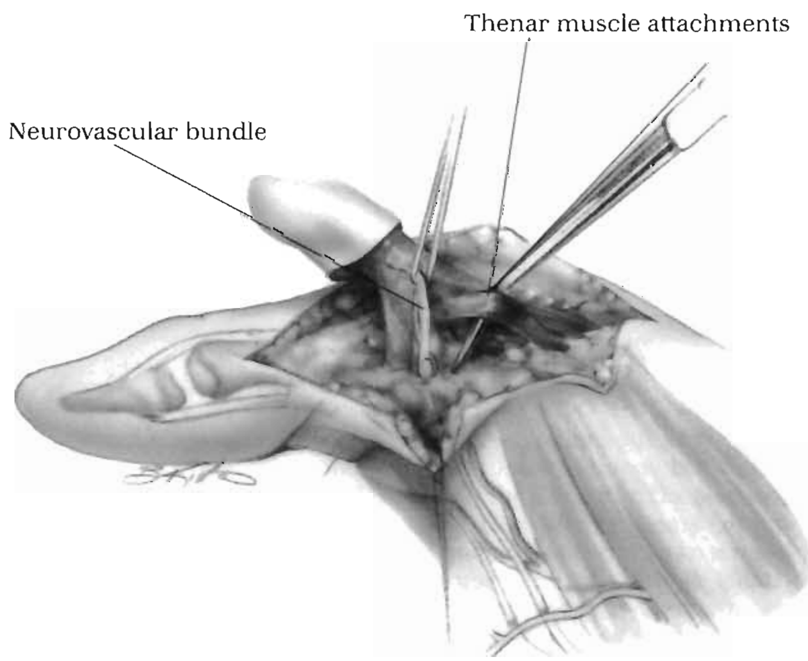
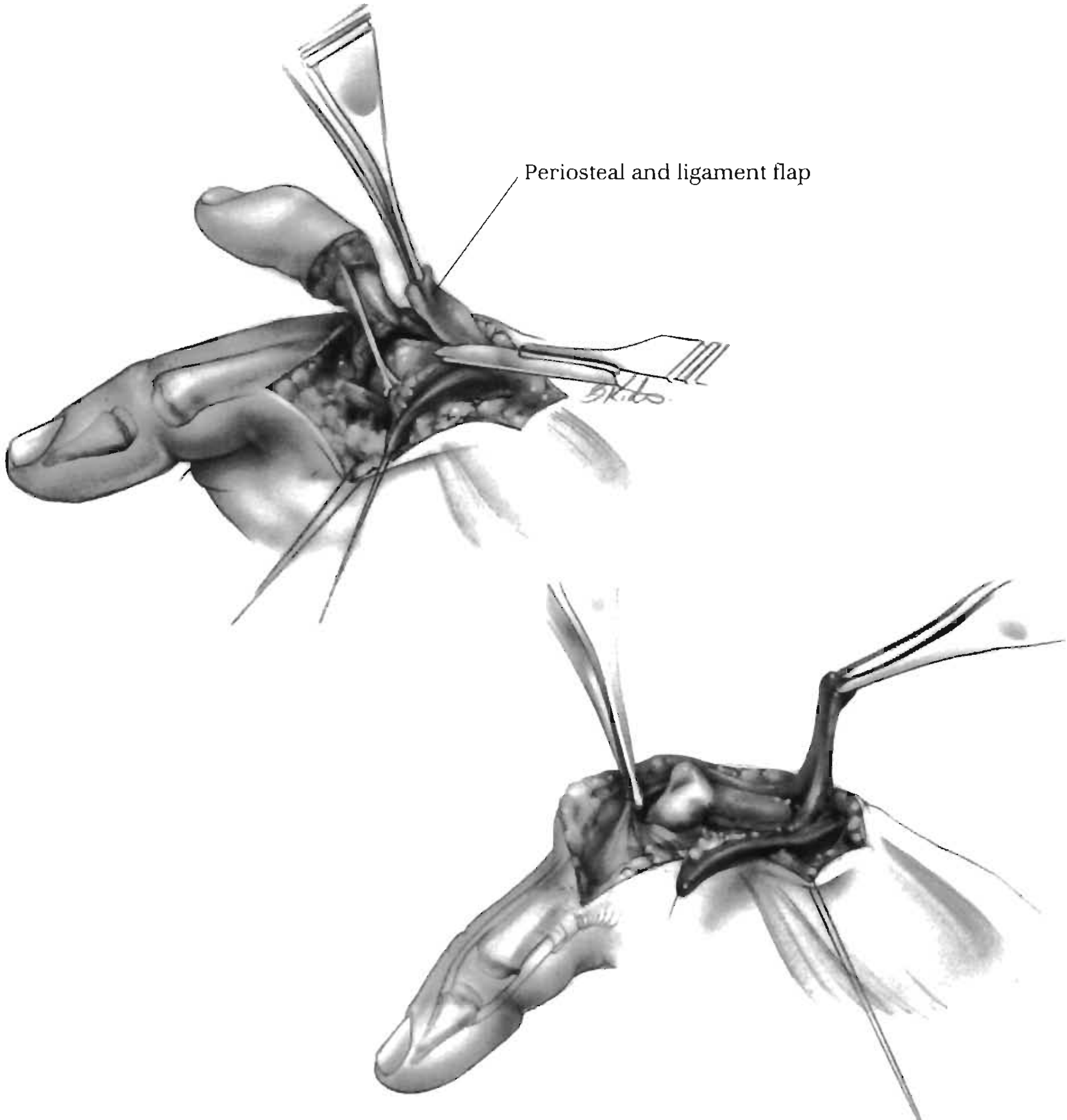


FIGURE 1-22. After the flaps are developed, the neurovascular bundles are identified and traced to their respective digits. This is to ensure that they are protected and the digit to be retained is innervated and vascularized. At this point, the thenar muscles are detached from the base of the radial digit. These will attach to the radial side of the radial digit by a broad tendon. Sufficient tendon and, if necessary, periosteum should be retained with the muscles to provide strong attachment to the retained digit.



A

B

FIGURE 1-23. With the thenar muscles detached and retracted out of the way, a flap of periosteum and ligament from the radial digit is raised. This flap **(A)** is then dissected proximally off of the metacarpal. It will be sutured into the radial side of the retained digit to reconstruct the radial collateral ligament. This is important because ulnar deviation is one of the most common complications of this procedure.

The radial digit is now removed and the remaining ulnar digit subluxated to demonstrate the condyle of the metacarpophalangeal joint **(B)**. This condyle is broader than normal and must be narrowed to provide good cosmesis as well as good stability for the retained digit. There is usually a small ridge on the articular surface of the condyle that identifies that portion of the condyle on which each of the thumbs articulated. In addition, there is frequently an ulnar deviation of the metacarpal head. In keeping with the principles outlined, it is necessary to correct this deviation at this time.

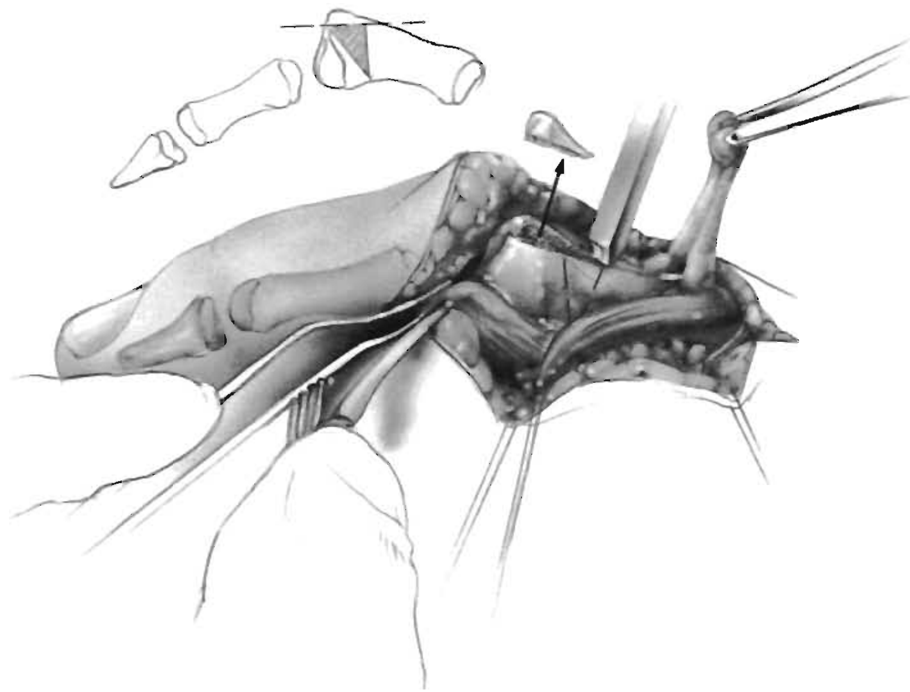


FIGURE 1-24. The excess radial portion of the condyle is removed with a small osteotome. A small closing wedge osteotomy is made just behind the condyle of the metacarpal. This is designed to correct the ulnar deviation. Any rotational malalignment can also be corrected. This osteotomy usually is fixed with one small Kirschner wire passed from the tip of the distal phalanx.

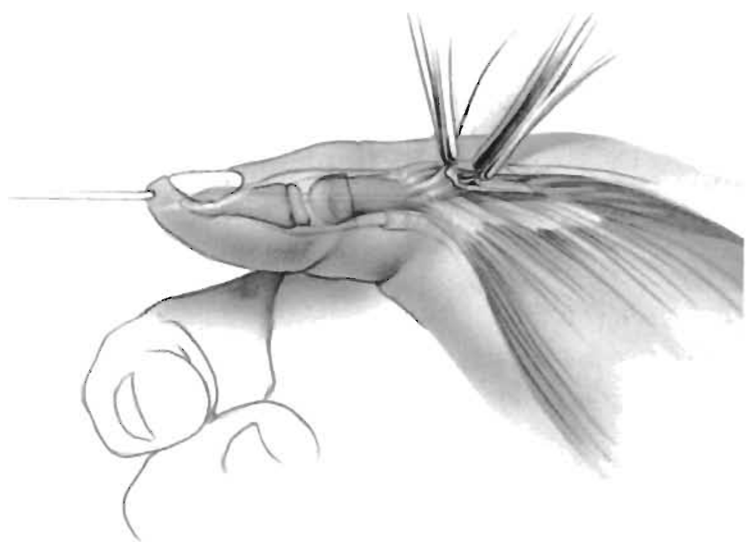


FIGURE 1-25. When the osteotomy is fixed, the periosteal and ligamentous flap that was raised from the discarded digit and radial side of the metacarpal is sutured to the radial side of the retained digit. Care should be taken in adjusting the tension of this repair. Subsequently, the thenar muscles are sutured over this to the base of the retained digit.

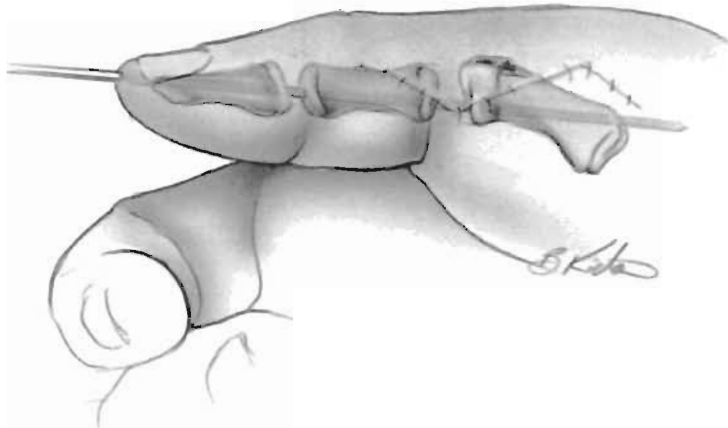


FIGURE 1-26. The skin is closed. There is no problem with a shortage of skin, but there is often some excess; this can be trimmed. The resulting suture line should not be linear. A rigid dressing and long arm cast are applied.

POSTOPERATIVE CARE

The cast is removed after 6 weeks, and a splint is fabricated to protect the repair of the radial collateral ligament. The splint is worn full-time for the first month while motion is started. After this, the splint is worn at night for 6 months.

References

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2. Wassel HD. The results of surgery for polydactyly of the thumb: a review. Clin Orthop 1969;64:175.
3. Marks TW, Bayne LG. Polydactyly of the thumb: abnormal anatomy and treatment. J Hand Surg 1978;3:107.
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5. Cheng JCY, Chan KM, Ma GFY, Leung PC. Polydactyly of the thumb: a surgical plan based on ninety-five cases. J Hand Surg [Am] 1984;9:155.

1.7 TRANSFER OF FLEXOR CARPI ULNARIS FOR WRIST FLEXION DEFORMITY

Wrist flexion deformity is a frequent problem in children with cerebral palsy. There are two aspects to the problem. The first, and the one discussed most often in relation to correction of the deformity, is function. The wrist is often held in flexion, pronation, and ulnar deviation, with inability to dorsiflex the wrist or release a grasp. The second problem is cosmetic. This rarely is considered by most authorities on the subject to be a worthwhile goal of surgery. For many patients, especially those with hemiparesis who are attending regular schools, this can be an important consideration.

The criteria for obtaining a good result with this operation were briefly mentioned in the follow-up article on the original patients (1). Tachdjian (2) lists eight prerequisites for this procedure. They are mentioned here as factors to be considered, some more strongly than others, rather than as absolute prerequisites.

- The flexor carpi ulnaris should have good motor power.
- There should be good passive dorsiflexion of the wrist, extension of the fingers, and supination of the forearm.
- The patient should be able to extend the fingers actively, with the wrist held in neutral.
- The patient should have good voluntary control over placement of the arm.
- There should be adequate sensory function in the hand.
- The patient should have reasonable intellect.
- The patient should be old enough to comply with the postoperative therapy program.
- No movement disorder, such as athetosis, should be present.

Hoffer and colleagues (3) studied spastic patients with dynamic electromyography and noted that the flexor carpi ulnaris co-contracted with the finger extensors. Because release is often more of a problem than grasp, they suggested transferring the flexor carpi ulnaris into the extensor digitorum communis to improve both release of grasp and wrist extension. In a subsequent report, Hoffer and colleagues (4) demonstrated the effectiveness of this in carefully selected patients and described the indications. In addition to failure to achieve the desired functional goals, the most common complication of this procedure is a wrist extension contracture. Hoffer and colleagues claimed that transferring the flexor carpi ulnaris into the extensor digitorum communis obviates this problem (4) (Figs. 1-27 to 1-29).

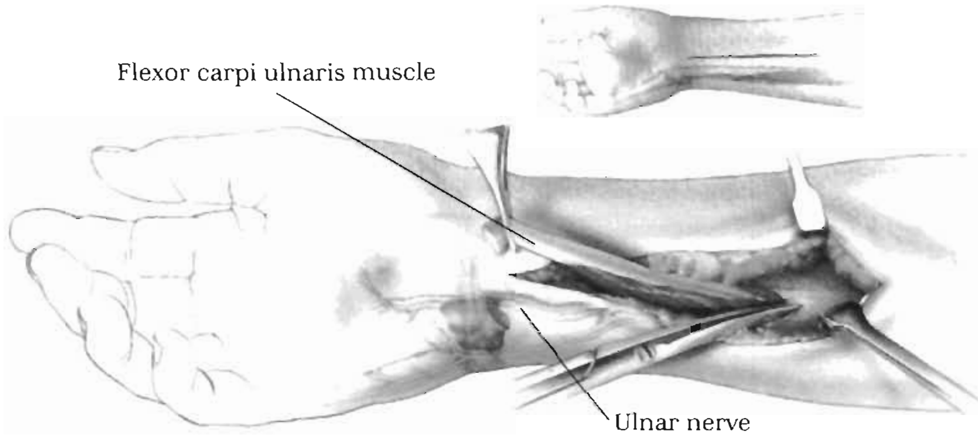

FIGURE 1-27. Although the procedure is usually performed with the patient in the supine position, the prone position facilitates exposure in the patient with an internal rotation contracture of the shoulder coupled with a pronation contracture of the forearm.

The procedure begins by detaching the flexor carpi ulnaris tendon and freeing up the muscle belly from its extensive origin along the ulna. Although two separate incisions were made originally, it makes more sense to make one incision because most of the dissection is done in the distal aspect of the forearm. The incision starts distally, at the flexor crease of the wrist and directly over the flexor carpi ulnaris tendon, where it inserts into the pisiform bone. It extends about midway up the forearm. A right-angled retractor can be used to elevate the skin at the proximal extent of the wound, allowing dissection as far proximally as the junction of the middle and distal one third of the forearm. The fascia over the tendon and the lateral aspect of the muscle are divided. The ulnar nerve lies directly under the tendon; therefore, caution must be used in freeing it from the pisiform bone.

After the tendon is divided, the muscle fibers along the lateral aspect of the muscle originating from the ulna are identified easily. These fibers must be freed by dissecting them off the periosteum of the ulna. The flexor carpi ulnaris receives its nerve supply from the underlying ulnar nerve. As the dissection proceeds proximally, it is important to identify and protect these branches. This dissection needs to extend proximally at least to the upper one third of the forearm—far enough to allow the muscle belly to be directed around the medial border of the ulna in a straight line.

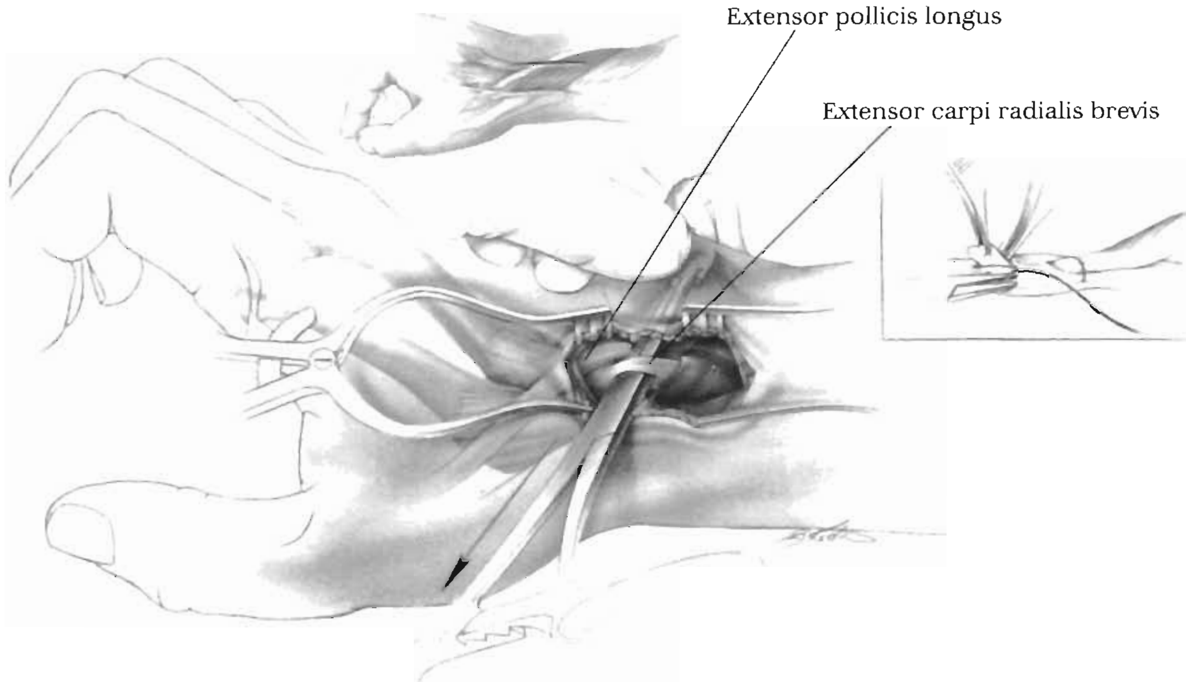

FIGURE 1-28. The second incision is made directly over the extensor carpi radialis and brevis tendons, starting at the extensor crease of the wrist and extending proximally for 3 to 4 cm. After incising the fascia, the two tendons can be identified: the most radial tendon is the extensor carpi radialis longus, and the more ulnar one is the brevis. Inserting the transfer into the extensor carpi radialis longus provides a better supination force and is more effective in overcoming ulnar deviation, whereas inserting the transfer into the brevis provides a more central pull. A subcutaneous tunnel is dissected from the proximal extent of the volar incision around the subcutaneous medial border of the ulna. A tendon forceps is used to bring the flexor carpi ulnaris around the medial aspect of the ulna through the subcutaneous tunnel and into the second incision on the dorsal aspect of the wrist. When the surgeon is confident that a sufficient portion of the intermuscular septum has been excised and that the tendon is running along a relatively straight path, the first incision is closed.

FIGURE 1-29. The flexor carpi ulnaris then is sutured into the desired tendon. As this is done, the wrist is held in about 45 degrees of extension, and the forearm is held in maximal supination. After the tendon anastomosis is complete, the wrist should flex passively at least 15 degrees past neutral with the fingers simultaneously going into extension.

The second wound is closed, and the patient is placed in a long arm cast with the wrist in slightly less than maximal dorsiflexion and the forearm in full supination. Because the underlying pathology is spasticity, the thumb should be incorporated in the cast in a position of abduction, and the metacarpal joints should be flexed about 15 degrees while the interphalangeal joints are in neutral.

POSTOPERATIVE CARE

The cast is removed after 4 weeks. A removable splint is fitted, which allows the wrist to be removed for therapy. Retraining of wrist extension, grasp, and release is begun at this time. Splinting of the wrist in extension is continued for up to 6 months.

References

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3. Hoffer MM, Perry J, Melkonian GJ. Dynamic electromyography and decision-making for surgery in the upper extremity of patients with cerebral palsy. J Hand Surg [Am] 1979;4:424.
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1.8 CORRECTION OF THUMB-IN-PALM DEFORMITY IN CEREBRAL PALSY

Children with cerebral palsy frequently have difficulty with hand function, and often most noticeable is the thumb deformity. The indications for correction of such deformities have been discussed in detail by several authors (1–3). Most authors have stressed the importance of the preoperative evaluation in the outcome, with assessment of voluntary control, sensation, cognition, and the ability to cooperate with a postoperative program being the most important factors.

House and colleagues (2) have classified the deformities by an assessment of the function of the thumb rather than its static position.

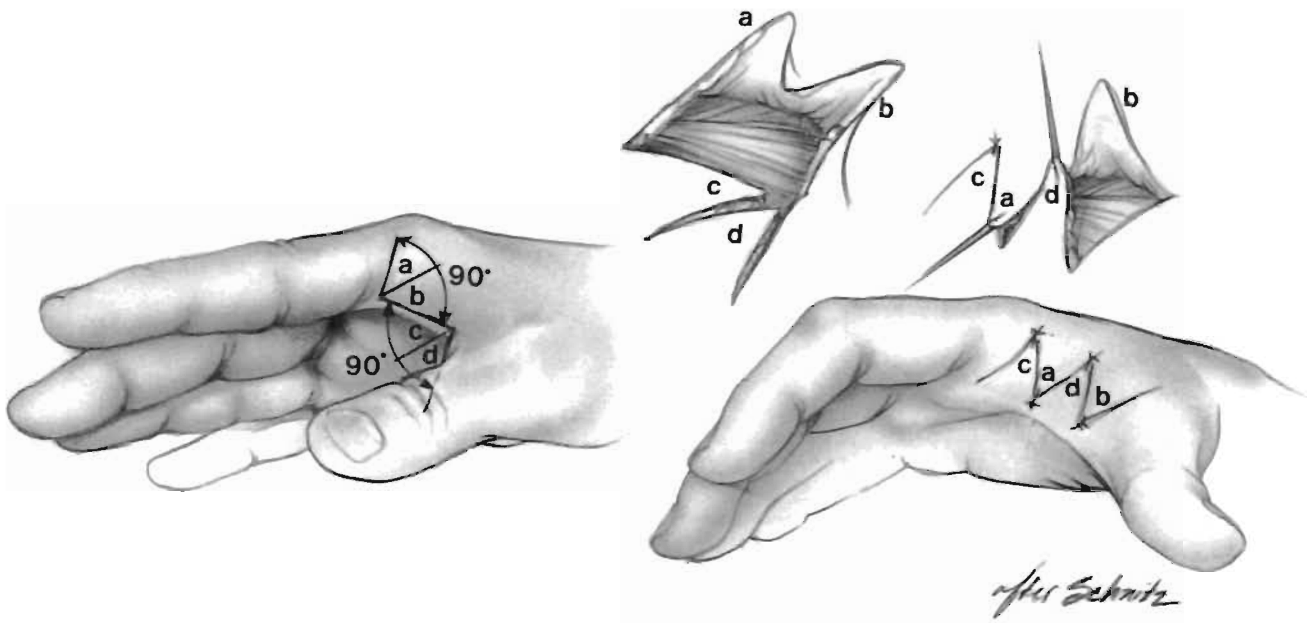
Type I: Metacarpal adduction contracture. This is the most common deformity and is usually associated with a contracture of the first thumb web space. It is caused by spasticity and contracture of the adductor pollicis and first dorsal interosseous muscles.

Type II: Metacarpal adduction contracture and metacarpophalangeal flexion deformity. In this deformity, the interphalangeal joint remains mobile, and the metacarpophalangeal joint is fixed in flexion by contracture of the flexor pollicis longus.

Type III: Metacarpal adduction contracture combined with a metacarpophalangeal hyperextension deformity or instability. This deformity is caused by spasticity of the extensor pollicis longus in the absence of spasticity in the flexor pollicis longus.

Type IV: Metacarpal adduction contracture combined with metacarpophalangeal and interphalangeal flexion deformities. This is usually caused by spasticity of the flexor pollicis longus and the intrinsic muscles of the thumb, but it may be caused by isolated spasticity of the flexor pollicis longus.

The steps that are taken in the correction of the deformities are considered in three categories: release of the skin and muscle contractures, augmentation of the weak muscles, and stabilization of joints (Figs. 1-30 to 1-33).



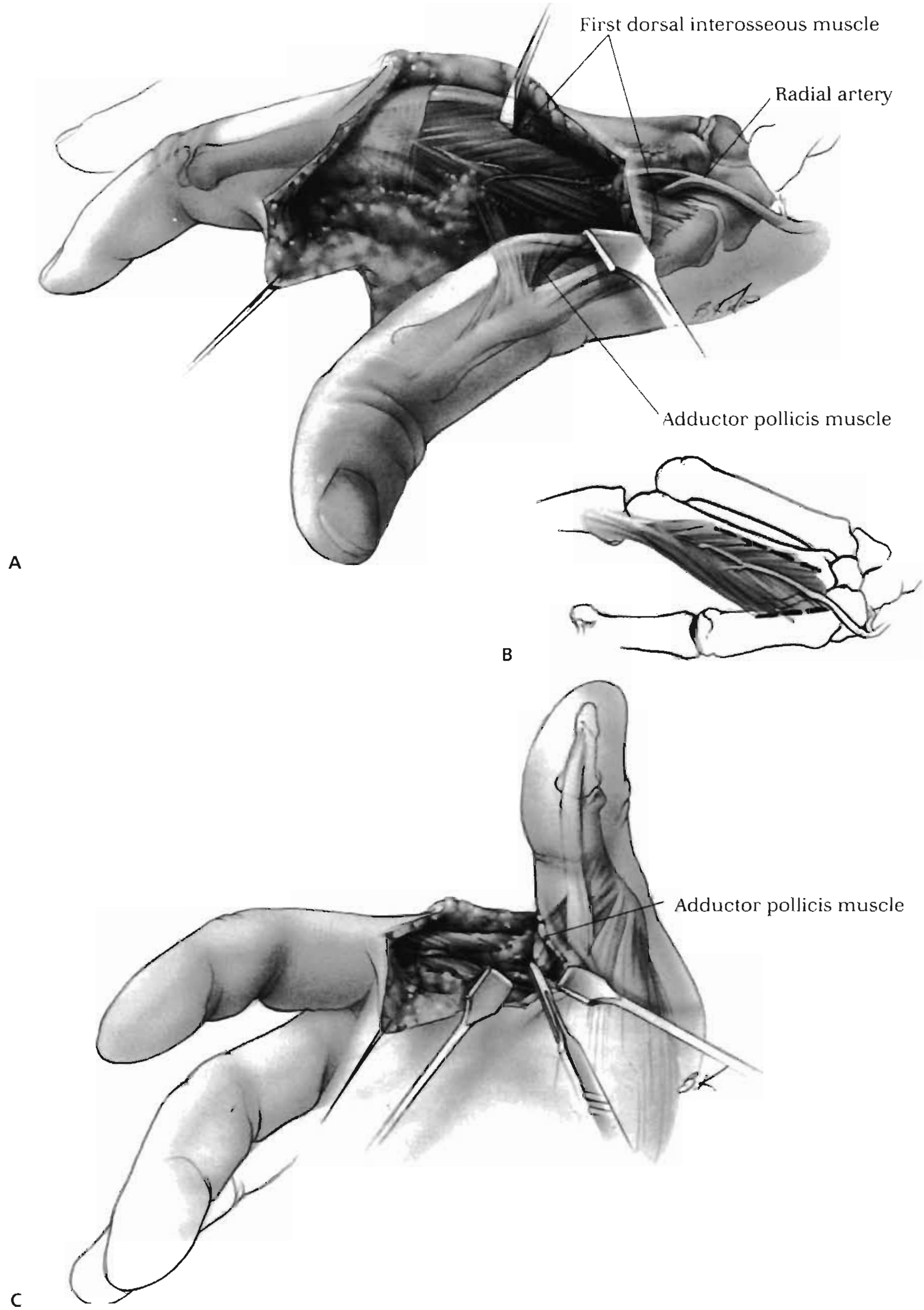
A

B

FIGURE 1-30. The release of the contracted first thumb web space is achieved by Z-plasty incision, through which the tight dorsal fascia and the muscles causing the contracture in the first place, the adductor pollicis longus and the first dorsal interosseous muscles, can be divided. The incision is a four-flap Z-plasty. This Z-plasty has been described using angles of 120 and 60 degrees or, as illustrated here, 90 and 45 degrees. Each limb of the incision should be of equal length. The first limb of the incision is made along the line of the maximal contracture. At each end of this incision and at 90 degrees to it, another incision **(A)** is made. This limb should be equal in length to half the length of the longitudinal limb. Finally, a third limb is added to each end of the incision, which bisects the right angle made by the first two limbs. This should be equal in length to the second limb. The incision **(B)** is closed by transposing the flaps.

FIGURE 1-31. After the flaps of the incision are developed and retracted and the dorsal fascia is divided **(A)**, the tight adductor pollicis and the first dorsal interosseous muscle are identified easily. The origin of the first dorsal interosseous muscle that arises from two heads, one on the first metacarpal and one on the second metacarpal, is released first. Care must be taken as the radial artery passes between these two heads to form the deep palmar arch. The portion inserting on the first metacarpal is released first. It usually is necessary to release at least a portion of the head originating on the second metacarpal **(B)** because the two heads join together close to their origin. ▶

After this, the adductor pollicis muscle is released by partially dividing it in its intramuscular portion. This muscle can be found running obliquely beneath the first dorsal interosseous muscle. Its division **(C)** is accomplished more easily, however, from the palmar aspect of the wound. If this does not provide sufficient abduction, it is necessary to release it from its origin on the third metacarpal, as described subsequently.


First dorsal interosseous muscle
Radial artery
Adductor pollicis muscle
A
B
Adductor pollicis muscle
C

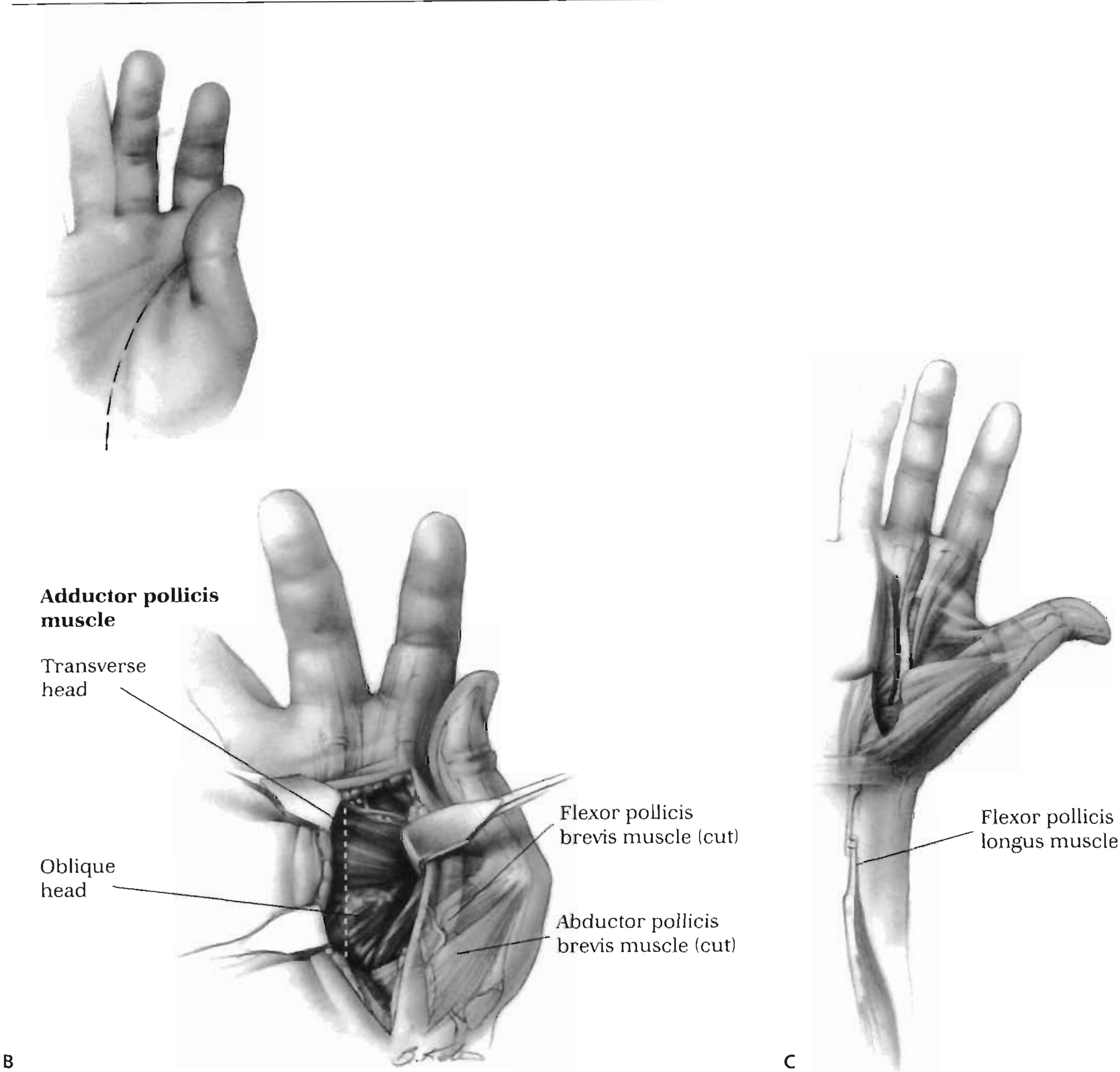


FIGURE 1-32. In the more severe type II deformities, it is usually necessary to release the origin of the adductor pollicis muscle from the third metacarpal and the origin of the flexor pollicis brevis from the flexor retinaculum. If necessary, a portion of the abductor pollicis brevis also can be released (4).

A palmar incision following the crease of the thenar eminence is used. The proximal portion of this incision **(A)** lies over the third metacarpal. After the skin and the fascia are divided **(B)**, the flexor tendons of the middle finger are retracted in the ulnar direction, whereas the neurovascular bundle and superficial palmar that arch along with the flexor tendons of the index finger are retracted in the radial direction. This exposes (distally to proximally) the transverse head of the adductor pollicis, the oblique head of the adductor pollicis, the flexor pollicis brevis, and the abductor pollicis brevis overlying the opponens pollicis muscle. The adductor pollicis muscle **(C)** is stripped off of the third metacarpal, whereas the origin of the flexor pollicis brevis is detached from the flexor retinaculum (transverse carpal ligament).

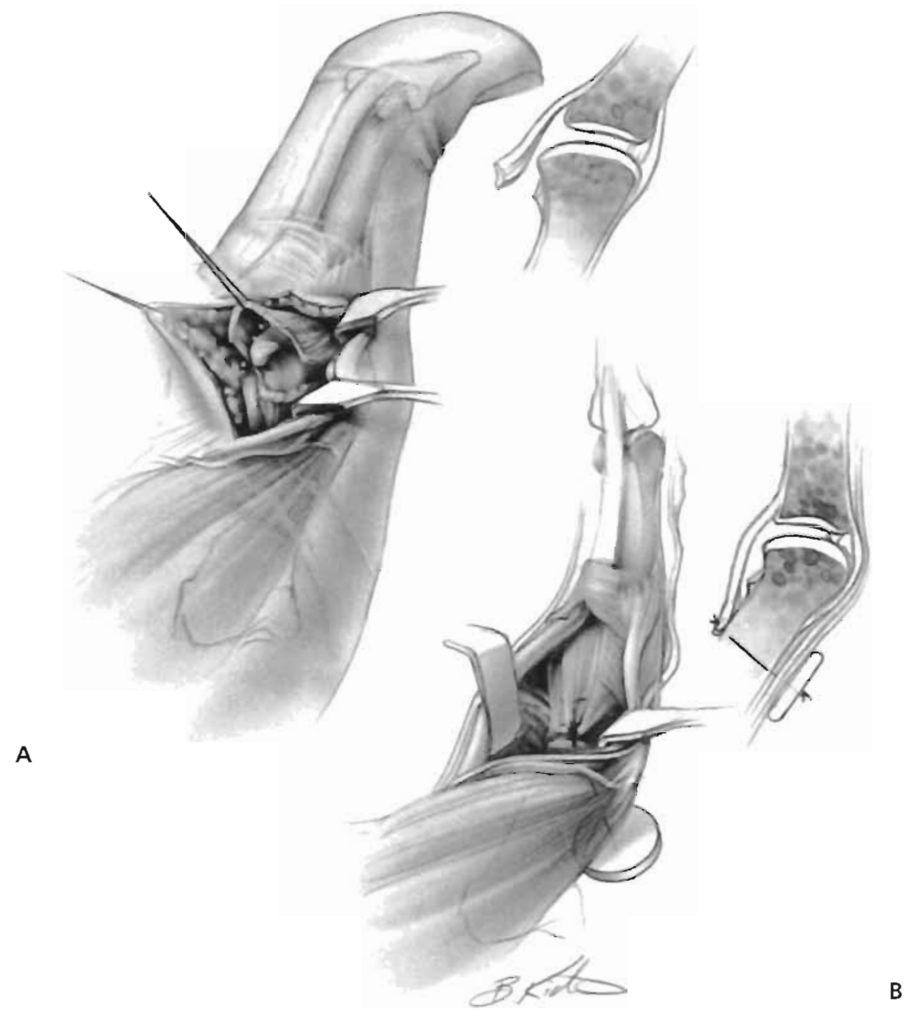


FIGURE 1-33. In type III deformities, it may be necessary to stabilize the thumb metacarpophalangeal joint. This can be done by arthrodesis. In the growing child, this can be accomplished by denuding the cartilage from the joint surface and fixing the joint with an intramedullary pin. This spares the growth of the physis.

Another method that preserves more of the function of the thumb, however, is described by Filler and colleagues (5). Through a V-shaped incision over the volar aspect of the metacarpophalangeal joint, as described for release of trigger thumb, the sheath of the flexor pollicis longus is partially excised to expose the tendon. As with release of trigger thumb, it is important to identify and retract the neurovascular bundles carefully, particularly the radial digital nerve that lies just beneath the skin and crosses the operative site. This exposes the volar plate or capsule. Its proximal insertion **(A)** is incised and freed. Both sides are then incised just outside of the sesamoid bones so that only the distal attachment remains. The joint is flexed 30 to 35 degrees and transfixed with a small Kirschner wire. The capsule is advanced proximally until it is taut. At this new point of insertion, a small groove is cut into the cortical bone, and a small drill hole is made from this groove to the dorsal surface of the metacarpal. A pull-out wire or strong absorbable suture is passed through this hole and tied over a button on the dorsum of the thumb **(B)** to secure the insertion of the volar plate into this groove.

In type IV deformity, it is necessary to lengthen the flexor pollicis longus. AZ lengthening is easily accomplished proximal to the wrist (see Fig. 1-32**C**).

There are numerous motors that can be used to augment the abductor pollicis longus, the extensor pollicis brevis, or the extensor pollicis longus. The palmaris longus, the brachioradialis, and the flexor carpi radialis muscles are commonly used.

POSTOPERATIVE CARE

Patients who have had only release or lengthening of contracted muscles are immobilized in a plaster splint or cast with the thumb in abduction and extension for 4 weeks. If arthrodesis or capsulodesis has been performed, immobilization may need to be continued for as long as 8 weeks. After immobilization is discontinued, the patient is started on a therapy program to mobilize and improve the function of the thumb as well as the fingers and wrist. An abduction splint is used continuously except during therapy for the next 6 to 12 weeks and then at nighttime only until dynamic balance has been achieved.

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1.9 CLOSED REDUCTION AND INTRAMEDULLARY FIXATION OF HUMERAL SHAFT FRACTURE

Occasionally, it is desirable to achieve stability of a humeral shaft fracture in a child or adolescent, not because the fracture will not heal but because it is difficult to maintain alignment. Examples of such situations include multiple trauma, multiple fractures in the same extremity, and severe head injury. Because flexible rods come in diameters ranging from 3.2 to 4.5 mm, depending on the type, most fractures in children requiring fixation can be treated with this method. The size of the bone in smaller children, however, often forces a compromise that results in less ideal fixation than would be achieved in an adult. Intramedullary fixation using a single portal in children is facilitated by having smaller and shorter rods in both the S and C configurations.

The humeral shaft may be fixed in one of two ways, and each has its relative indications depending on the location of the fracture. These techniques are described for adults (1–3).

The first method, retrograde, is to insert flexible rods from the distal end. This is suitable for fractures of the midshaft and proximal humerus but is not suitable for fractures of the distal half. The canal should be large enough to accommodate two rods. The insertion point for this method is usually through a portal on the dorsal surface of the humerus just proximal to the olecranon fossa.

The second method, antegrade, is to insert the fixation from proximal to distal. This method is accomplished most quickly by placing a single rod through a portal in the region of the greater tuberosity. In this technique, either a flexible or a more rigid Rush rod can be used. Usually, only a single rod can be placed with this method, but in the smaller child or when speed is important, a single Rush rod provides alignment for the fracture. A larger deltoid-splitting incision can be used to create a portal large enough for two flexible rods to be inserted. This incision requires great care to avoid injury to the axillary nerve, the location of which in a child may not be obvious to the surgeon who seldom uses this approach (Figs. 1-34 to 1-40).

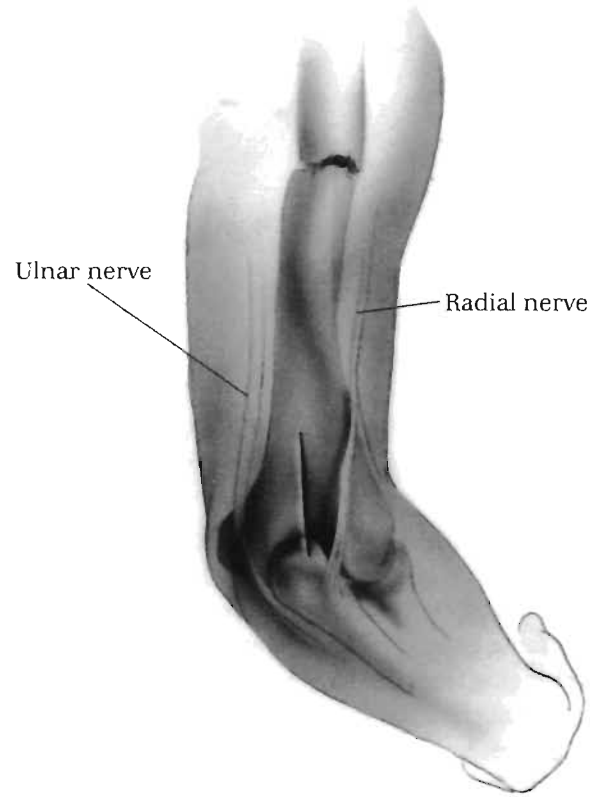


FIGURE 1-34. For both the retrograde and antegrade procedures, the patient is placed on a radiolucent operating table with the patient's head at the foot of the table to allow access for the image intensifier. The patient is positioned more to the side of the operating table opposite the surgeon so that the metal edge of the table does not block the view of the image intensifier. In retrograde nailing, a tourniquet can be used. Before beginning the operation, it is advisable to demonstrate that the fracture can be reduced and that the image intensifier can visualize the entire humerus.

For retrograde nailing, the arm is positioned across the body. A posterior midline incision is made extending from the olecranon fossa proximally for about 4 to 6 cm, depending on the size of the child. The incision is made sharply down through the triceps fascia, and the muscle fibers are split by blunt dissection to expose the posterior surface of the humerus.

The only major structure that concerns the surgeon is the radial nerve that travels distal medially to laterally. In the adult, the nerve lies about 10 cm proximal to the lateral epicondyle, but this distance is proportionally less in the child. The incision should not extend so far proximally that it encounters the nerve, unless the surgeon desires to explore the nerve.

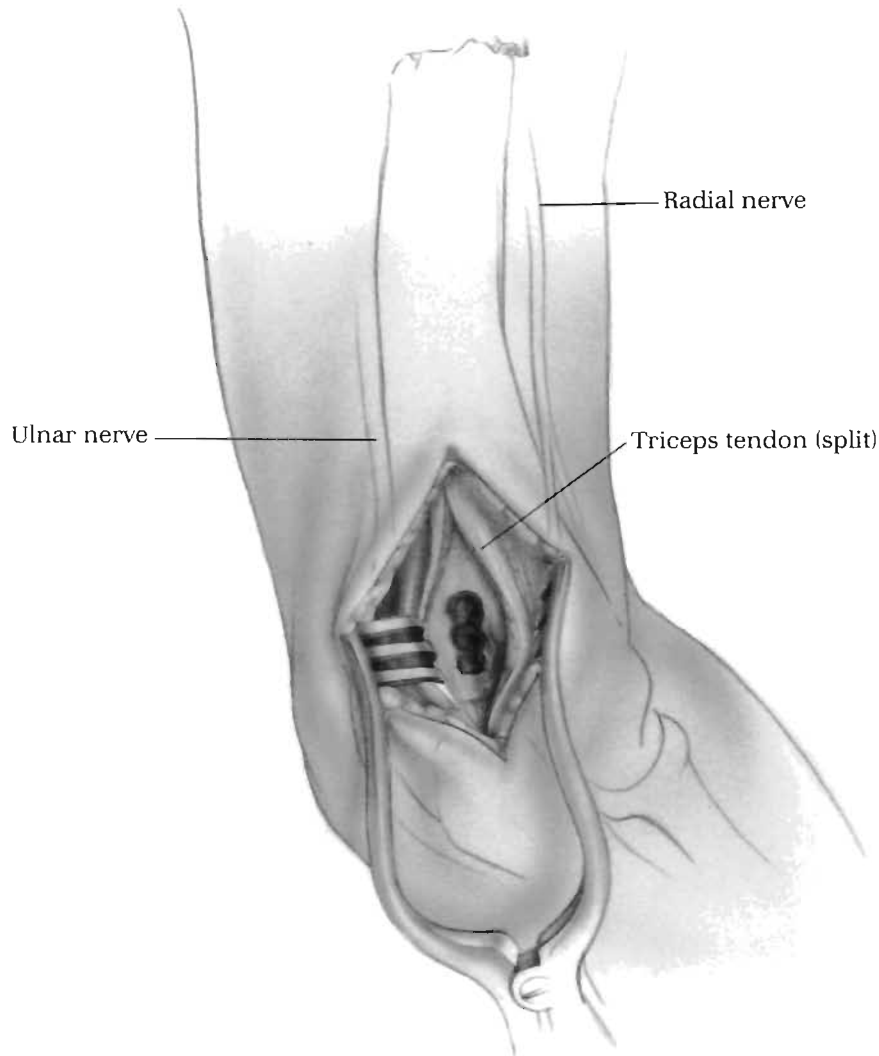
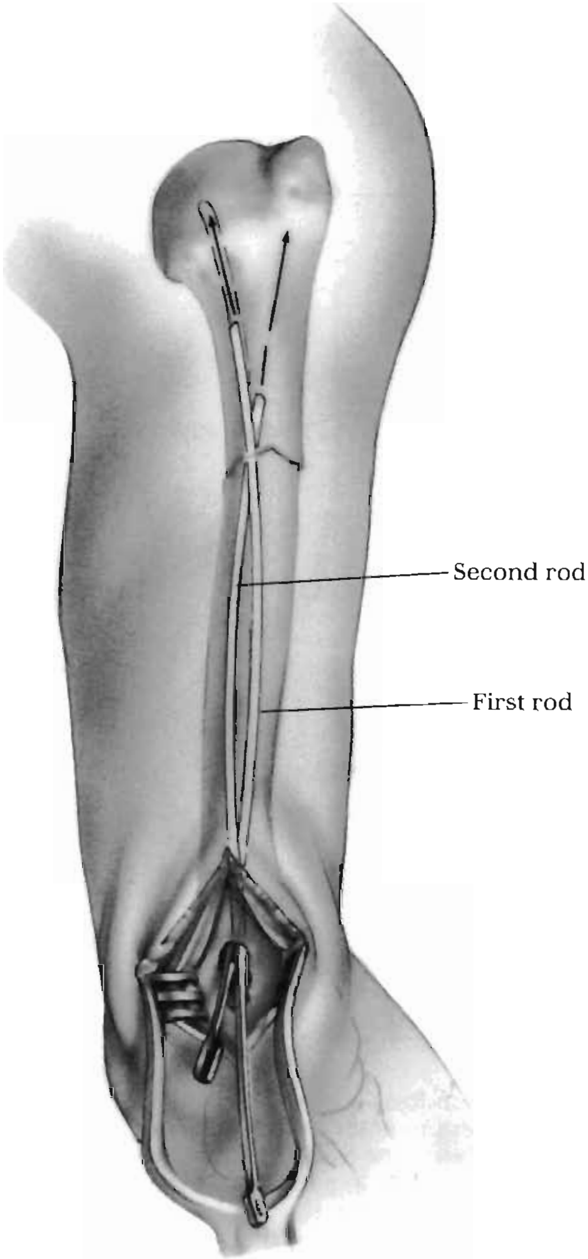


FIGURE 1-35. The superior lip of the olecranon fossa is identified, and a drill hole is made in the cortex far enough above the fossa to enter the medullary canal. In the adult, this is 2 to 3 cm, but it is proportionally less in the child. Additional drill holes are made proximal to this and connected with a rongeur. In addition, the hole should be made as wide as the canal. If this hole is not made sufficiently wide and long, the pressure exerted by the rods may break the cortex, loosening the three-point fixation essential in this method of fixation.



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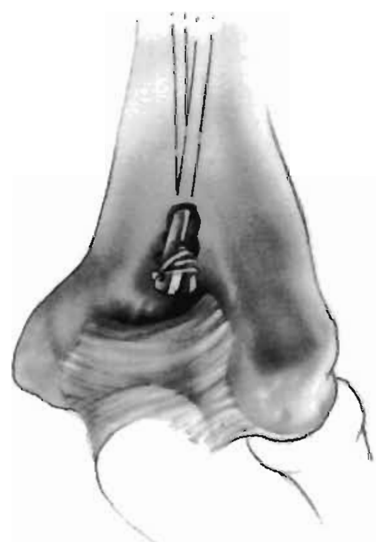

B

◀ **FIGURE 1-36.** The correct size of the rods is estimated by holding a rod next to the humerus and viewing both with the image intensifier. The first rod is inserted and driven to the fracture site. The fracture is reduced and the rod driven across into the proximal fragment (not as easily as it sounds here). The best way to be sure of the correct length is to drive it in completely, checking with the image intensifier to be sure it remains 1 cm from the articular surface of the humerus. If it is not, the rod is withdrawn partially, leaving it across the fracture, and another rod of the correct length is inserted.

The first rod is not inserted all the way. If it was used to measure the length, it is partially withdrawn. The second rod **(A)** is now inserted. It is important to have the nails end in different areas proximally to provide stability in rotation. Ideally, one nail goes into the greater tuberosity and the other toward the articular surface of the humeral head, but adequate stability is usually achieved short of this ideal. Positioning of the rod is accomplished by the bend in the rod and turning it after it is inserted.

With both rods in place and neither completely seated, a wire is passed through the eyelets of the rods. The rods are driven in completely. Only the eyelets should be protruding outside of the cortex. The wire **(B)** is twisted tight, binding the rods together.

A final check with the image intensifier is made to be sure that the nails are positioned correctly and that the fracture is not distracted. The wound is closed. A drain is not necessary.

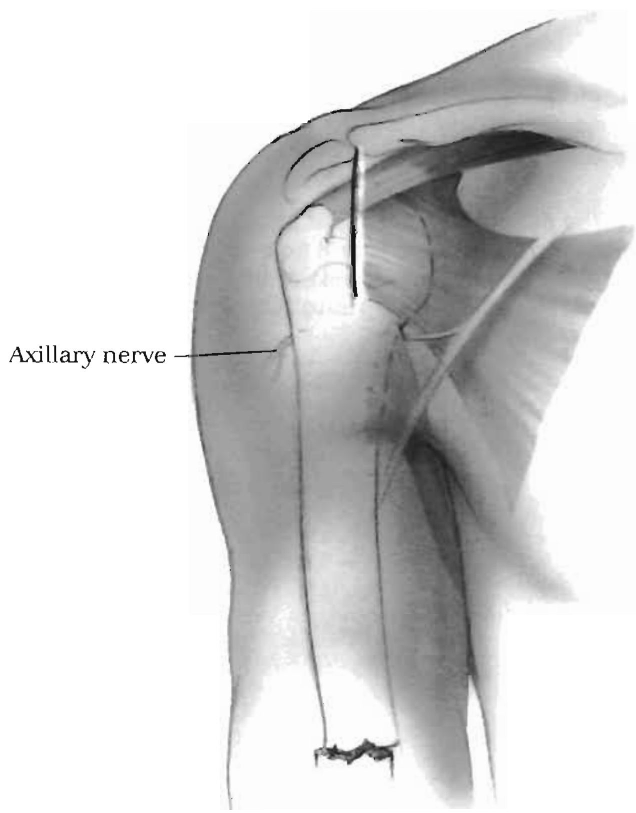

FIGURE 1-37. For the antegrade fixation with flexible nails, a small incision is made in the anterior deltoid. The incision is extended distally from the tip of the acromion for a distance of 2.5 to 3 cm. The main structure to be aware of is the axillary nerve, which crosses at the distal end of this incision. It should not be seen.

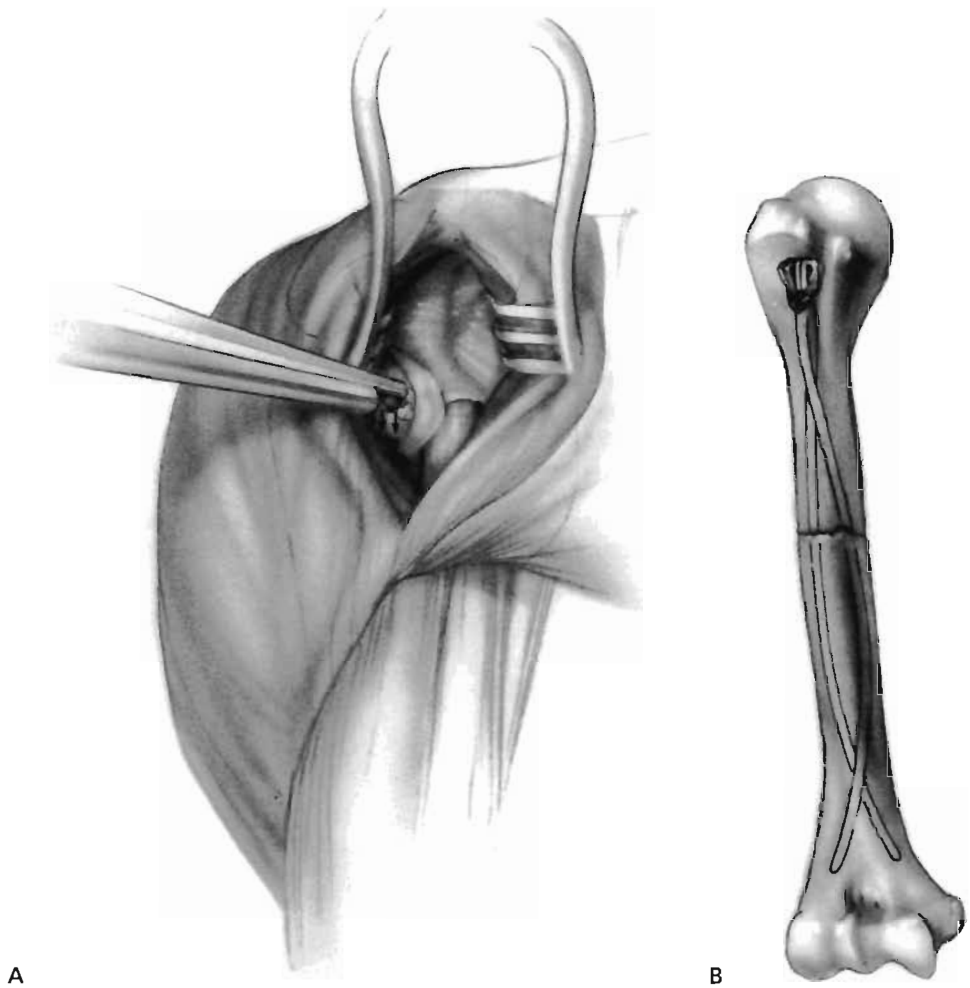

FIGURE 1-38. A: The deltoid fibers are split by blunt dissection to expose the periosteum of the shaft, which is opened. A drill hole large enough to admit a rongeur is made in the anterolateral metaphyseal area of the humerus just below the tip of the greater tuberosity. **B:** The hole is enlarged to accommodate the rods, two if possible.

FIGURE 1-39. When speed is important and only a single rod to help maintain alignment is desired, the incision can be smaller. The rotator cuff is split, and a straight Rush rod is inserted through the tip of the greater tuberosity. This does not provide rotational stability and less fixation of the fracture in general, but it helps maintain alignment in a coaptation splint. Because of the rod tip location, impingement occurs, and the rod will have to be removed.

A, B C, D

E,F

FIGURE 1-40. A, B: Radiographs of a 12-year-old boy with multiple trauma, including fracture of the humerus. Because of the difficulty in maintaining alignment in the splint while the other problems are being treated, the surgeon elected to rod the fracture to maintain the alignment. **C, D:** Radiographs taken at the conclusion of the surgery showing the alignment. **E, F:** Healing after 8 weeks.

POSTOPERATIVE CARE

Depending on the stability, a coaptation splint may be applied. Healing is usually sufficient within 3 to 4 weeks to discontinue this and begin range-of-motion exercises. The rods are removed electively after healing is complete.

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1.10 CLOSED REDUCTION AND PERCUTANEOUS PINNING OF SUPRACONDYLAR FRACTURE OF THE HUMERUS

Historically, supracondylar fractures of the humerus have had a high complication rate. The most common complication is cubitus varus, and the most dreaded complication is Volkmann ischemic contracture. These complications have all but disappeared (1,2). The reason for this is the improved management of these fractures, which includes an appreciation of the causes of compartment syndrome, the understanding of the pathomechanics of the deformity, and the uses of skeletal fixation to avoid displacement.

The two essentials in the treatment of a supracondylar fracture are an accurate reduction and the use of percutaneous skeletal fixation to permit the elbow to extend to 90 degrees while maintaining reduction. Without fixation, it is necessary to maintain the elbow at 110 degrees or more of flexion to maintain the reduction. With the subsequent swelling that occurs around the elbow, this position restricts venous drainage from the forearm, resulting in increased swelling and compartment syndrome. If the elbow is extended to 90 degrees, there is a likelihood that the reduction will be lost.

To understand the importance of accurate reduction, it is necessary to understand both the anatomy of the humerus at the fracture site and the mechanics of how the deformity occurs (Figs. 1-41 to 1-52).

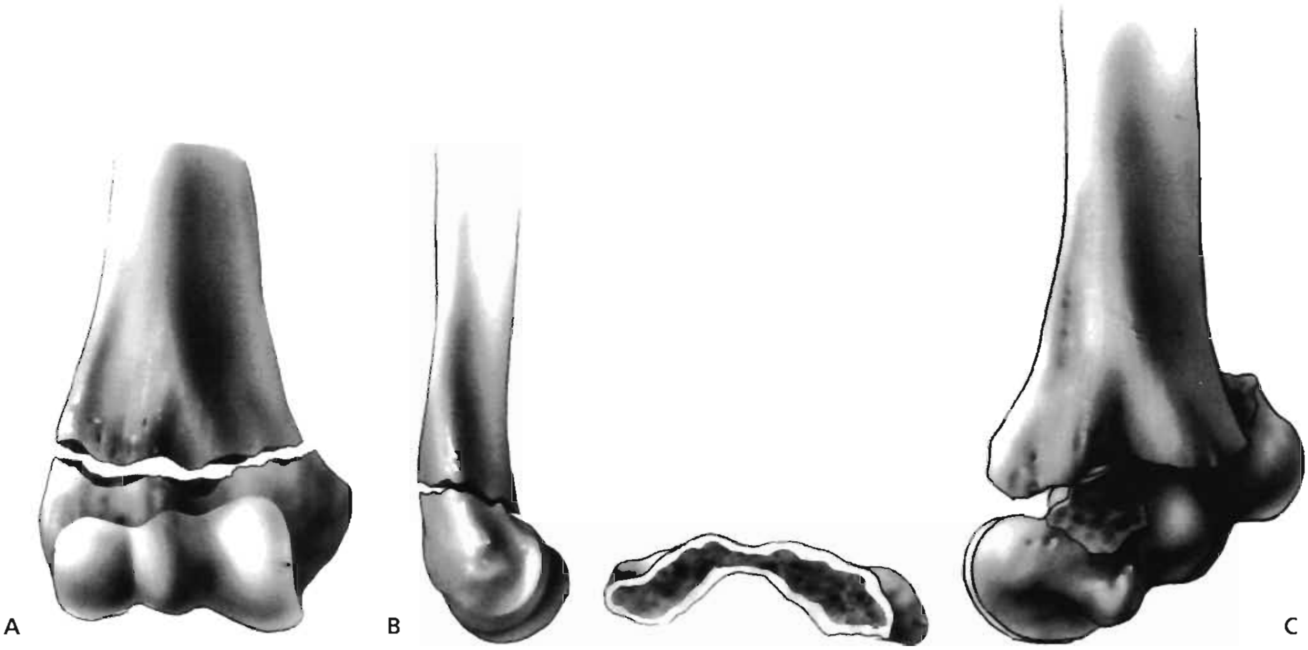


FIGURE 1-41. The supracondylar fracture of the humerus **(A)** occurs through the thinnest portion of the bone: the area of the coronoid fossa anteriorly and the coracoid fossa posteriorly. A cross-section of this area **(B)** demonstrates the medial and lateral bone masses, with the central portion being but a thin strip of bone. If the reduction **(C)** does not achieve and maintain rotational correction, there will not be stability of the reduction, and the distal fragment may tilt and angulate, producing deformity. This rotational deformity can be seen clinically in cases of angular deformity. Because of the large range of rotation in the shoulder joint, this rotational deformity is not apparent cosmetically or functionally (3).

The reduction of a supracondylar fracture is not difficult if each of the steps in the reduction described by Rang (4) are performed in the proper sequence. It is important to remember that this reduction does not require strength, and in fact, if the reduction is not done gently, the remaining periosteal hinge will be torn, creating an unstable situation and a much more difficult reduction.

FIGURE 1-42. Proper positioning of the patient, the image intensifier, and the assistant greatly simplifies the procedure. It must be emphasized that this is a radiographic technique.

The recording tube of the image intensifier becomes the operating table. The patient is shifted to the side of the table so that the shoulder is at the edge. While the surgeon scrubs, the nurse prepares the arm. A tourniquet can be applied in case an open reduction is necessary. The arm is draped with an extremity sheet. A sterile cover is placed over the image intensifier, which is brought into the operating table directly under the arm, perpendicular to the table, and under the sterile limb drape. An additional sheet can be wrapped around the arm of the image intensifier to produce a completely isolated sterile field. If the surgeon is right-handed, he or she stands above the arm and the assistant below.

FIGURE 1-43. The first step in the reduction is the application of traction to the arm, with it flexed about 15 degrees to reduce the distal fragment in line with the proximal fragment. In most extension supracondylar fractures, there is an intact periosteum posteriorly that aids in the reduction by providing a stable fulcrum against which to work.

When the proximal fragment has penetrated the brachialis muscle, the reduction will not be possible until the fragment is disengaged from the muscle. Using a milking maneuver, it is often possible to free the bone (5,6).

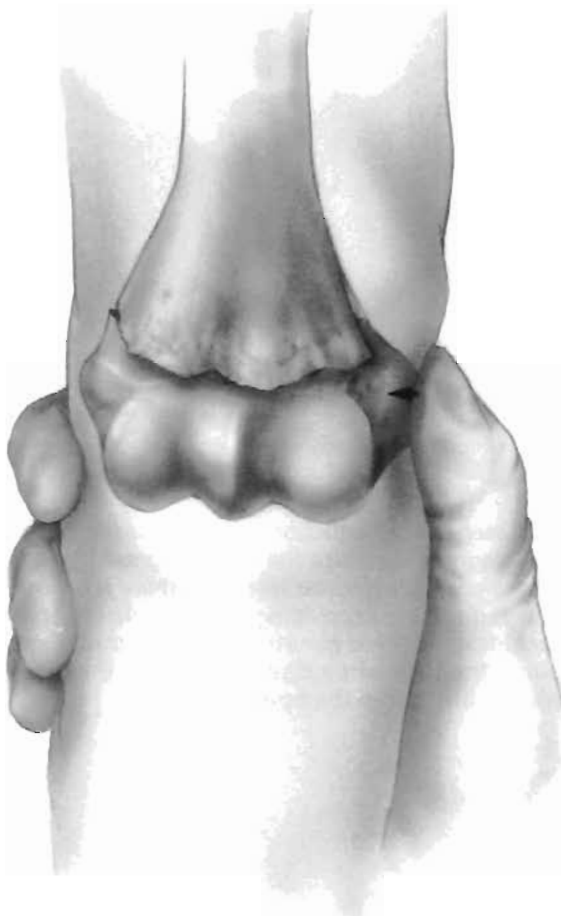


FIGURE 1-44. The second step is the correction of the medial or lateral displacement. This can be seen from the preoperative radiograph or the image intensifier during the reduction. It must be performed before the surface of the two bony fragments are brought into contact because after they are reduced, it is impossible to slide one over the other.

FIGURE 1-45. The third step is to correct the rotation. This must be done before the two fragments are brought into apposition. If the rotation is not correct, the fragments must be disengaged before another attempt at correction of the rotation. In most cases, the distal fragment requires external rotation.

FIGURE 1-46. With rotation and medial and lateral displacement corrected, the posterior displacement can be corrected. While the assistant supports the arm, the surgeon places one thumb behind the medial condyle and the other behind the lateral condyle. Pushing forward, the surgeon corrects the posterior displacement. The elbow is then flexed, which reduces the fracture.

The final step of percutaneous pinning is to pronate (if medially displaced) or supinate (if laterally displaced) the arm to tighten the remaining medial or lateral periosteal hinge.

The assistant holds the elbow in acute flexion, which maintains the reduction.

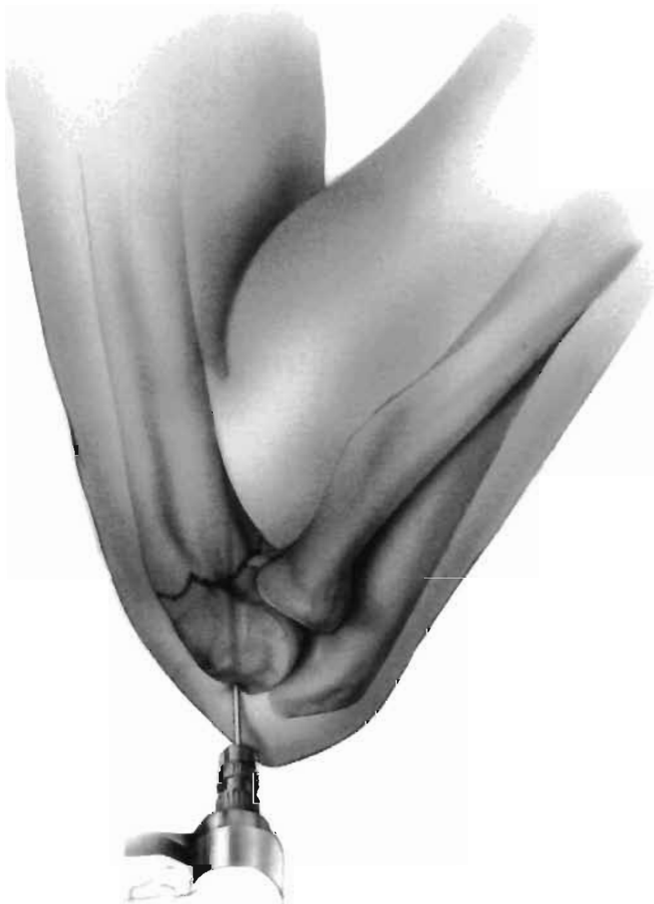


FIGURE 1-47. The arm is examined with the image intensifier to determine the adequacy of the reduction. Four views should be examined by internally and externally rotating the arm back and forth at each view to ensure that the proper aspect of the reduction is seen. The anteroposterior view is the least helpful because the overlying forearm obscures the bony detail of the humerus. The arm is held acutely flexed while the lateral view is examined. If the diameters of the two fragments at the fracture site are different, malrotation is present. If the proper angle between the condyles and the shaft has not been restored, hyperextension and lack of full flexion of the elbow results.

Next, the lateral and medial condyles are examined by oblique views. The internal oblique view demonstrates the lateral condyle, and the external oblique view demonstrates the medial condyle. If the lateral view shows that the rotation is incompletely reduced, these oblique views demonstrate which condyle is not completely reduced and whether more internal or external rotation is needed.

When the reduction is achieved, the percutaneous pins are inserted. Usually, 0.062-mm Kirschner wires are adequate for the fixation. One medial and one lateral pin provide the optimal degree of stability (7). When the lateral pin is inserted first, it is possible to extend the elbow slightly to palpate the bony landmarks better on the medial side of the elbow and avoid subluxating the ulnar nerve out of the groove. Sometimes, however, this displaces the fragments because it is more difficult to rotate the arm internally than externally.

The assistant continues to hold the elbow acutely flexed while rotating the arm with the lateral condyle facing up. The lateral condyle is palpated, and the Kirschner wire on the drill is pushed through the skin and into the bone. The image intensifier can be used to determine whether the location is correct and to aid in directing the wire so that it does not pass too far anteriorly or posteriorly and miss the proximal fragment. The wire should engage the opposite cortex.

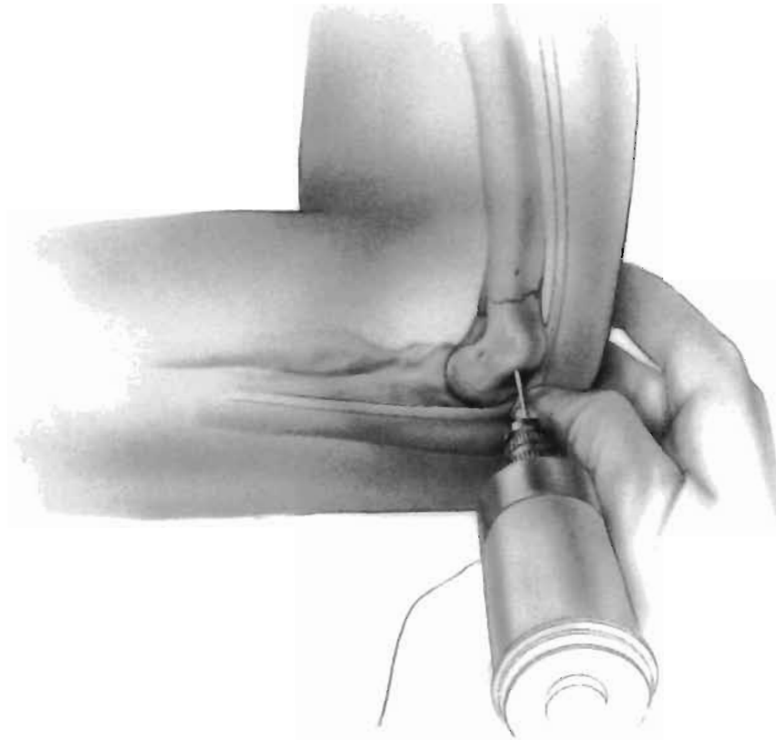


FIGURE 1-48. The arm, still held in acute flexion, is rotated until the medial condyle faces up. The thumb of the left hand (right-handed surgeon) finds the medial epicondyle. If swelling makes this difficult, the elbow can be extended slightly. The thumb should roll off of the inferior edge of the epicondyle into the ulnar grove and remain there holding the nerve in the grove. The Kirschner wire is started just at the tip of the thumb and is directed with image intensifier guidance, as in the previous example. If the surgeon is uncertain about the location of the ulnar nerve, a small incision over the ulnar groove can be made and the ulnar nerve located and held out of the way with a small curved hemostat.

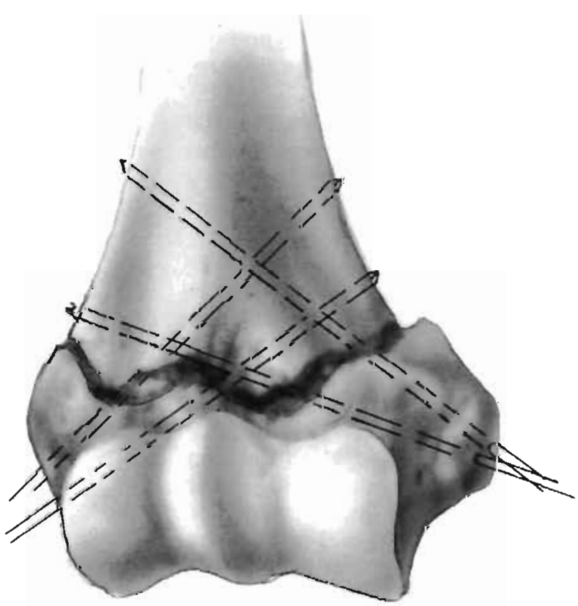
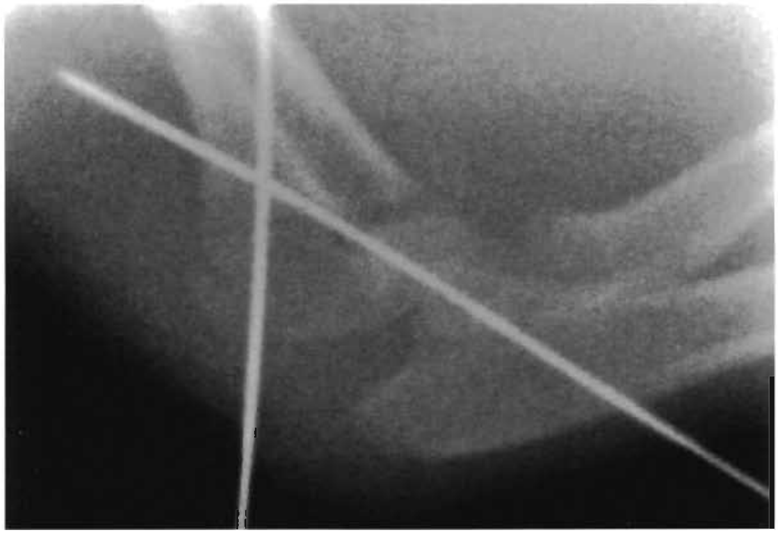


FIGURE 1-49. Both pins should engage the opposite cortex. Ideally, they pass up the medial and lateral columns of bone and do not cross at the fracture site. It is important to ascertain that the pins are in the distal fragment because, in the surgeon's desire to avoid the ulnar nerve, the pin may start too far proximally and miss the distal fragment. These views from the image intensifier are recorded as the final films because they will be far superior to any films taken through the cast, and no further change in the fracture can occur if the pins are placed properly. Finally, the arm can be extended fully and examined clinically for any deformity.



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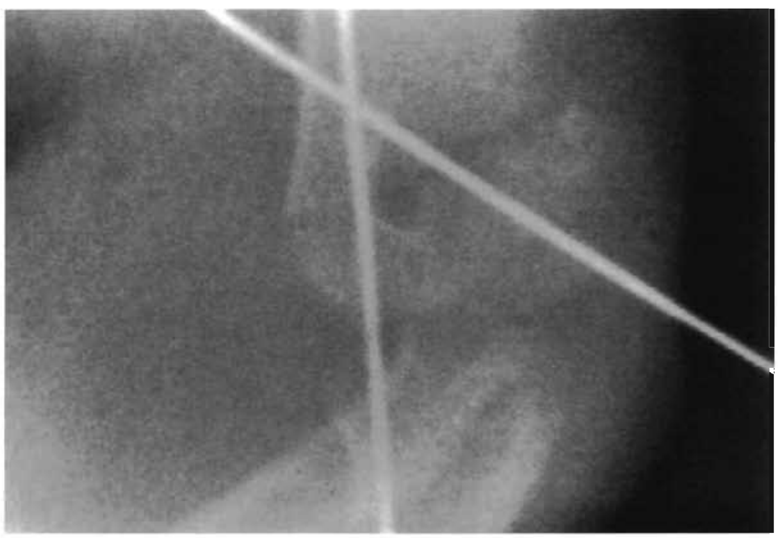

B

FIGURE 1-50. After placement of both pins, the arm is again examined in all four views with the image intensifier to confirm the reduction and the placement of the pins. The internal rotation oblique view **(A)** demonstrates the lateral condyle, and the external oblique view **(B)** demonstrates the medial condyle. If the fracture is not anatomically reduced, these views show which condyle is incompletely reduced.

If all is satisfactory, the pins are cut and bent over, leaving them outside the skin to facilitate removal in the office.

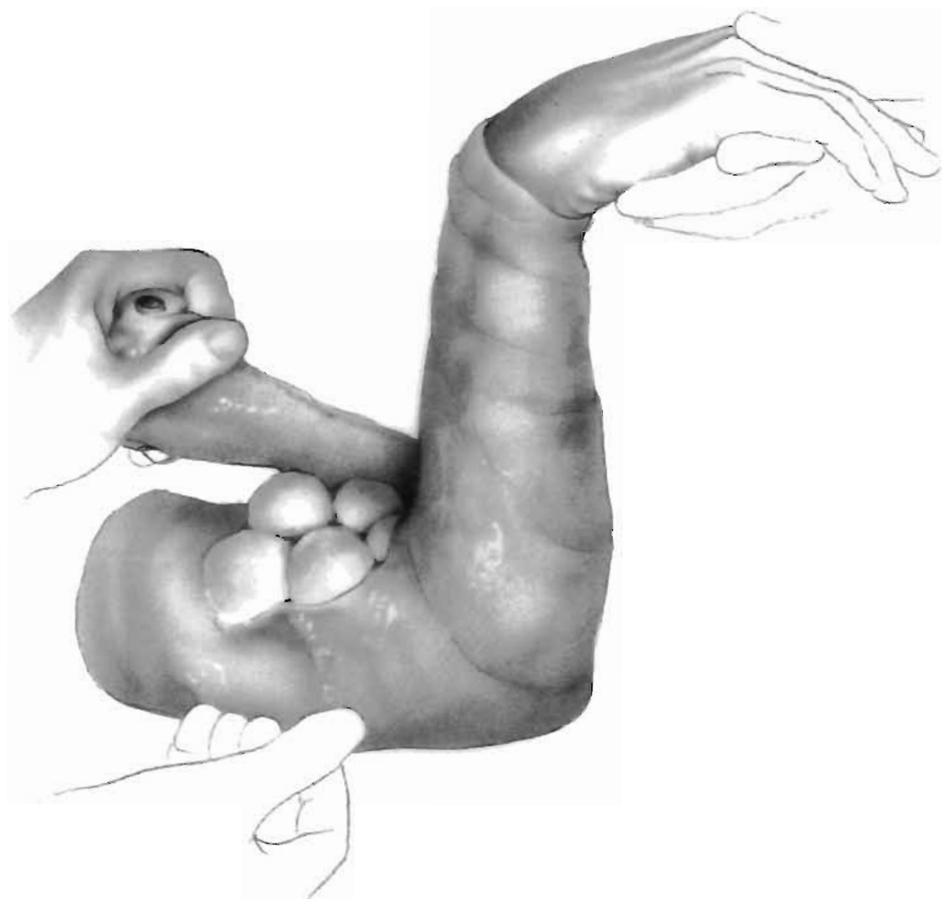

FIGURE 1-51. The arm is held in 90 degrees of elbow flexion and either pronation or supination, as indicated. Cotton balls, or fluffs, are placed into the antecubital space to prevent the cast and padding from constricting this area and to allow for swelling in the elbow region, which could lead to venous obstruction. A solid long arm cast is applied, and with the room for swelling in the elbow region, splitting the cast is not usually necessary.

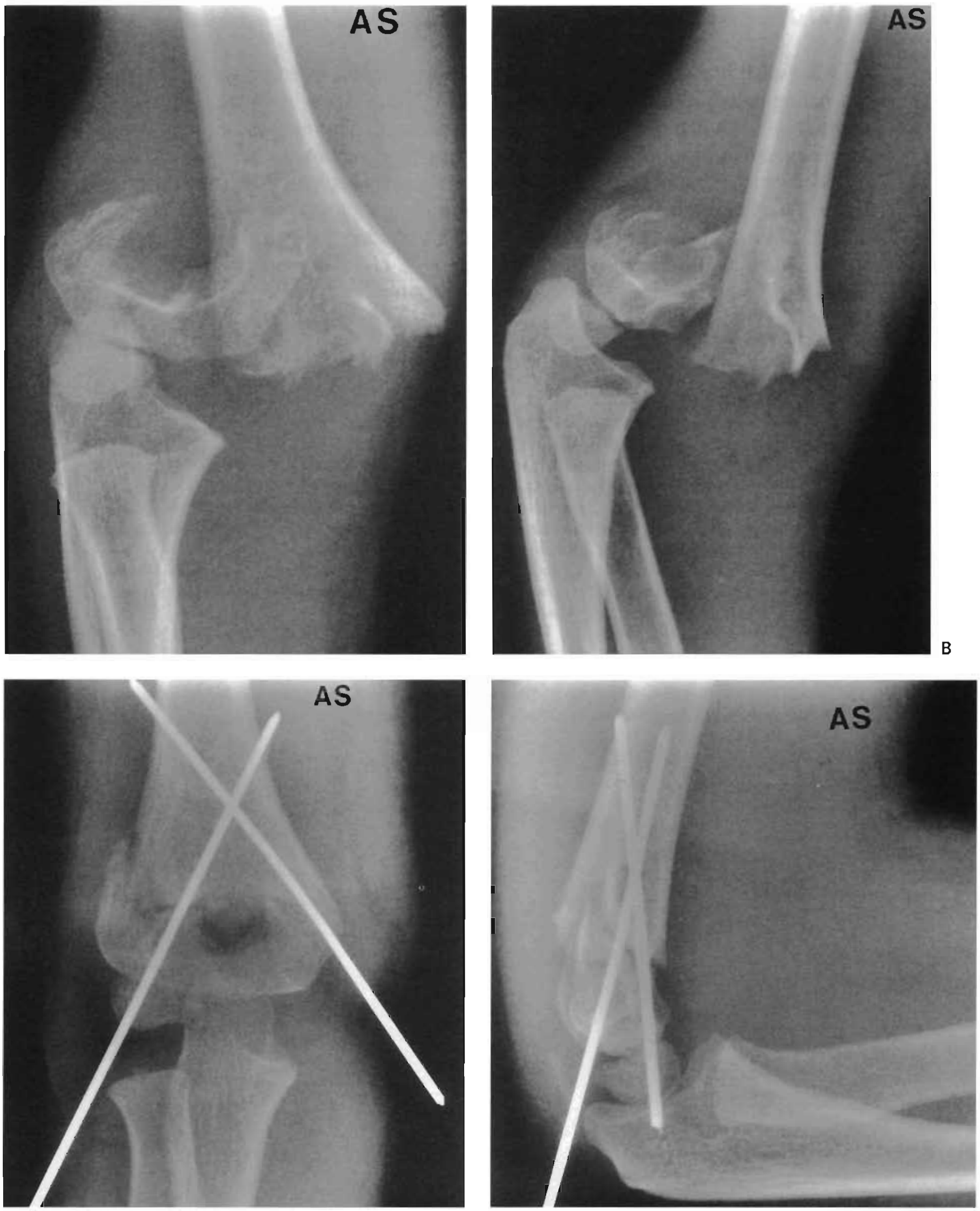

FIGURE 1-52. **A, B:** A typical grade III supracondylar fracture of the humerus. **C, D:** The anteroposterior and lateral views after reduction. Note that the fracture is reduced anatomically, the pins engage the opposite cortex, and both pins are in the distal fragment.

POSTOPERATIVE CARE

The cast is left in place for 3 to 4 weeks. It is removed, and anteroposterior and lateral radiographs of the distal humerus are taken. If these show initial healing, as evidenced by periosteal new bone, the pins are removed. This may cause the patient apprehension but should cause little or no physical discomfort.

The patient should remain in the sling, removing it only to do active and passive extension exercises under the supervision of a parent. Three weeks after removal of the pins, another set of radiographs is obtained, which should demonstrate healing of the fracture. Gradual resumption of activities is permitted. Full extension should be achieved by 3 months, although some children may require longer.

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1.11 OPEN REDUCTION OF SUPRACONDYLAR FRACTURES OF THE HUMERUS

In certain circumstances, it is not possible to achieve an anatomic reduction of a supracondylar fracture. In such cases, open reduction is indicated. The previous teaching that this should not be done because it will result in stiffness has been disproved by common experience and various reports. When a supracondylar fracture is irreducible, the surgeon should pause to think of the reasons. If comminution is the problem, a posterior approach, either working around the triceps or detaching it in some way, is probably the best approach. If there is any suspicion that the neurovascular structures are either injured or interposed between the fracture fragments, an anterior approach that allows access to these structures is best. This is the most universal approach for an irreducible supracondylar fracture of the humerus because it gives direct access to the obstacle to the reduction and allows safe exposure of the neurovascular structures. This approach is illustrated here.

Several physical findings before and during reduction suggest that the anterior approach as the best one. The pucker sign, tenting of the skin on a spike of bone, indicates that the spike has penetrated the brachialis muscle, which is the first obstacle to reduction of the fracture. (After reducing the bone beneath the brachialis muscle, the periosteum may be the next obstacle.) If the muscle can not be "milked" off of the bone, an open reduction is necessary, and the anterior approach is the most direct. Often, as the fragments are manipulated, the surgeon cannot feel the crepitus characteristic of bone on bone contact. This is usually replaced by a soft rubbery feeling and inability to achieve an anatomic reduction. This is usually caused by interposed soft tissue, which may include muscle, periosteum, or the neurovascular bundle. There may be vascular embarrassment of the hand or an absent radial pulse, which may make exposure of the neurovascular bundle advisable during the open reduction. These findings likewise suggest an anterior approach.

When the spike of bone is medial and the distal fragment is posterolateral, the surgeon should suspect that the neurovascular bundle is involved. This would best be approached with an anterior medial incision. When the proximal spike of bone is lateral, it is possible that the radial nerve is over the spike of bone or, more rarely, is interposed in the fracture site. This situation would best be approached by an anterior lateral incision (Figs. 1-53 to 1-55).

FIGURE 1-53. The incision starts on the anteromedial aspect of the arm and crosses in the flexion crease of the elbow. If the surgeon is uncertain about whether the neurovascular bundle is trapped in the fracture site, he or she should begin with the vertical portion of the incision and only a small portion of the horizontal limb. If the bundle is in the fracture site or more access to it is needed, the incision is continued across the antecubital crease.

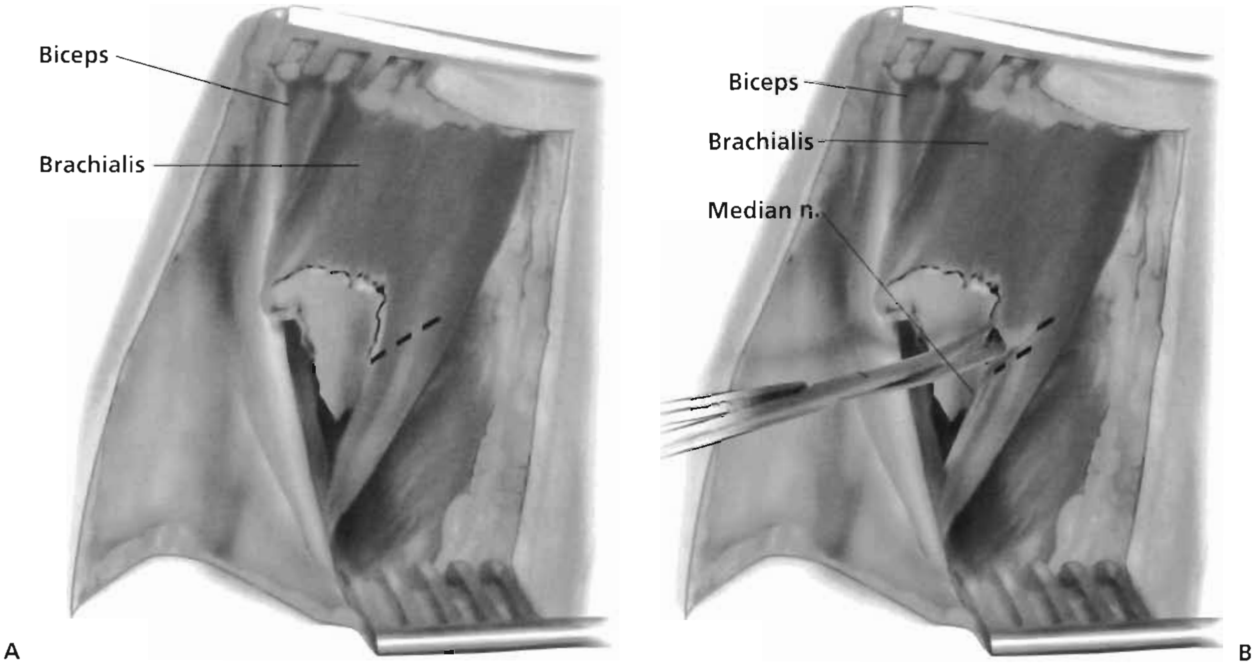
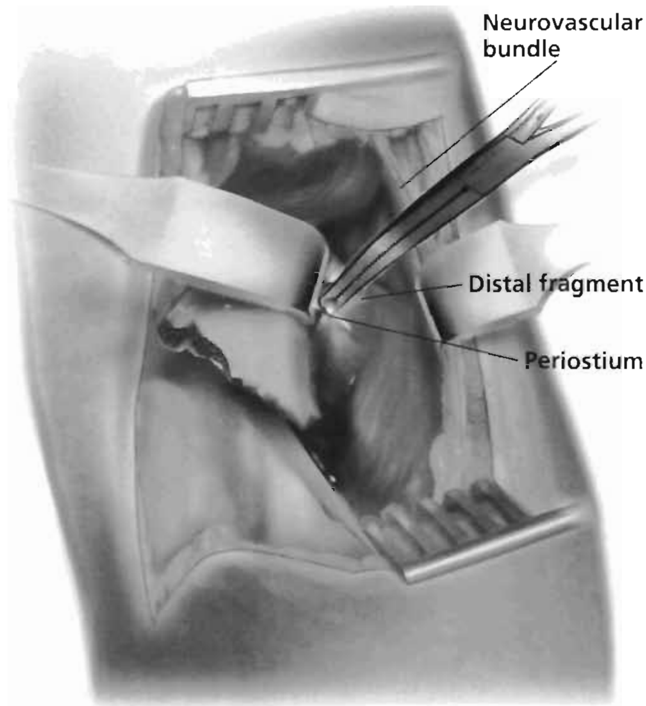


FIGURE 1-54. As the dissection continues through the fatty tissue onto the metaphyseal spike, great care should be taken because the neurovascular bundle may be anywhere on or around the the spike of bone. In addition, the traumatized vessels in children are very small and can easily be confused with small veins in the antecubital space. Caution is necessary to avoid dividing important vessels.

After spreading through the fatty tissues, the proximal spike of bone is the first structure identified because it is often subcutaneous or covered only by a thin veil of tissue and portions of the brachialis muscle **(A)**. Before proceeding with further exposure of the bone, it is necessary to identify the neurovascular bundle. Carefully dissect across the anterior aspect of the metaphyseal fragment until the bundle is identified (*dotted line*) **(B)**. In most cases in which there is vascular compromise to the limb, the adventitia of the artery is caught on the proximal spike of bone, acutely kinking the vessel. If not found there, the bundle may lie adjacent to the bone or course beneath it interposed between the two fracture fragments. If the neurovascular structures are in the fracture site, more extensive exposure is necessary to free them. Identification of the neurovascular bundle is not the primary goal of the operation (unless the circulation is impaired) but rather is an essential step in the exposure. Removal of the obstructing muscle and (more importantly) the periosteum is the step that makes reduction possible.



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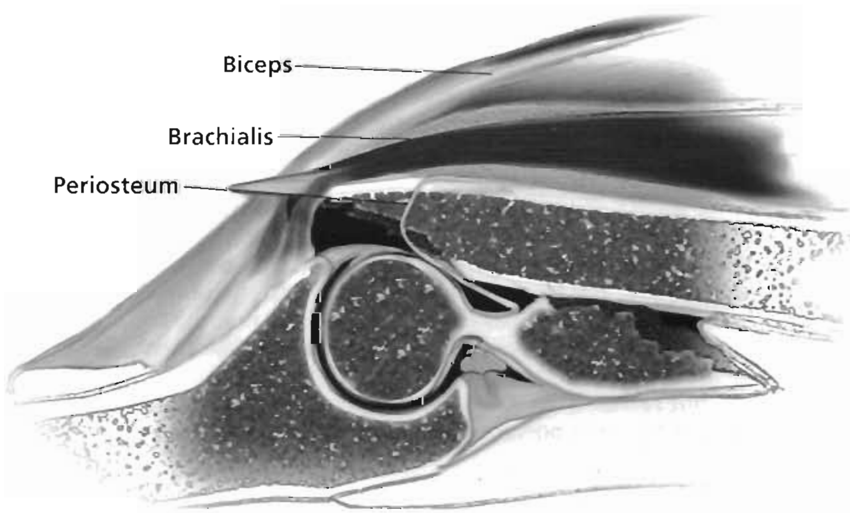

B

FIGURE 1-55. After the vessel is free and identified, it is gently retracted **(A)**. If the surgeon is certain of the identification of the neurovascular bundle and can retract it far enough for the next step, it is not necessary to dissect it any further. The next step is to identify the distal fragment. This may be the most difficult step for the surgeon performing this procedure for the first or second time. The distal fragment is posterior and lateral. It is easy to palpate but difficult to visualize and impossible to reduce because the periosteum that is torn off of the anterior metaphysis of the humerus is folded over the fractured surface of the distal fragment **(B)**. The proximal fragment has essentially "button-holed" through the periosteum, which has closed around the distal fragment and trapped the proximal fragment. This is now the main block to reduction.

With the neurovascular bundle safely retracted medially and the proximal fragment retracted laterally, the distal fragment can be exposed. Reach in with a forceps or hemostat and grasp a cut edge of the periosteum. Carefully cut the periosteum along the fractured edge of the distal fragment to open the button hole **(A)**. After this is freed sufficiently, the distal fragment can be brought anterior and reduced. After this reduction, the fragments are pinned in the usual manner.

POSTOPERATIVE CARE

The postoperative care is the same as the closed reduction with an additional week usually necessary for healing.

1.12 SUPRACONDYLAR HUMERAL OSTEOTOMY FOR CORRECTION OF CUBITUS VARUS

Of all the complications that are possible after supracondylar fracture of the humerus, none is more common than cubitus varus. The deformity results from incomplete reduction or loss of reduction. The mechanism of the deformity explains the components (1). The distal fragment is rotated internally, allowing it to tip into varus, and hyperextension often occurs. The usual 10 degrees of hyperextension with concomitant loss of flexion is seldom noticed by the patient and is not a significant problem. The internal rotation of the distal fragment may result in slight loss of external rotation, but the rotation arch of the shoulder is so great that this also goes unnoticed by the patient (2). The varus tilt of the distal fragment, however, reverses the usual carrying angle of the elbow from slight valgus to varus. This, combined with the prominence of the lateral condyle, which is also accentuated by the rotation of the distal fragment, produces a noticeable deformity but rarely any functional loss. Often, the cubitus varus deformity is not apparent for several months, leading some authorities to speculate that it is due to a growth disturbance. This is not the case, however. The deformity is not noticed until extension of the elbow joint is restored, and it becomes increasingly obvious as the last degrees of extension are gained.

Understanding the components of the deformity in relation to the problem the patient experiences is important to the surgical correction. It is usually not necessary to attempt to correct either the rotation or the posterior angulation, and to do so greatly increases the difficulty of the osteotomy and leads to a higher complication rate (3–5). The carrying angle of the patient's elbow is usually the problem that the patient or parents want corrected.

Two complications are reported with enough frequency after corrective osteotomy that they deserve attention. The first is the prominence of the lateral condyle after the simple closing of a lateral based wedge. As in correction of ankle valgus by a supramalleolar osteotomy (see Chapter 6, Procedure 6.6), simply closing the wedge without medially displacing the distal fragment often makes the prominence of the lateral condyle greater. This has been reported in some series as a causes of dissatisfaction (5,6). Complex osteotomies, as well as rotation and hyperextension of the distal fragment, have been described to correct this problem (7,8). Prominence of the lateral condyle can be minimized by making both cuts of the osteotomy of equal length, although this may not totally correct the problem in the severe deformity (3). A simple way to deal with this problem is to perform a simple closing lateral wedge osteotomy with two equal limbs, fix it with a single lateral Kirschner wire, and inspect the arm in full extension. If the prominence of the lateral condyle is objectionable, the wire is removed, the distal fragment is displaced medially, and the osteotomy is fixed with both medial and lateral pins. Although medial displacement of the distal fragment eliminates the stability of the periosteal hinge that is achieved with a simple closing wedge osteotomy, it is no more difficult to secure than a fresh supracondylar fracture (Figs. 1-56 to 1-60).

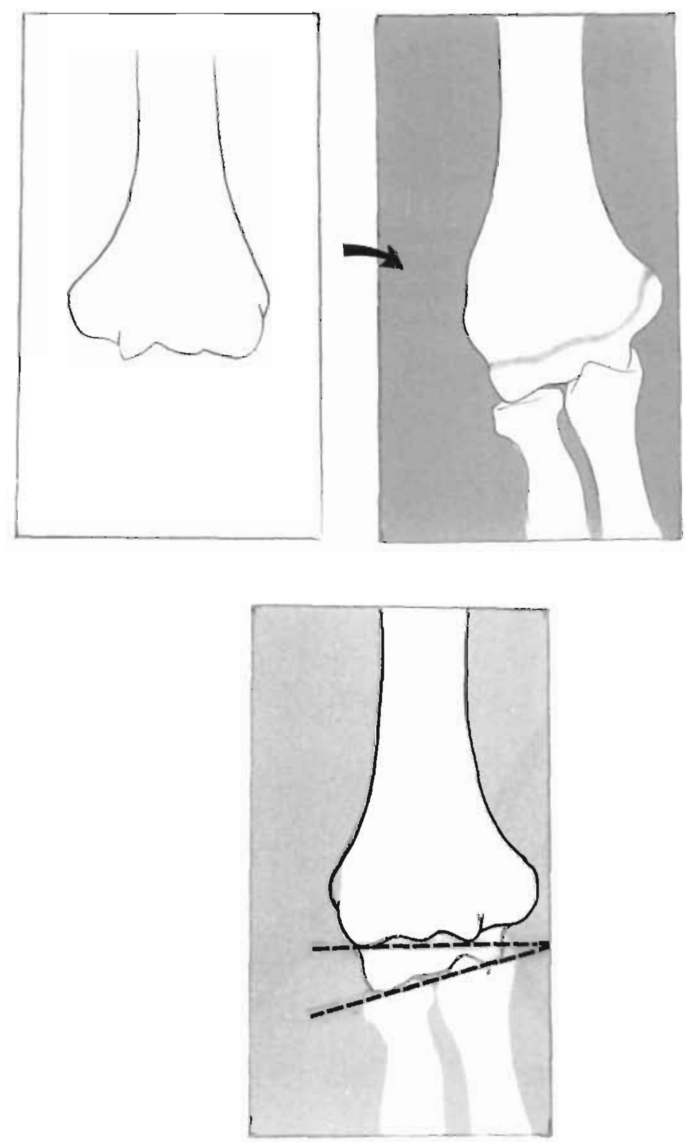

FIGURE 1-56. The size of the wedge of bone to be removed is determined by obtaining radiographs of both arms in full extension and full supination. A simple method to estimate the wedge is described by Oppenheim and colleagues (3). A tracing of the normal arm is reversed and superimposed on the abnormal arm. The approximate size of the wedge can be determined at this time. If the distal limb of the osteotomy is greater than the proximal limb, the prominence of the lateral condyle is accentuated. Plan the limbs to be of equal length.

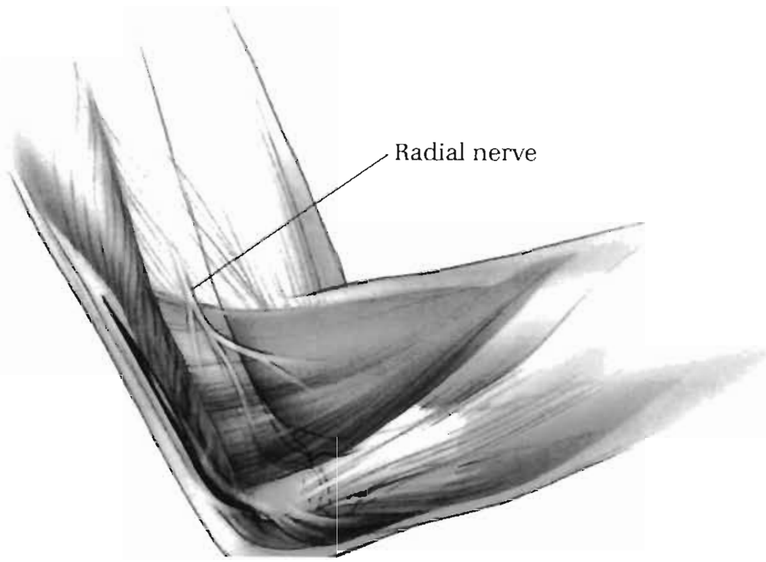

FIGURE 1-57. The osteotomy can be performed through a posterior triceps-splitting approach or a lateral incision. The latter is far easier for the surgeon and the patient. The patient is supine with the arm on a narrow translucent hand board. The incision is about 4 to 5 cm in length and is placed slightly posterior to the epicondylar ridge, to make the scar less noticeable.

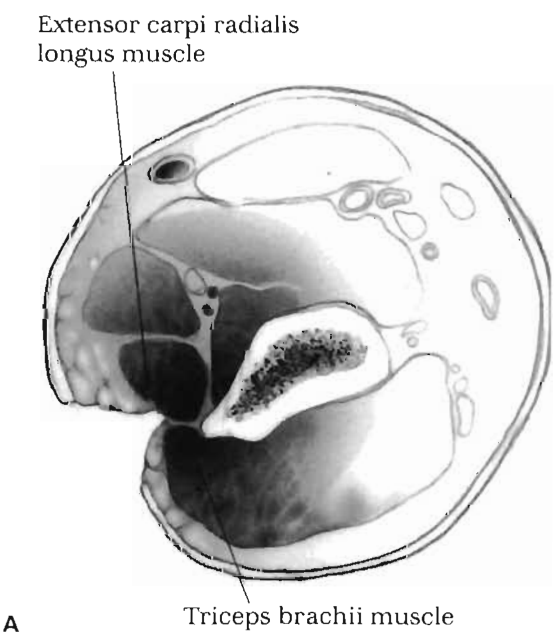

FIGURE 1-58. The incision **(A)** is carried down to the epicondylar ridge with the triceps muscle posteriorly and the extensor carpi radialis longus muscle anteriorly. The periosteum is split, and the distal humerus is exposed subperiosteally **(B)**, both anteriorly and posteriorly to the medial side. If desired, small Kirschner wires can be drilled into the bone along the proposed limbs of the osteotomy and the location and size of the wedge verified on the image intensifier.

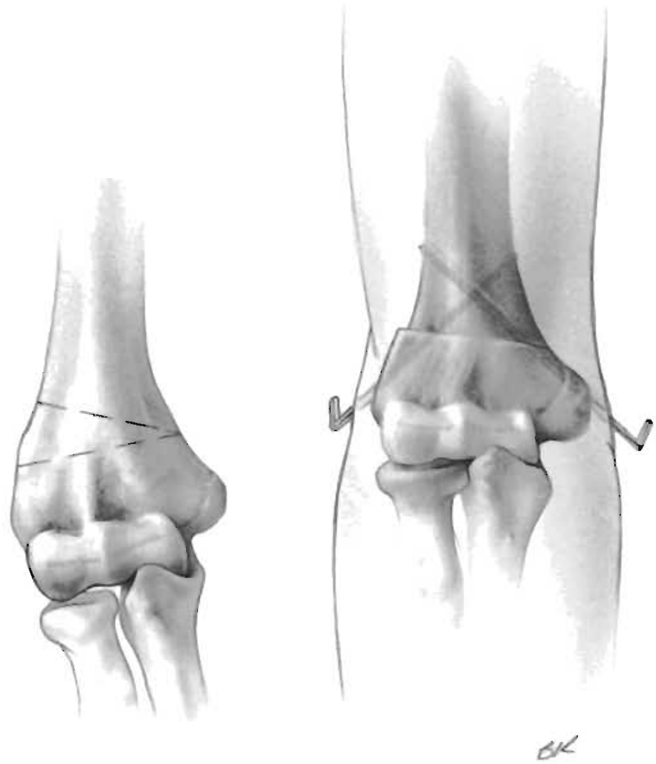

FIGURE 1-59. A small power saw is used to remove the wedge of bone. If no displacement of the distal fragment is planned, a small portion of the medial cortex is left intact and "green-sticked" to close the wedge. This greatly enhances the stability and allows fixation with only one lateral Kirschner wire. The surgeon, however, should be certain that the fracture of the medial cortex is complete and there is no tendency for the osteotomy to spring open.

With the osteotomy fixed, the arm is extended and the correction inspected. If there is a lateral prominence, the pin is removed, the distal fragment is displaced medially, and medial and lateral Kirschner wires are placed as in the percutaneous fixation of a supracondylar fracture. Stability at the osteotomy site can be tested with the arm extended and the osteotomy site exposed. In this way, there should be no surprises with loss of fixation. The image intensifier should be used to ensure that the wires have transfixed both fragments and that they engage the opposite cortex.

The wound is irrigated and closed. A small drain can be used if desired. The Kirschner wires are left protruding through the skin and are bent over. A long arm cast is applied with the elbow at 90 degrees of flexion and the forearm in pronation, as would be done for a medially displaced supracondylar fracture. Several cotton balls placed in the antecubital space next to the skin under the cast padding permit swelling to occur without restriction from the cast.

A, B

C

FIGURE 1-60. AW is a 7-year-old girl who presented with a moderate cubitus varus deformity of the arm 1 year after closed reduction of a supracondylar fracture of the humerus **(A)**. The osteotomy was planned to remove a wedge of bone slightly smaller than 1 cm. Because a large wedge was not required, it was easier to plan the cuts to be of nearly equal length. With the wedge closed and no medial displacement **(B)**, the arm showed no lateral prominence. Six months later **(C)**, healing is complete, and full motion is regained.

POSTOPERATIVE CARE

The treatment is the same as that after supracondylar fracture, except that healing may occur at a slightly slower rate. After about 4 weeks, there should be sufficient callus to allow the pins to be removed. The patient is left out of a cast or splint and wears a sling for the next 3 weeks while starting active range-of-motion exercises. When radiographic union is achieved, the use of the sling is discontinued, and the patient can resume full activities after full motion is restored.

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1.13 OPEN REDUCTION AND INTERNAL FIXATION OF DISPLACED LATERAL CONDYLE FRACTURE OF THE HUMERUS

Lateral condyle fractures are the second most common fracture around the elbow in children. These fractures, like supracondylar fractures, have earned a bad reputation because of frequent complications. When all lateral condyle fractures are considered, most are nondisplaced and can be treated with cast immobilization. When they are displaced, however, open reduction with internal fixation is the treatment of choice. The two keys to avoiding complications are accurate reduction and rigid internal fixation.

The role of percutaneous fixation with or without closed reduction is unclear (1,2). Whether all fractures treated with percutaneous fixation really needed it or would have done just as well without it is uncertain, and it has not yet been demonstrated adequately that closed reduction is sufficiently accurate in a large series of displaced fractures. Mintzer and colleagues (3) recommend arthrography to determine joint congruity followed by closed reduction and percutaneous fixation in all fractures displaced less than 2 mm; however, these are the same fractures (less than 2 mm of displacement) that many authorities believe can be treated safely with a cast alone (4).

The high incidence of displacement after delayed union or nonunion in this fracture may be due to several factors. Many of these fractures, particularly the Milch type II, are inherently unstable. The large flexor muscle mass is attached to the fragment. Therefore, the fragment is affected not only by flexion and extension and varus and valgus but also by pronation and supination—a fact that can be demonstrated at the operating table. Finally, the fracture is intraarticular, an area of very thin and less active periosteum. It has also been said but not proved that synovial fluid may interfere with the healing. All of these factors call for accurate reduction and rigid fixation.

An additional complication, more often seen in cases with delay in reduction, is avascular necrosis of the trochlea. Most of these cases occur in people undergoing late reduction. Avascular necrosis of the trochlea is unusual in untreated fractures, leading to speculation that the extensive dissection required for the late reduction disrupts the blood supply to the fragment (5,6). The message for the surgeon is to avoid dissection of the muscle from the fragment, especially posteriorly, where the blood supply enters the trochlear fragment (7) (Figs. 1-61 to 1-65).

FIGURE 1-61. The operation is performed with a tourniquet and with the patient supine. The arm should be positioned so that image intensifier views can be obtained to verify the location of the pins: the reduction is visualized directly. This is done by bringing the patient to the edge of the operating table so that the arm can be moved over the image intensifier or by using a translucent arm board. A small, straight incision directly over the lateral condyle is used. The large Kocher incision is not necessary. The landmarks of the lateral condyle can be difficult to identify in the younger child with a swollen elbow. Flexing the elbow to 90 degrees and attempting to locate the radial head can help, but in the displaced fracture, the landmarks are often absent.

FIGURE 1-62. The incision is made through the skin and the subcutaneous tissues. The thin fascia containing the fracture hematoma is encountered, and all of the tissue is blood stained. Opening this fascia exposes the fracture site. The fragment should be pulled distally while thorough irrigation of the joint and operative field is performed to remove the hematoma and tissue staining. Only after this is the anatomy obvious.

At this stage, the surgeon can see only the fracture site and has a limited view into the joint. The surgeon may be tempted to start the reduction; however, such a view is inadequate to achieve the first goal of the surgery: an accurate reduction. To gain a better view of the joint, the synovial attachments to the distal fragment must be severed. It should be possible to insert the blade of a retractor, such as an Army-Navy retractor, across the joint. The intact joint surface on the medial side of the joint should be seen to achieve an accurate reduction. Finally, in preparation for the reduction, the periosteum is trimmed from the distal fragment to allow visualization of the cortical surface so that accurate apposition to the proximal fragment can be achieved. Avoidance of dissection on the posterior aspect of the fragment is imperative to avoid interference with its blood supply.

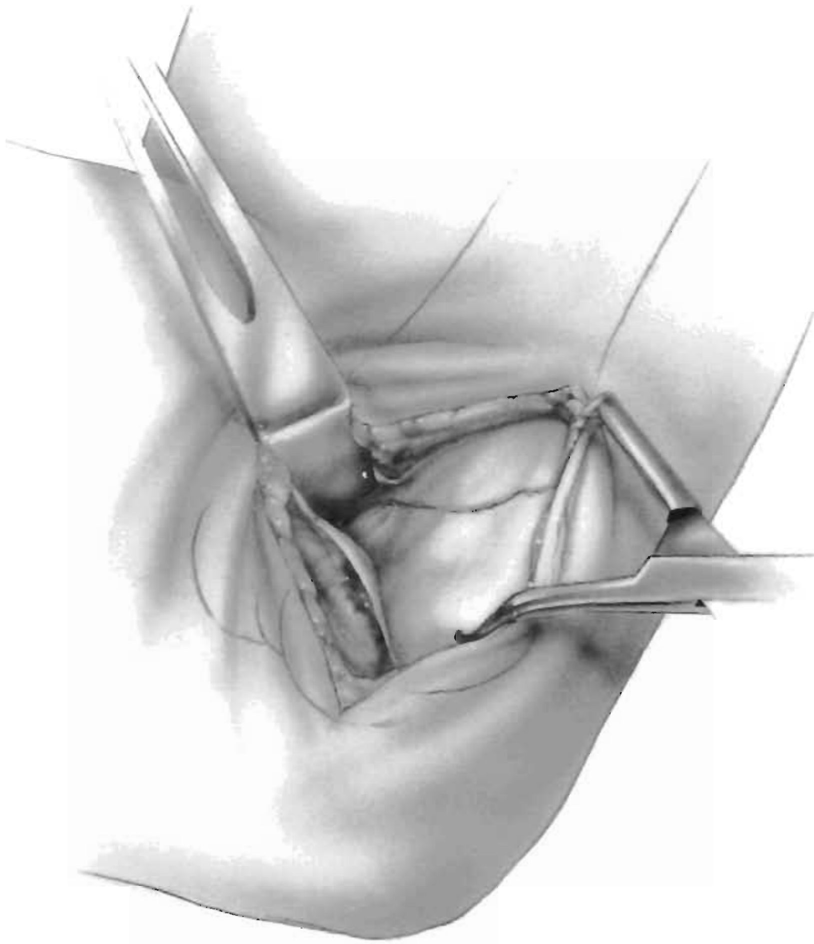
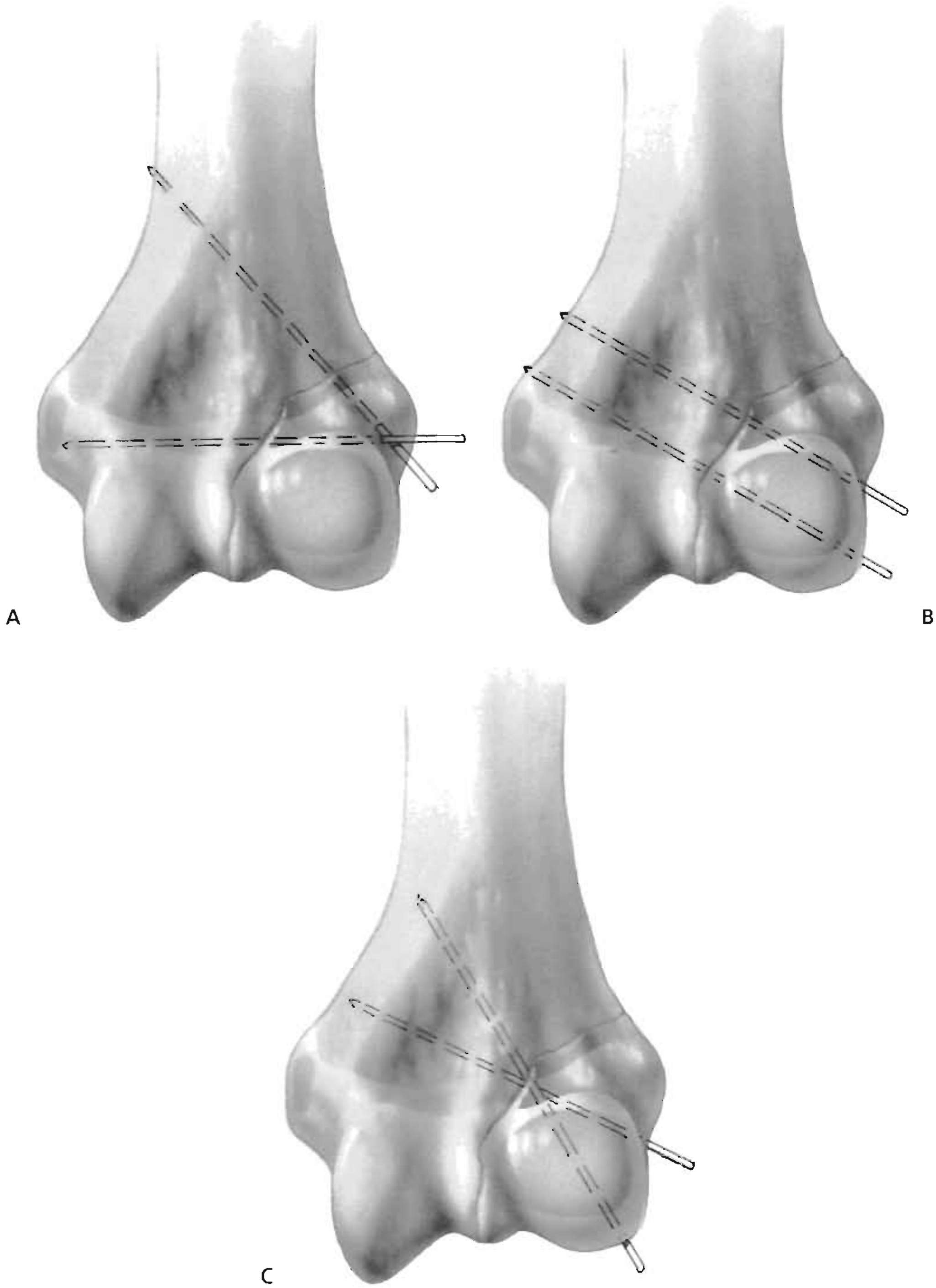


FIGURE 1-63. The fracture fragment is reduced. It is rotated as well as displaced. The fragment can be grasped with a sharp towel clip or a small fracture reduction forceps and manipulated into position. Flexion of the elbow helps. After the fragment is reduced, it can be held in place with a similar type of forceps or held with the same forceps, which is often easier. Before inserting the pins, a final check for accurate reduction is performed. The reduction is verified in three areas: the metaphysis laterally, the metaphysis anteriorly, and the intraarticular surface.

FIGURE 1-64. Perhaps in this fracture more than any other, the placement of the pins is crucial because this is a small fragment that has many strong forces trying to displace it. Although theoretically it may be desirable to keep the pins in the metaphysis, this is not necessary. In fact, the metaphyseal fragment is often small, and attempting to keep the pins only in the metaphysis of the fragment can result in inadequate fixation. The stability of the fixation is increased the further apart the pins are in the fragments.

In the ideal fixation **(A)**, the pins cross laterally to the fragment, with one going across to the medial condyle and the other more proximal to the medial cortex above the fossa. In small children with little ossified metaphysis or epiphysis **(B)**, parallel pins as far apart as possible are easier. Pins that cross within the distal fragment or at the fracture site **(C)** should be avoided because they provide the least rotational stability. If possible, the pins are inserted through intact skin. This is achieved by having the assistant approximate the wound edges with the fingers of the free hand while holding the fracture fragment with the other hand. The pin is inserted, and there will be no tenting of the skin when the wound is closed. Sometimes, the pin comes through the incision. This causes no problems, and the incision is closed around the pin. After verifying the pin placement and, if desired, the fracture reduction on the image intensifier, the pins are cut and bent over to facilitate easy removal.

The wound is closed, and dressings are applied. A long arm cast is applied with the elbow flexed to 90 degrees, the forearm in neutral, and fluffs in the antecubital space.


A
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C

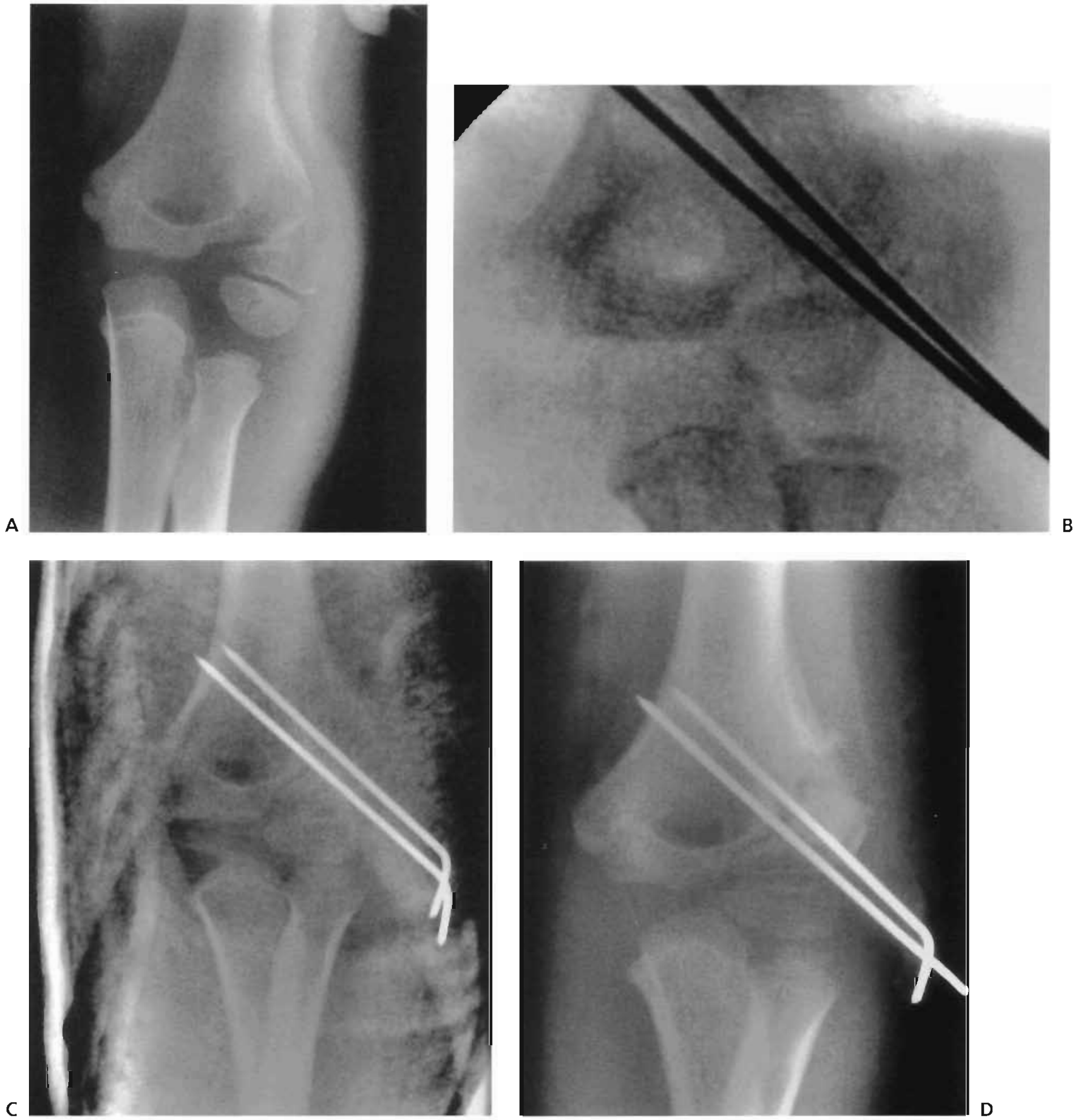

FIGURE 1-65. A: The anteroposterior radiograph of a displaced lateral condyle fracture. **B:** The intraoperative view on the image intensifier screen. The resolution of this picture is not as good as that on a radiograph, and minor degrees of residual displacement can be missed. It is important to see the fracture line anteriorly across the joint. **C:** The anteroposterior view in the cast; this too is an image that is difficult to interpret. **D, E:** The fracture 4 weeks after surgery. The minor amount of residual lateral displacement can be seen on the anteroposterior view, whereas the lateral view shows that the rotation is correct. The early callus is an indication that it is safe to remove the pins. This patient regained full motion in 10 weeks.

E

FIGURE 1-65. ***(Continued)***

POSTOPERATIVE CARE

The procedure may be performed on an outpatient basis. The patient returns in 4 weeks, and the cast is removed. Anteroposterior, lateral, and most important, internal rotation oblique radiographs of the distal humerus are obtained. Healing is assessed. If the fracture gap is narrowing and there is periosteal new bone bridging the two fragments, the pins are removed. The patient is then treated according to the surgeon's judgment, either with a splint and no movement or with a sling and flexion and extension range of motion. After 6 to 8 weeks, the fracture should be healed, which is confirmed by the radiograph.

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1.14 OPEN REDUCTION AND INTERNAL FIXATION OF FRACTURES OF THE MEDIAL EPICONDYLE

Fracture of the medial epicondyle is largely age dependent as a result of the ossification of the epicondyle. Ossification begins at about 4 to 6 years of age, and fusion occurs at about 15 years of age. Early in the process, the medial epicondyle is a part of the entire distal humeral epiphysis. As growth continues, between 9 and 14 years of age, this apophysis becomes separated from the main epiphysis, which is when most of these fractures occur.

The medial epicondyle is a traction apophysis, with attachments of the flexor carpi radialis, the flexor carpi ulnaris, the flexor digitorum, the palmaris longus, and the pronator teres originating at least in part from it. In addition, the ulnar collateral ligaments, as well as part of the capsule of the joint, take origin from this apophysis.

The main mechanism of injury is avulsion. A fracture can occur even as an isolated throwing injury in an adolescent. A significant number of these injuries, however, are also associated with a dislocated elbow, which often reduces spontaneously, trapping the fragment in the joint.

Minimally displaced fractures do not need reduction; immobilization for 3 to 4 weeks is usually sufficient. The indications for operative versus nonoperative treatment are controversial only in those patients in whom the fragment is displaced significantly. Significant displacement is accompanied by rotation of the fragment, a finding that may be difficult to elicit from the radiograph. A significant preponderance of articles that compare both types of treatment report better results with nonoperative treatment than with operative treatment (1–4). In our experience, however, it seems that in those fractures with significant disruption of the lateral stability and extensive soft tissue tearing, restoration of motion is quicker and more complete in those that are treated with open reduction and fixation.

There is less disagreement on three other indications for surgical treatment: incarceration of the fragment in the joint, instability of the joint, and ulnar nerve symptoms.

Closed reduction is understood to be futile when a physician understands the attachments to the fragment and the rotation they produce. In addition, if nonoperative treatment produces such good results, why bother with closed reduction? Closed reduction with percutaneous pinning seems equally senseless given the rotation of the fragment and the proximity of the ulnar nerve. Nonoperative treatment could be recommended on the basis that if symptoms persisted, the fragment could be excised, a procedure that is successful in relieving most of the persisting problems (Figs. 1-66 to 1-69).

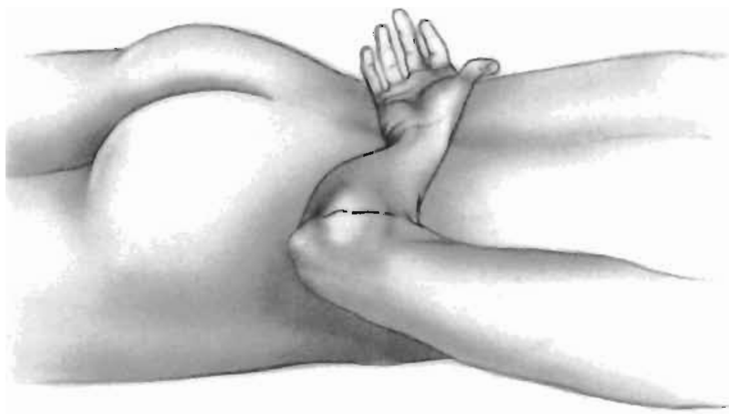


FIGURE 1-66. Traditionally, the patient is supine with the arm extended on a hand table. This, however, makes the operation difficult (5). The reasons for this are apparent in the anatomy: the medial epicondyle is posterior, and the forces displacing the fragment are greater with the arm in external rotation and the forearm supinated, which is the position required to see the fracture site. It is easier to place the patient supine with the arm across the lumbar spine. A small transverse incision in the elbow crease at the fracture site provides direct access to the fracture and leaves a small scar.

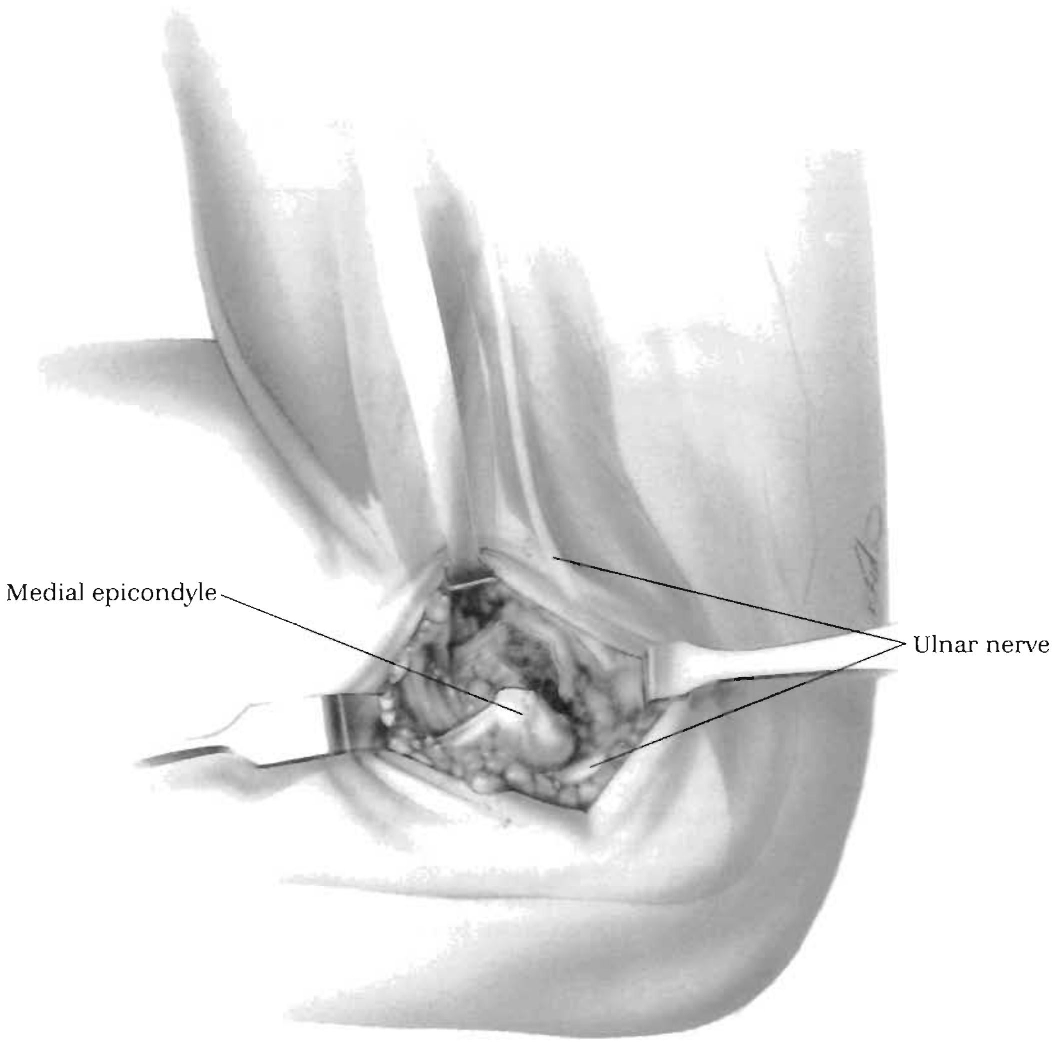


FIGURE 1-67. After the skin and the subcutaneous tissues are divided, the fracture is hidden only by hematoma. Much of the tissue staining can be removed by dabbing the wound with a wet sponge: this, as in all fracture work, makes the anatomy easier to see. The fragment can be grasped with a sharp towel clip or small fracture clamp to pull it distally, allowing irrigation of the joint and exposure of the surfaces of the fracture with a small periosteal elevator.

Although it is not necessary to identify the nerve if there are no symptoms preoperatively, it is essential to know its general location and that it is not in the fracture site. The nerve does not have to be disturbed to reduce and fix this fracture; however, it usually lies along the posterior margin of the fracture.

FIGURE 1-68. The fracture is reduced with the towel clip. There is little force required to bring it into position because all of the attached structures are relaxed in this position. The fragment is fixed with an appropriately sized cannulated screw or two Kirschner wires. ▶

The use of the screw is possible in the larger fragments seen in adolescents, and it does not have to be removed. The surgeon, however, must be certain that the screw has achieved adequate fixation by penetrating the opposite cortex. In addition, it is important to be certain that the screw does not add to the prominence of the epicondyle, or it will be a source of continuing irritation.

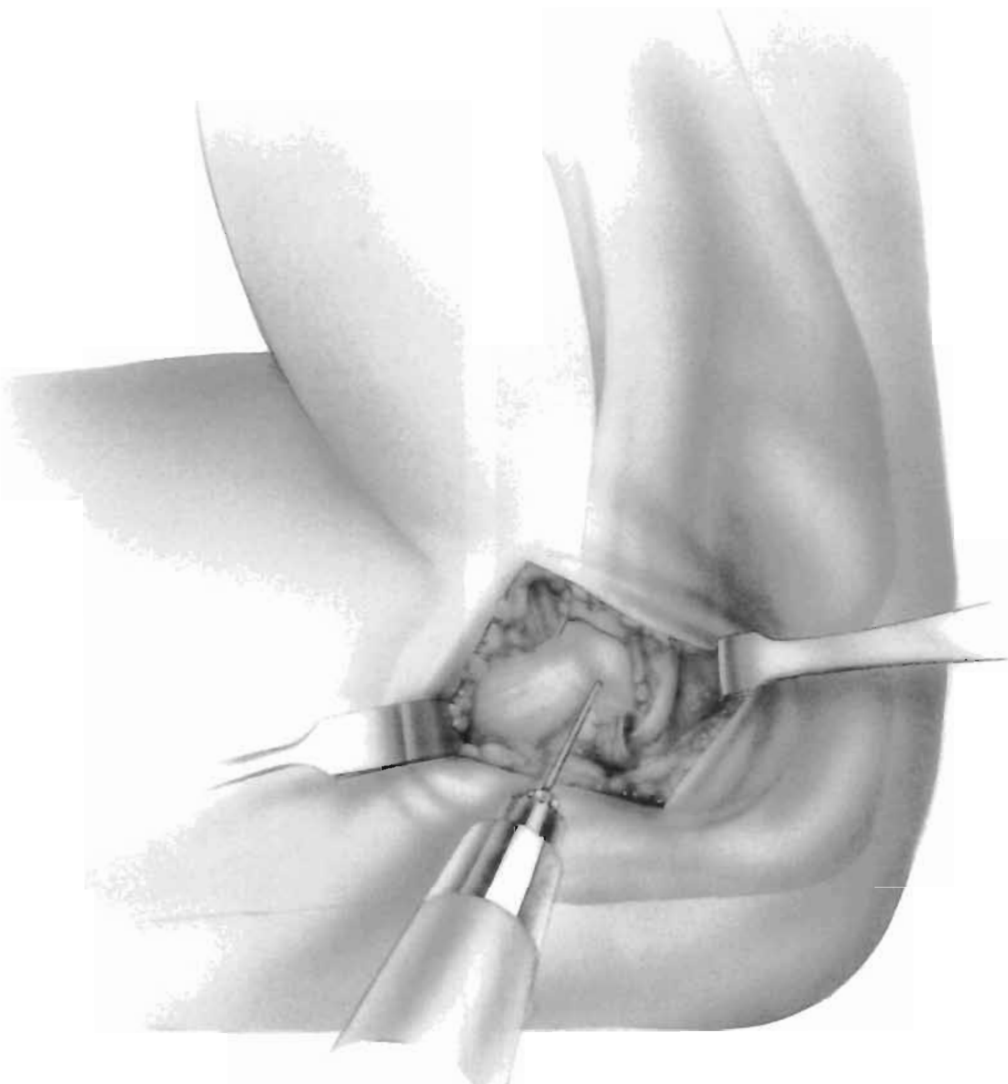


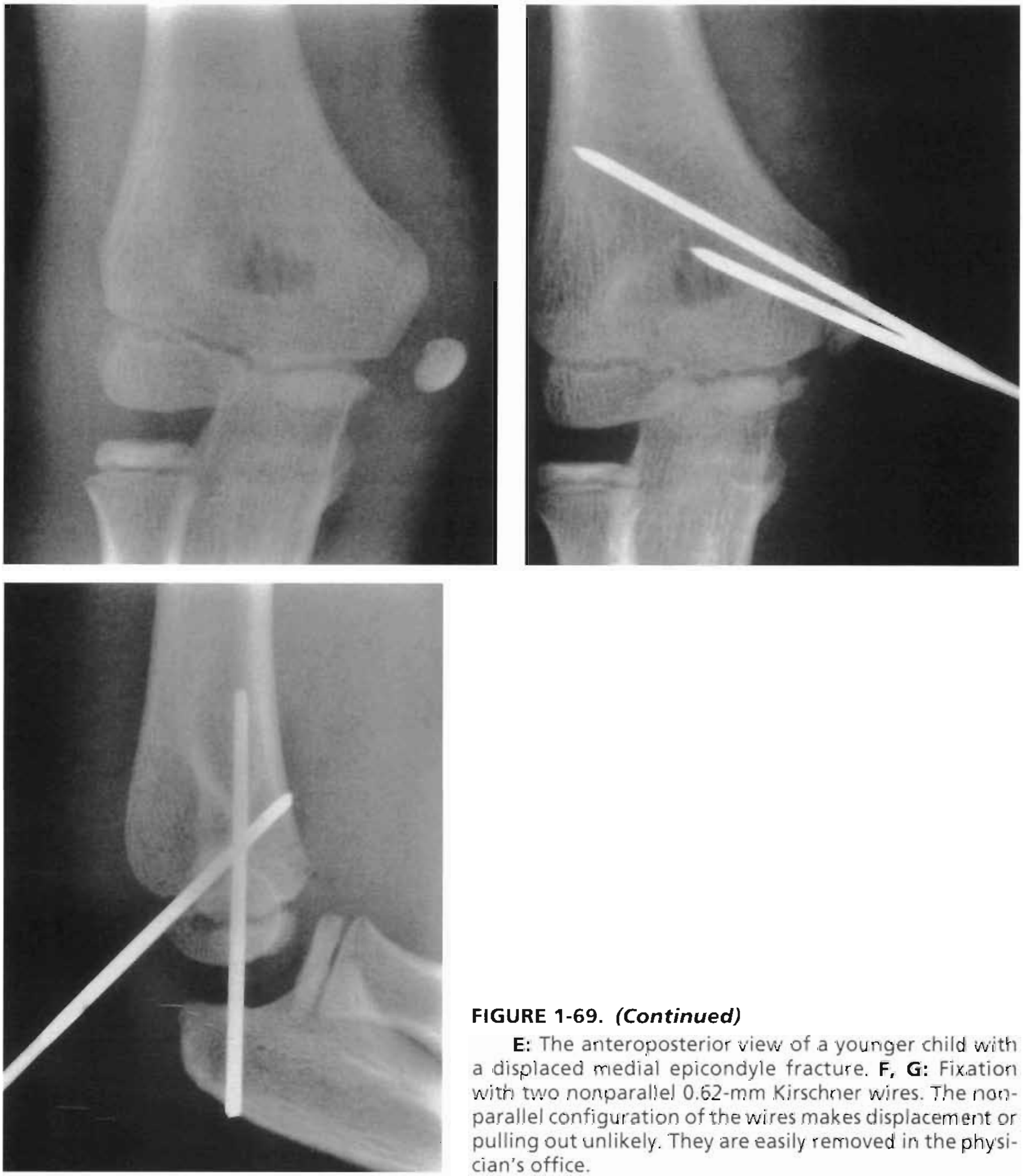
FIGURE 1-68. ***(Continued)***

Kirschner wires provide excellent fixation and can be removed easily in the physician's office after 3 to 4 weeks. With the transverse incision, it is relatively easy to place the wires through the skin separate from the incision. The assistant holds the fragment in place with the clamp in one hand while approximating the skin edges with the other, so that there will not be undue attention on the skin around the wires after the incision is closed. The wires may also be placed through the incision and cut long, and the skin is pulled over wires, allowing them to puncture through the skin at the appropriate spot.

The wires are advanced to engage the opposite cortex. When the proper placement is confirmed, the wires are bent over outside of the skin. This results in fewer wound problems than when the wires are buried. When left beneath the skin, they usually erode through with wound complications by the time the cast is removed. In addition, they are difficult to remove. The main benefit of use of the screw is that early motion can be started; however, beginning motion at 3 weeks, when the wires usually are removed, has not resulted in any loss of motion in this age group.

After wound closure, the arm is placed in a long arm cast. Cotton balls placed in the antecubital space to allow for any swelling and around the pins to prevent movement make the use of a circular cast safe. The circular cast can be lighter, stronger, and more comfortable than the usual splint.

FIGURE 1-69. A, B: A dislocated elbow with a medial epicondyle fracture. The medial epicondyle fragment is in the joint. **C, D:** The results after open reduction and fixation with a small screw. It is important that the screw engage the opposite cortex because it may pull out. This screw does not appear to accomplish that. If a small 3.2-mm screw is used, it must engage the anterior or posterior cortex because it will not be long enough to reach the opposite lateral cortex. This form of fixation works well in older children, in whom motion should be started early. The screw does not need to be removed.



E F G

FIGURE 1-69. ***(Continued)***

E: The anteroposterior view of a younger child with a displaced medial epicondyle fracture. **F, G:** Fixation with two nonparallel 0.62-mm Kirschner wires. The nonparallel configuration of the wires makes displacement or pulling out unlikely. They are easily removed in the physician's office.

POSTOPERATIVE CARE

The surgery can be performed as an outpatient electively within a few days of injury. If performed at night, the patient is discharged the next morning. After 3 weeks, the cast is removed, and anteroposterior and lateral radiographs are obtained. Periosteal new bone usually indicates that the pins can be pulled and motion started. The patient is instructed to continue to wear the sling for an additional 2 to 3 weeks until motion is improved and healing is more complete.

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1.15 CLOSED, PERCUTANEOUS, AND OPEN REDUCTION OF RADIAL HEAD AND NECK FRACTURES

Radial neck fractures in children present the orthopaedic surgeon with a dilemma regarding decision making (closed or open reduction) and the technical aspects of how to get the radial head reduced when there is no attachment to it that can be manipulated and how to keep the radial head reduced when it consists almost entirely of articular surface. There are many recommendations, but they are often confusing. Confusion increases because the actual degree of angulation of the radial head may not be accurately portrayed by a single radiograph unless it happens to be exactly perpendicular to the axis of angulation.

The consensus in the literature that the results of open reduction for this fracture are worse than the results of closed reduction may be because these were initially worse fractures. There is also the belief, however, that the surgery itself, along with the usual methods of internal fixation, contributes to the poor results. For this reason, the technique of percutaneous reduction, initially attributed to Bohler (1), described by others (2,3), and recently popularized (4,5), is a method of reduction that may be superior to open reduction for most fractures that fail closed reduction. Percutaneous reduction is a viable choice because many radial head fractures, once reduced, are stable without internal fixation, which is true with open reduction as well (6).

Regardless of the severity of the fracture and the amount of displacement, begin with an attempt at closed reduction because any improvement in the position of the fragment makes the percutaneous reduction easier (Figs. 1-70 to 1-77).

FIGURE 1-70. The closed reduction of this fracture is ideally accomplished with the aid of an image intensifier so that the radial head can be rotated to see the maximal deformity. Infiltration of the joint with local anesthetic to assess the amount of pronation and supination helps in deciding on the adequacy of reduction, and the surgeon may rely on this factor instead of the amount of angulation. If closed reduction is planned, this local infiltration can be supplemented with a Bier block. A Bier block, however, does not reliably provide pain relief around the elbow.

Two techniques for closed reduction are described. The first is that described by Kaufman and colleagues (7). This technique is easier, does not require a skilled assistant, and is frequently successful. In this technique, the elbow is flexed to 90 degrees to relax the capsule. The surgeon holds the arm at the wrist while the opposite hand is used to affect the reduction. This is done by rotating the forearm while the thumb of the other hand palpates the radial head. The arm is rotated until the maximum deformity is palpated, and then the thumb is used to manipulate the radial head back into position.

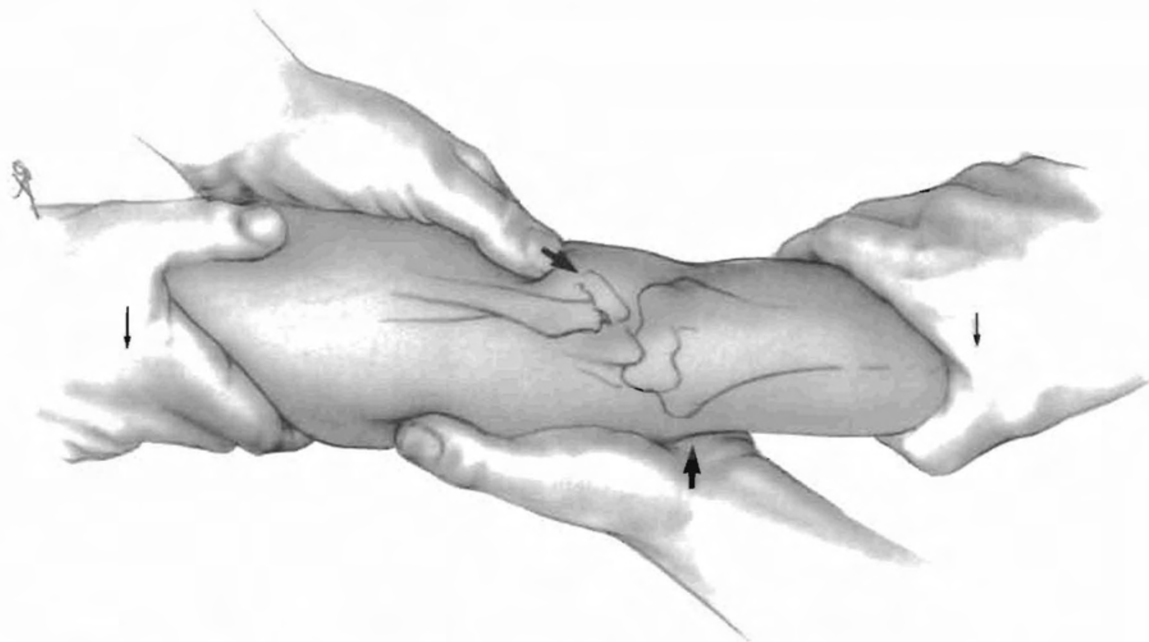
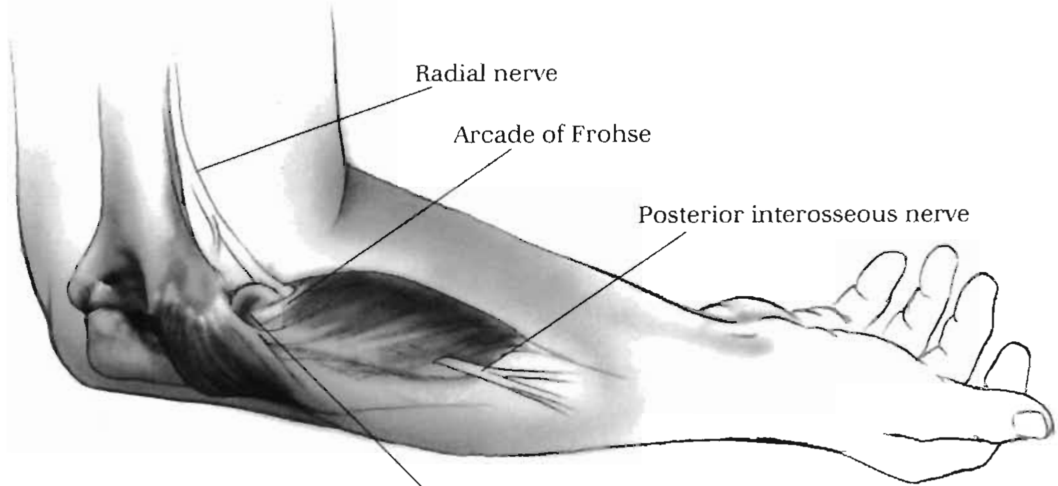
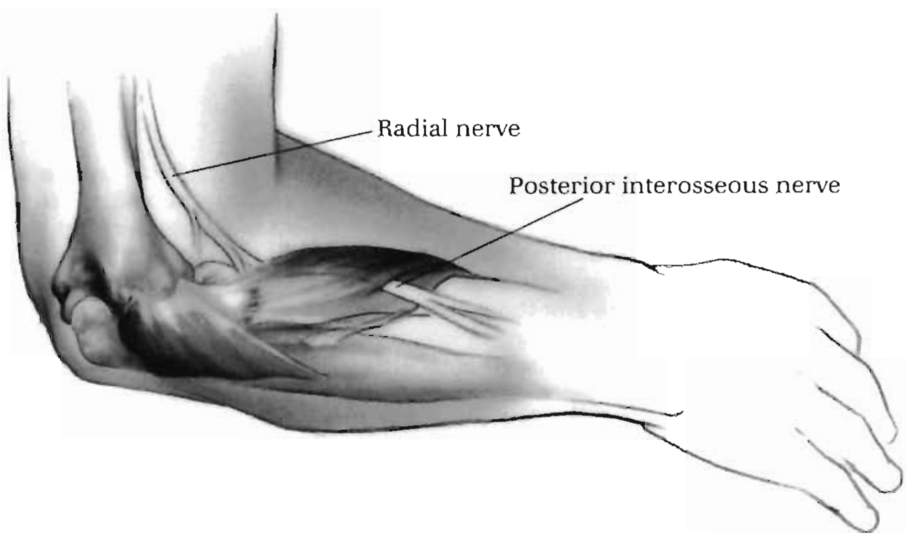


FIGURE 1-71. If this method fails, the method described by Patterson can be attempted (8). In this technique, the elbow is extended, the forearm is supinated, and a varus stress is applied to the elbow while the surgeon attempts to reduce the fragment. The radial head is much more difficult to palpate using this technique, the capsule probably is not as relaxed, and an understanding assistant is necessary.

If reduction is successful, the arm should be rotated through a range of pronation and supination while viewing under image intensification to be sure that the radial head is stable. This also determines the residual angulation, and the surgeon can observe the range of motion. Sixty degrees of pronation and supination is usually acceptable.



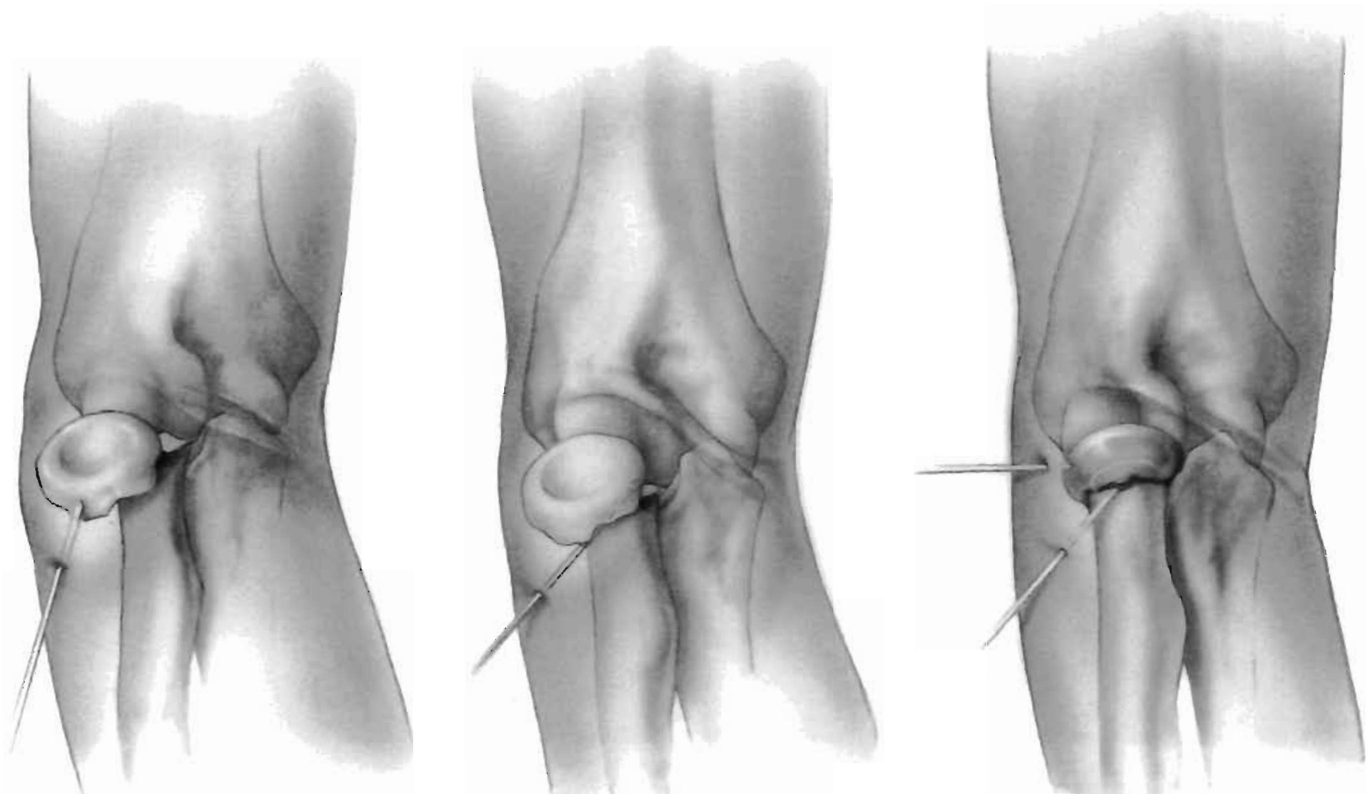
A



B

FIGURE 1-72. If closed reduction is not successful, the next step should be reduction by the percutaneous technique. This usually requires a general anesthetic. The patient is positioned at the edge of the operating table with the arm on a radiolucent arm board. A tourniquet is not necessary. The only equipment necessary is a small blade, to make an entry wound, and two Steinmann pins of sufficient size, to resist bending.

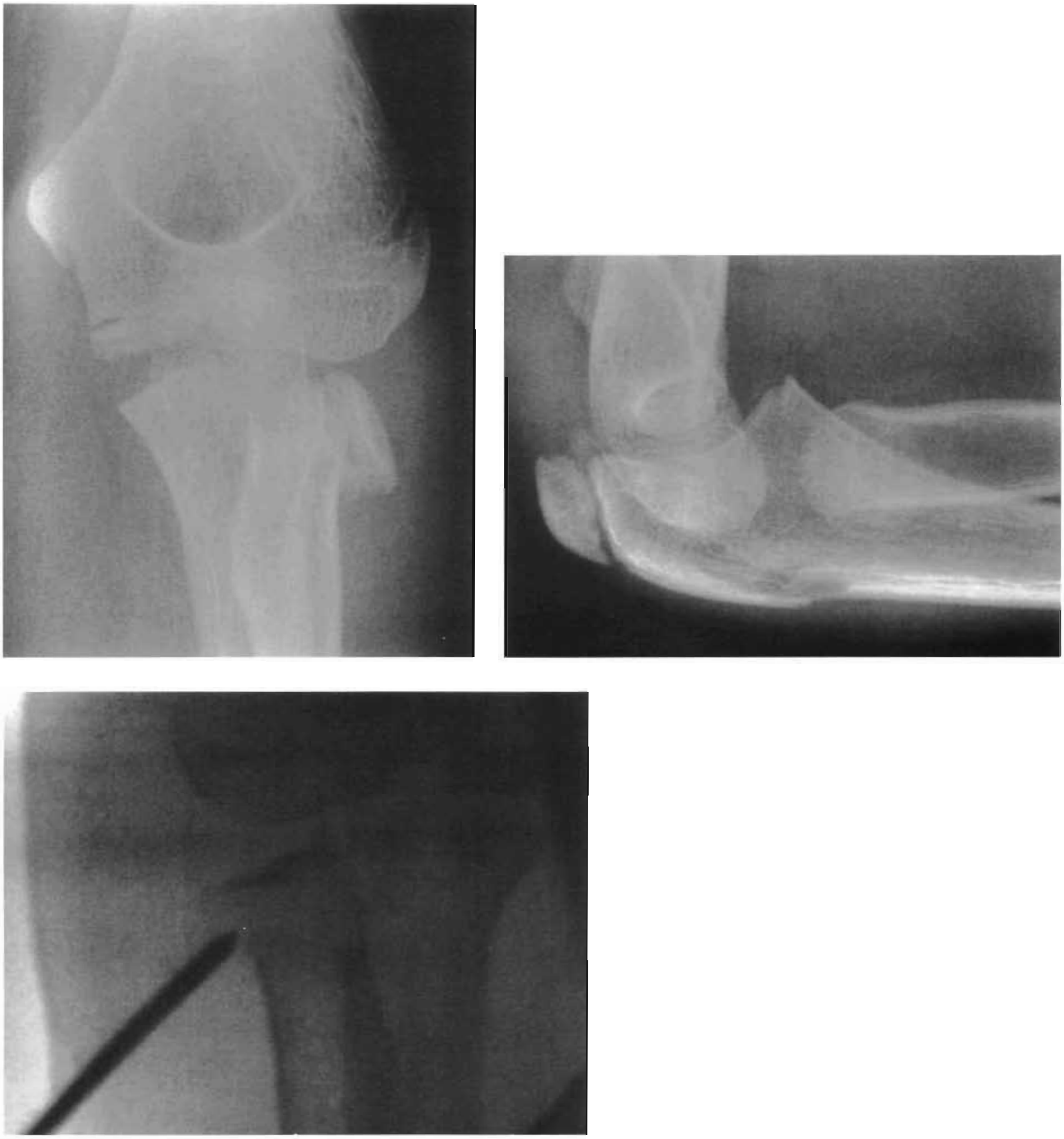
The main anatomic consideration is the posterior interosseous nerve. This nerve, a branch of the radial nerve, enters the arcade of Frohse just distal to the fracture site. When the forearm is supinated **(A)**, the nerve lies posteriorly, and when the forearm is pronated **(B)**, the nerve lies anteriorly. The arm should be pronated and the entry site kept as posterior on the radius (close to the ulna) as possible. The entry site is distal to the fracture and can be determined by using the image intensifier to line up the Steinmann pin in the desired position and with the desired angle to the radial head fragment.



A B C

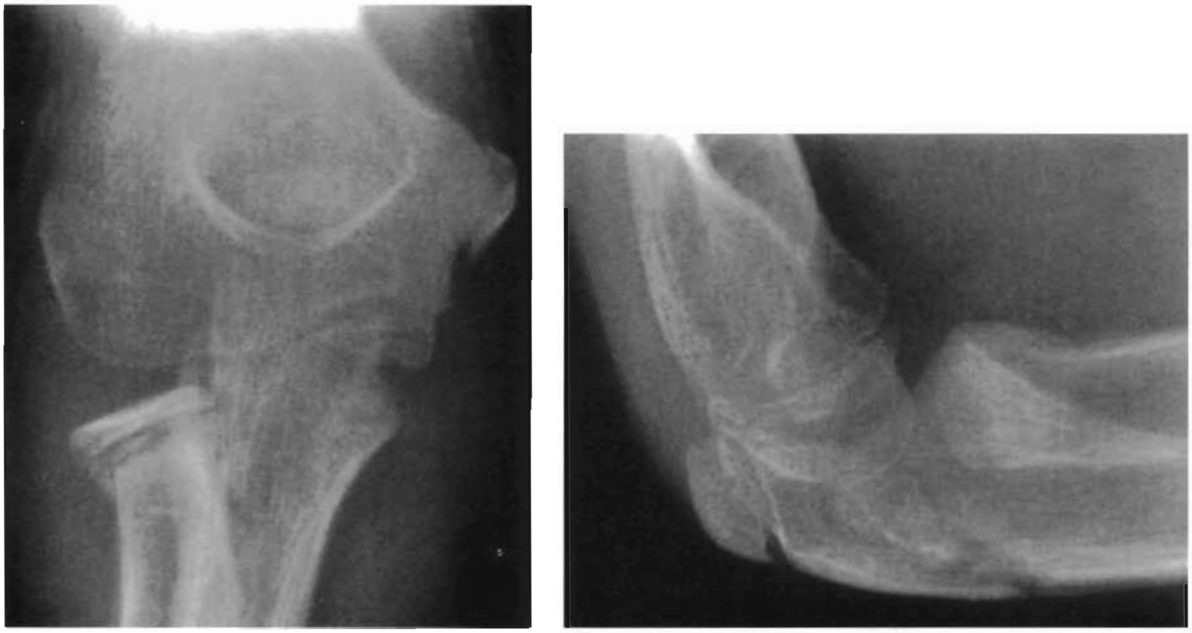
FIGURE 1-73. The technique can be used with leverage on the fragment or direct pushing on the fragment. Often, both of these are necessary. With the image intensifier, the Steinmann pin is inserted. The forearm is rotated until the image is at a right angle to the plane of displacement (i.e., the maximal angulation is seen). The fragment **(A)** can be pushed proximally. The pin **(B)** is inserted into the fracture site, and the fragment is levered upward to bring the fracture surfaces closer to a more parallel plane. When this is achieved **(C)**, the fragment is pushed back into place by the surgeon's opposite thumb, a second Steinmann pin, or the same pin.

The forearm is rotated while watching the radial head with the image intensifier. This checks the stability of the reduction and the maximal residual angulation, and the range of motion can be observed. If the reduction and stability are satisfactory, the arm is immobilized for 3 weeks at 90 degrees of flexion and at a position of pronation and supination that the surgeon believes is the most stable.



A B C

FIGURE 1-74. The anteroposterior **(A)** and lateral **(B)** views of a 12-year-old girl with a severely displaced radial head fracture. Note the associated olecranon fracture that frequently accompanies radial head and neck fractures. This required no treatment apart from immobilization. Closed reduction under general anesthesia was not successful because of the severe displacement. The Kirschner wire **(C)** pushes the radial head back into position.



D E

FIGURE 1-74. ***(Continued)*** Four weeks later **(D, E),** the cast was removed. The patient regained full motion.

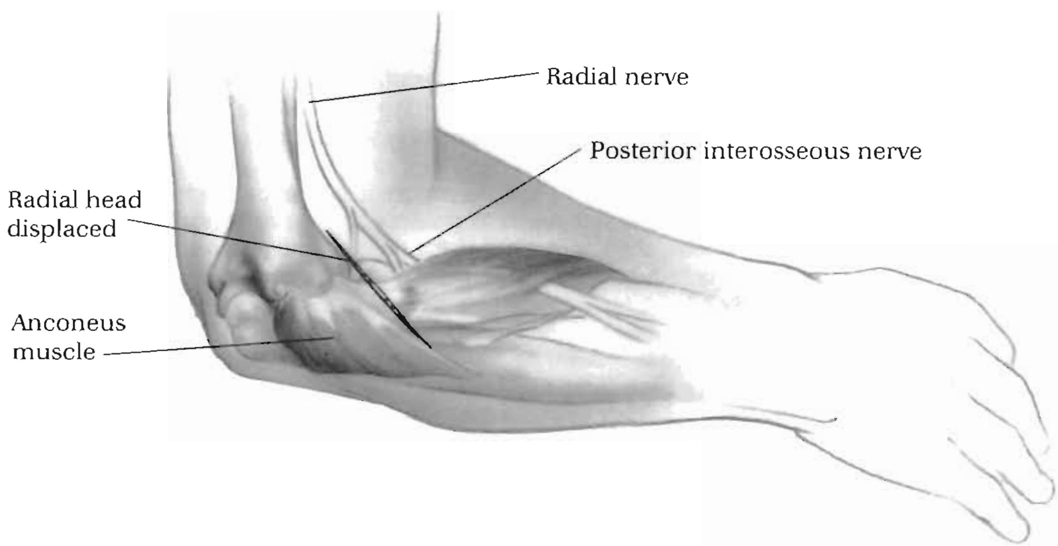


FIGURE 1-75. If percutaneous reduction fails, open reduction is necessary if the displacement is not acceptable. The classic posterolateral approach to the radial head is ideal for open reduction. Although limited in its exposure, it provides all that is necessary through a small anatomic approach. The patient is positioned either supine or prone.

The arm is pronated to place the posterior interosseous nerve out of the way of the surgical dissection. With the elbow flexed 90 degrees, a straight incision is made, beginning on the lateral epicondyle of the humerus. The incision angles distally toward the ulna, crossing the head of the radius.

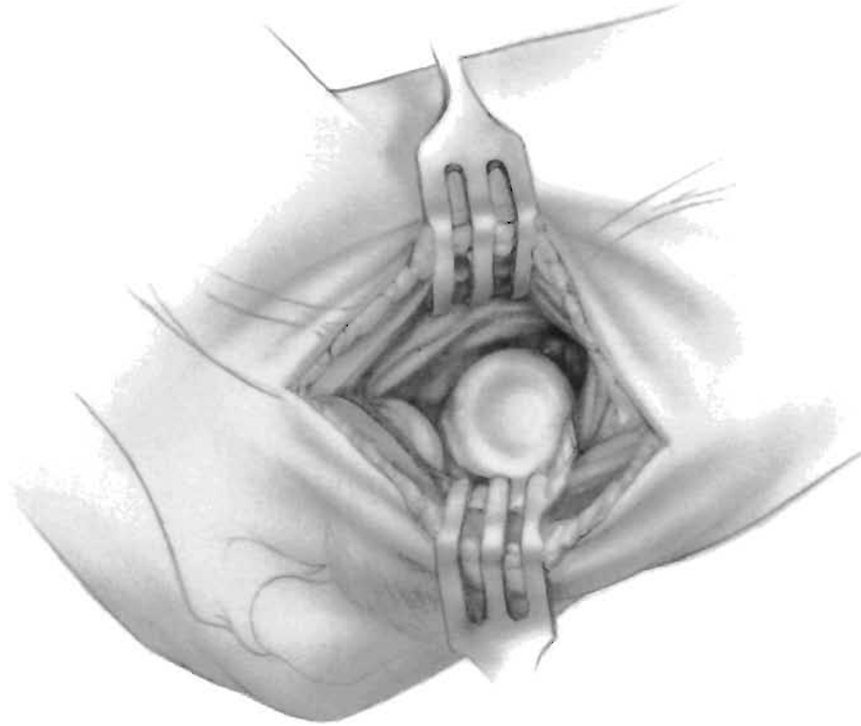


FIGURE 1-76. The fascia is incised in line with the incision. The interval sought is that between the anconeus muscle posteriorly and the extensor carpi ulnaris muscle anteriorly. The origin of these muscles blends on the humeral epicondyle; therefore, it is easier to find the interval distal. When this interval is identified, the muscles are separated easily. The interval can be widened by sharply dissecting some of the fibers of the extensor carpi ulnaris from the epicondyle. There is no way to extend this interval distally in a safe manner.

After the radial head is exposed, an effort to reduce it should be made with as little disturbance to the soft tissue attachments as possible. If the radial head is outside of an intact orbicular ligament, the ligament must be divided and repaired.

After the radial head is reduced, the forearm should be pronated and supinated to determine the stability of the reduction. If stable, no fixation is used. If unstable, however, fixation of some type is necessary. Placement of a pin through the capitellum, across the radial head, and into the radial neck should be avoided because the complications from this fixation are high (6,9). Obliquely placed pins are the most common method. The wires are best cut flush with the bone to avoid the need for subsequent surgical removal. If there is a metaphyseal fragment, fixation with small screws is a good choice. If they are small enough (e.g., 1.5 mm), they can be left in place.

FIGURE 1-77. A, B: A dorsally displaced fracture of the radial neck that requires open reduction and internal fixation. The problem with this fracture is the fixation to be used. **C, D:** Results using small Kirschner wires. It is difficult to cut these wires close enough to the bone to avoid irritation to the surrounding tissues. Although this patient did well, he required later removal of the wires. The use of small 1.5- and 1-mm screws, which should not require later removal, is a better choice.

POSTOPERATIVE CARE

After reduction, the wound is closed, and a cast is applied as with a closed fracture. Depending on the stability and the amount of remaining soft tissue attachments, the cast may be left in place for 3 to 6 weeks, although the sooner motion is started the better. Because avascular necrosis and delayed healing may occur, the surgeon may decide on longer immobilization if no soft tissue attachments remain or resorption of the fracture site is seen.

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1.16 INTRAMEDULLARY FIXATION OF FOREARM FRACTURES

Most completely displaced both-bone forearm fractures in children can be treated with closed reduction and casting. In addition, anatomic reduction is not necessary for a good result. Nevertheless, the orthopaedic surgeon is sometimes faced with the need for internal fixation of such fractures. This occurs most often in the adolescent child who is approaching skeletal maturity and in cases in which severe swelling makes successful casting of an unstable fracture unlikely or closed reduction and casting fail. In these situations, the choice of plate or intramedullary fixation can be difficult (1). Many reports on the use of intramedullary fixation attest to its growing popularity (2–5).

When open reduction is indicated, the usual treatment is to plate the bones. This requires a large operative approach and is associated with significant complications at plate removal, especially refracture. The differences between adults and children are shown when considering what is needed in the treatment of these fractures. In adults, there are two problems with forearm fractures treated nonoperatively: inability to maintain alignment and delayed healing. In children and adolescents, however, healing is seldom a problem, occurring promptly if alignment can be maintained. The problem in children and adolescents is maintaining alignment; for this reason, intramedullary fixation is a good choice.

Intramedullary nailing of forearm fractures is not a new technique. Reports of the use of Kirschner wires for this purpose date back to the 1920s (6,7). In the 1950s, special nails were developed for this purpose (8). Although these methods proved superior to closed reduction in adults, they were replaced by compression plating. Because of the more limited requirements of intramedullary fixation in children's fractures, these methods are coming back into use (9–11). The anatomic alignment is less precise after treatment with intramedullary rods than with plates; however, the amount of malalignment is well within that accepted for children's fractures (12).

All sizes are encountered while treating children of all ages. There is not an ideal device with the desired strength to immobilize and the flexibility to allow easy passage for the smallest bones. Although there are a variety of flexible nails available, the surgeon may have to work with Kirschner wires or Steinmann pins of appropriate size and flexibility for the child's bones. In the radius, small flexible rods, such as the Ender rods, may work for older children, whereas Kirschner wires are often best for smaller children. Rush rods in the ulna impart rigidity and strength and usually are easy to insert because of the straight path of the canal.

Because the forearm bones are smaller and surrounded by far less muscle than bones that are usually treated by intramedullary fixation, the bones tend to take the shape of the rod that is inserted. Therefore, it is important to contour the desired shape into the less flexible rods. Intramedullary fixation can be used as the sole means of immobilization of the fracture (11,12) or to maintain alignment as an adjunct to cast treatment (10). It is not suitable for fractures of the radius distal to the narrow portion of the diaphyseal shaft because the large medullary canal allows too much displacement of the fragments.

Theoretically, the first bone to be reduced should be the one that is easiest to reduce and fix because it imparts greater stability and restores length, both of which facilitate reduction of the second bone. In practice, the ulna is almost always the easiest to reduce because it is subcutaneous and easily palpated. In addition, this bone almost always accepts a Rush rod, whereas the radius may require something thinner and more flexible. Frequently, the radius is so well aligned or can be manipulated into a reduced position after fixation of the ulna that it does not need to be fixed.

Finally, not all fractures that require open reduction are best treated with intramedullary fixation. Fractures treated late for loss of position may not permit the easy passage of a rod. More mature adolescents pose a difficult problem in balancing the problems of plating with the delayed healing that may occur with intramedullary rods. In these circumstances, open reduction with internal fixation is often the best treatment (Figs. 1-78 to 1-83).

FIGURE 1-78. It is easiest to position the patient supine, with a small translucent board extending from the operating table. This facilitates the use of the image intensifier and allows the surgeon to stand while flexing the patient's arm across the chest for access to the proximal part of the ulna. A tourniquet should be placed in case the fracture site must be opened.

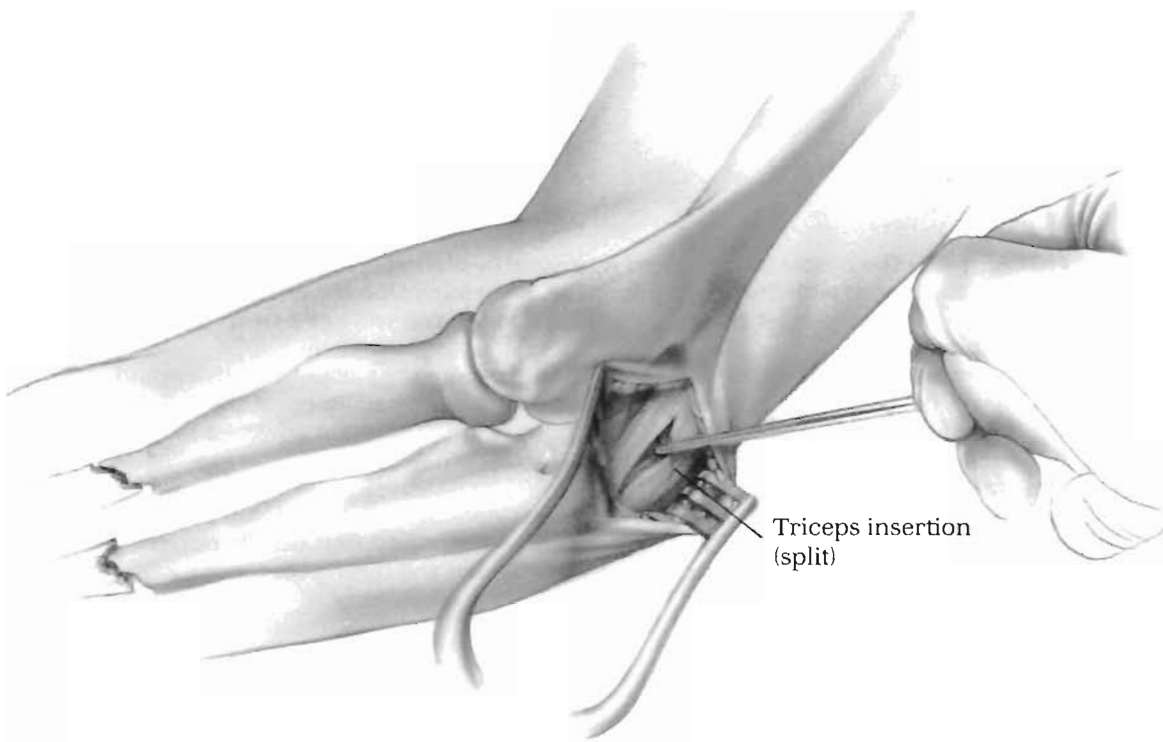

FIGURE 1-79. The ulna is exposed at its proximal tip by a small incision that is carried sharply down to bone through the triceps insertion. (The incision is illustrated larger than necessary for clarity.) A drill and then an awl are used to make a hole opening into the medullary canal of the ulna.

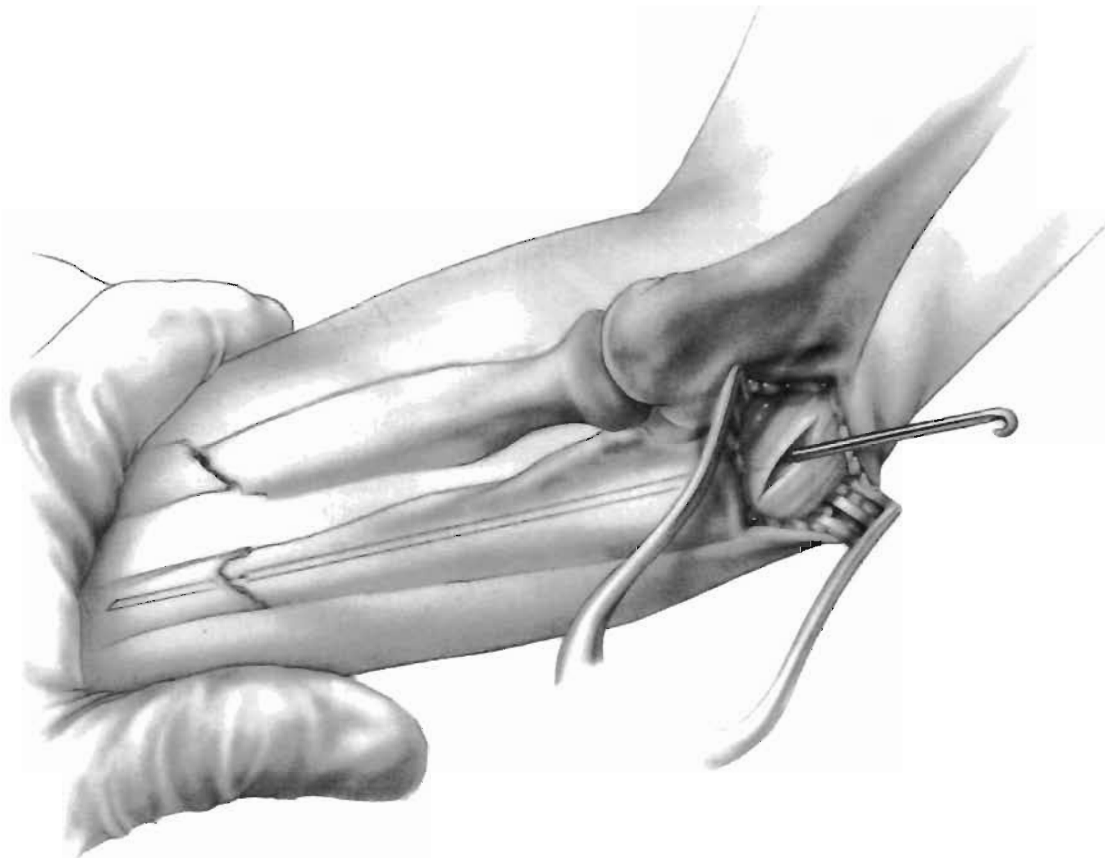

FIGURE 1-80. The proper length of rod is selected by placing it alongside the arm and checking the length with the image intensifier. Remember that the distal canal of the ulna is narrow, and in most children, the 1/8-inch Rush rod will not pass to the distal end of the ulna.

The rod of correct length is inserted up to the fracture site and just slightly beyond. This makes it easier to hook the distal fragment of the protruding tip of the rod during the reduction maneuver. The ulna is reduced, and the assistant advances the rod. If the ulna can not be reduced closed, a small incision is made to facilitate reduction and passage of the rod.

The rod is usually prominent beneath the subcutaneous tissue and tends to be sensitive to repeated contusion. This problem can be minimized (but usually not eliminated) by impacting the rod beneath the triceps tendon and closing the tendon with a suture.

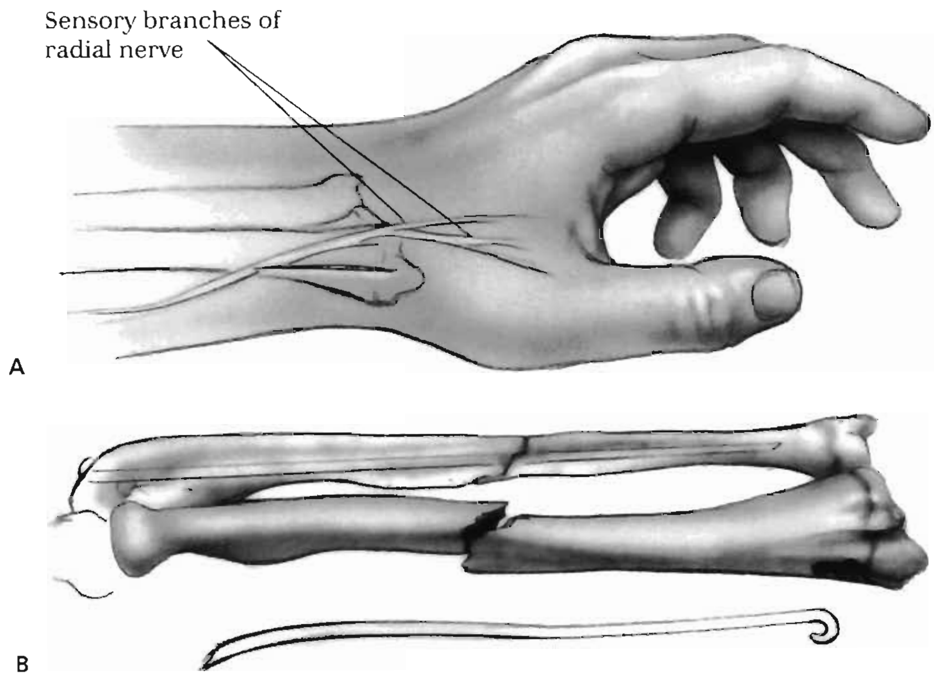

FIGURE 1-81. The radius can be approached in one of two ways. The lateral approach is most common, with the entry point proximal to the physis. The hole can be enlarged proximally, creating an oval opening to facilitate insertion. Care must be taken to avoid damage to one of the radial sensory branches **(A)**, although this does not appear to be the problem in children that it is in adults. The disadvantage of this approach is the large amount of curve that the rod must accommodate and what to do with the end of the wire. It is difficult to place under the skin and risks infection if left out of the skin. Usually, the Kirschner wire has to be smaller and more flexible if inserted this way. A small bend **(B)** within 0.5 cm of the tip of the rod helps it deflect off the medial cortex as it is being inserted, whereas a lateral bend is necessary to accommodate the lateral bow in the radius.

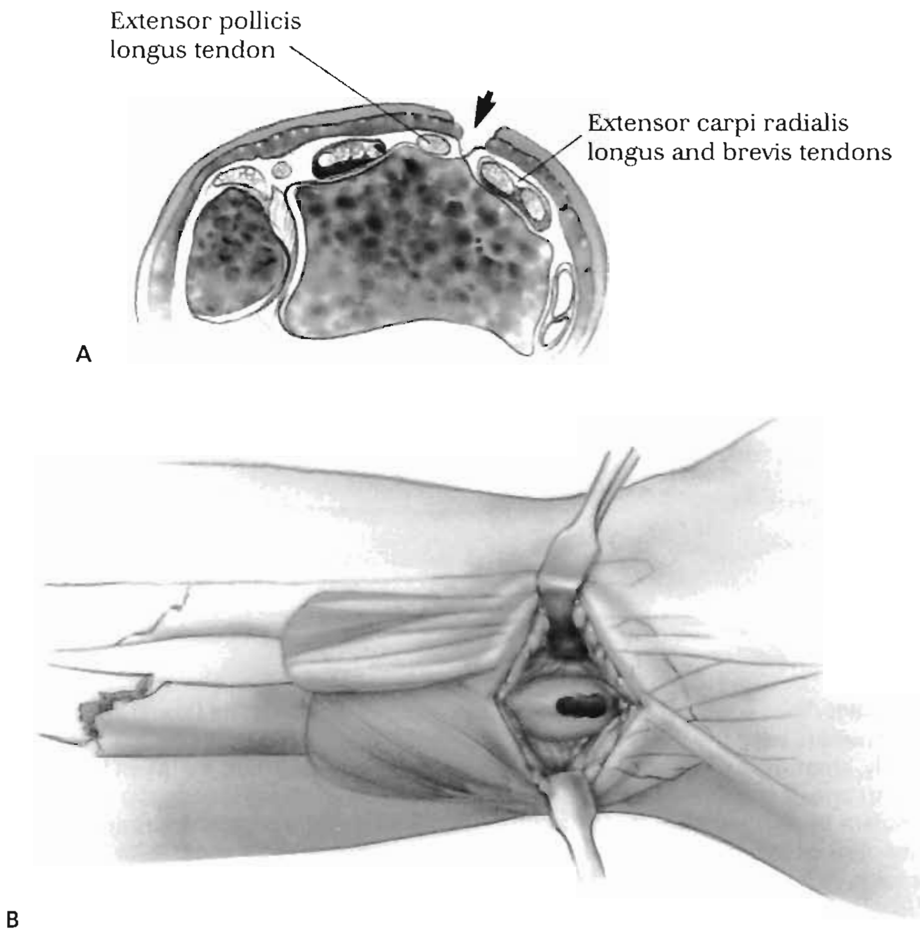

FIGURE 1-82. The dorsal approach is the other approach. The radius can be reached, as Street (13) recommended, by splitting the extensor carpi radialis brevis and longus tendons or by going between these tendons and the extensor pollicis longus tendon lateral to reach the Lister tubercle **(A)**. Again, it is important to stay proximal to the physis, which avoids interference with the extensor pollicis longus tendon as it curves around the Lister tubercle. After a drill hole is made into the medullary cavity **(B)**, it is enlarged proximally. This approach offers more direct access to the medullary canal. A small bend should be placed in the tip of the rod, as described previously. If the rod has any rigidity, it should be bent to accommodate the lateral bow of the radius.

A, B C, D

FIGURE 1-83. The anteroposterior **(A)** and lateral **(B)** radiographs of a 10-year-old boy who sustained a grade 1 open fracture of the radius and ulna. At the time of surgery, it was observed that the proximal fragment of the radius had punctured the skin on the volar aspect of the forearm. After exploration, irrigation, and minimal débridement, it was not possible to secure a stable reduction. As described previously, the ulna and then the radius were treated with intramedullary rodding. The radiographs 4 months after surgery **(C, D)** show the healing and the position of the rods. Note that the 1/8-inch Rush rod is usually either too large or too stiff to advance into the distal ulna. A more flexible Steinmann pin was used in the radius. This makes it easier to pass, is less likely to alter the radial bow, and provides adequate alignment.

POSTOPERATIVE CARE

Depending on the rigidity of the fixation and the surgeon, the patient can be left without a cast or treated with a cast. Some authors report prompt healing when each bone is instrumented with a rod and no external immobilization is used (10,11). All of the patients we treat are immobilized. Immobilization is discontinued when there is radiographic evidence of sufficient healing. In adolescents, this may take up to 12 weeks. The pins can be removed when healing is complete, and this usually can be accomplished with local anesthetic and sedation.

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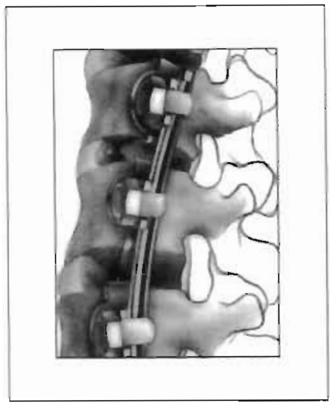

2

THE SPINE

TECHNIQUES OF POSTERIOR SPINAL FIXATION

Posterior spinal fusion has evolved significantly since the 1950s. This evolution has been extremely rapid since the 1990s and has changed significantly since the last edition of this atlas. This chapter presents various techniques of posterior spinal fusion, beginning with the Harrington instrumentation and ending with the hybrid technique, used in many centers today, which combines dual rods, hooks, wires, and screws in any combination. Although many of the procedures described will seem out of date to some, they are still widely used in many parts of the world for economic reasons. In addition, the teaching of the various techniques, such as hook placement and sublaminar wiring, may best be understood today in their historical context.

John Hall has written an excellent history of spinal instrumentation that emphasizes the pivotal role played by Paul Harrington (1). Instrumentation of idiopathic scoliosis was pioneered in the United States by Paul Harrington in the early 1950s. His instrumentation consisted of a single straight rod adapted for a hook at each end. The hooks were placed in a sublaminar position and distracted, thus straightening the curve. The fixation was supplemented by a flexible threaded rod on which were placed multiple compression hooks that were designed to grip the transverse processes of the thoracic vertebrae on the convex side of the curve. The Harrington instrumentation gained wide acceptance by scoliosis surgeons by the late 1960s and, with modifications, was the standard until the Cotrel-Dubousset instrumentation became available in the early 1980s. With widespread use, the limitations of the Harrington rods became apparent: they diminished the normal thoracic kyphosis and lumbar lordosis, and its attachment at only two vertebrae was weak and insecure, requiring cast immobilization.

The next modification of the Harrington rod (the Moe modified Harrington rod) was an attempt to circumvent an increasingly recognized problem of the straight distraction Harrington rod: eliminating the normal sagittal contour of the spine. The distal end of the rod was squared and designed to fit into a hook with a squared hole. With this rod and hook, the rod could be bent, and its rotation into the scoliotic curve would be prevented by its inability to rotate in the hook. This was of limited usefulness because the hook could rotate under the lamina and the bending of the rod did not exert a great effect on the sagittal contour of the spine because it was attached only at the ends of the curve.

In the late 1970s, the technique of sublaminar wiring started to find acceptance in the United States. This was used primarily for paralytic curves because it provided a marked improvement in an area where the Harrington rod was the weakest. By using two rods attached to each vertebra, the fixation was secure, the forces were spread over all of the laminae and not just at each end, and the transverse forces of the wires pulling the spine to the rod were thought to help in the correction of the curve. Useful as it was, the Luque technique had its problems. Methods of fixation of the rods at each end were difficult, and the rods would often slide under the wires, permitting rotation of the spine. In addition, there remained a high degree of concern about passing wires into the spinal canal and the possibility of neurologic injury.

It was not long before the square-end Harrington rod was combined with sublaminar wires to aid in the maintenance of the sagittal contour in correction of idiopathic scoliosis. For many surgeons, this was the preferred method of correcting idiopathic scoliosis during the late 1970s and the early 1980s. The combination of distraction forces to lessen the magnitude of the curve and increase the curve radius and transverse forces, which more efficiently correct the larger radius but smaller magnitude curve, was a technique that also increased the stability of the construct.

The next major advance in scoliosis instrumentation was the Cotrel-Dubousset instrumentation. When the Cotrel-Dubousset spinal instrumentation was introduced in the early 1980s, it fit in with the growing realization that scoliosis was a multiplanar deformity and provided the surgeon with the tools to begin to correct the spine in multiple planes. The instrumentation permitted the attachment of multiple hooks attached to a rod that could be distracted, compressed, or rotated and then locked in place on the rod. The pedicle hook, which had been available for the Harrington rod, was an integral part of the instrumentation for the thoracic spine because it provided more rigid fixation to the vertebra during the rotation of the rod. Today, the Cotrel-Dubousset instrumentation has evolved, and numerous other forms of instrumentation using the same concepts are available. Although each has its own purported advantages, they all follow the basic concepts introduced by Cotrel and Dubousset.

The last addition to instrumentation of scoliosis is the pedicle screw. Originally designed by Harrington in 1966 for spondylolisthesis correction, this has proved to be very useful in gaining added correction to the lumbar spine. Although pedicle screws have been used for many years in the surgery of adult lumbar spine disorders, their introduction into scoliosis surgery has been delayed by litigation, and only a few reports documenting its advantages have appeared (2,3).

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2.1 POSTERIOR EXPOSURE OF THE THORACIC AND LUMBAR SPINE

Many techniques have been developed for exposure of the spine posteriorly. The technique illustrated here is that taught by John E. Hall, M.D. There are two goals in this exposure: the structures that are a part of the procedure must be seen clearly, without bits of shredded soft tissue remaining, and the blood loss should be minimal.

This exposure, like all others, is based on the anatomy. The exposure follows the same principles for exposure of the radius or the tibia: muscles and ligaments are released from their attachments, and the bone is exposed subperiosteally (1). When performed in this manner, the blood loss for the exposure of the thoracic and the lumbar spine for fusion of a double curve should not exceed 100 mL in the usual patient. To minimize blood loss, the surgeon should expose each segment completely the first time, not leaving soft tissue on the bone that will have to be removed later (Figs. 2-1 to 2-9).

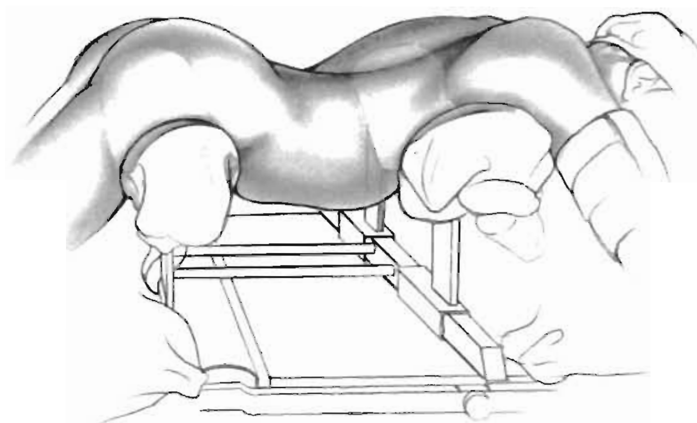
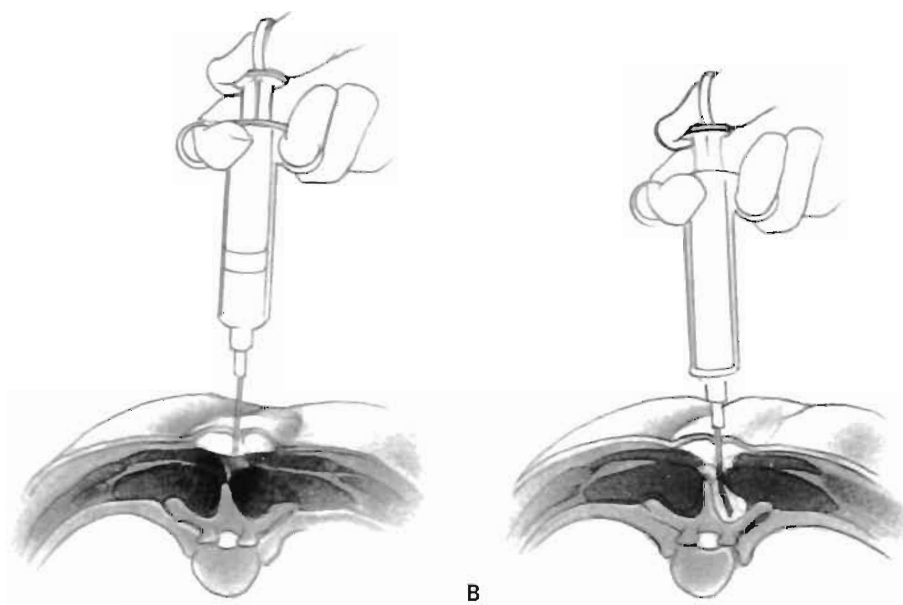


FIGURE 2-1. The patient is positioned on a frame such as the Relton-Hall frame or the Jackson table so that the abdomen is free. This reduces the pressure on the abdomen and reduces the intraoperative blood loss (1,2). Care should be taken that the cephalad bolsters are not impinging on the axilla and that they are pressing against the lateral chest wall. The breasts should be "tucked" between the bolsters to minimize pressure. Likewise, it is important to be certain that the iliac crests are padded and that a good deal of the pressure from the bolsters is on the proximal portion of the thigh below the bolsters. The arms should not be hyperabducted, and the ulnar nerves should be free. It is important to check the preoperative radiograph for a cervical rib. Improper arm positioning in these patients may result in a C8 or T1 palsey. The entire back, as well as the posterior pelvis, is in the operative field so that bone from the posterior iliac crest can be obtained for arthrodesis.



A B

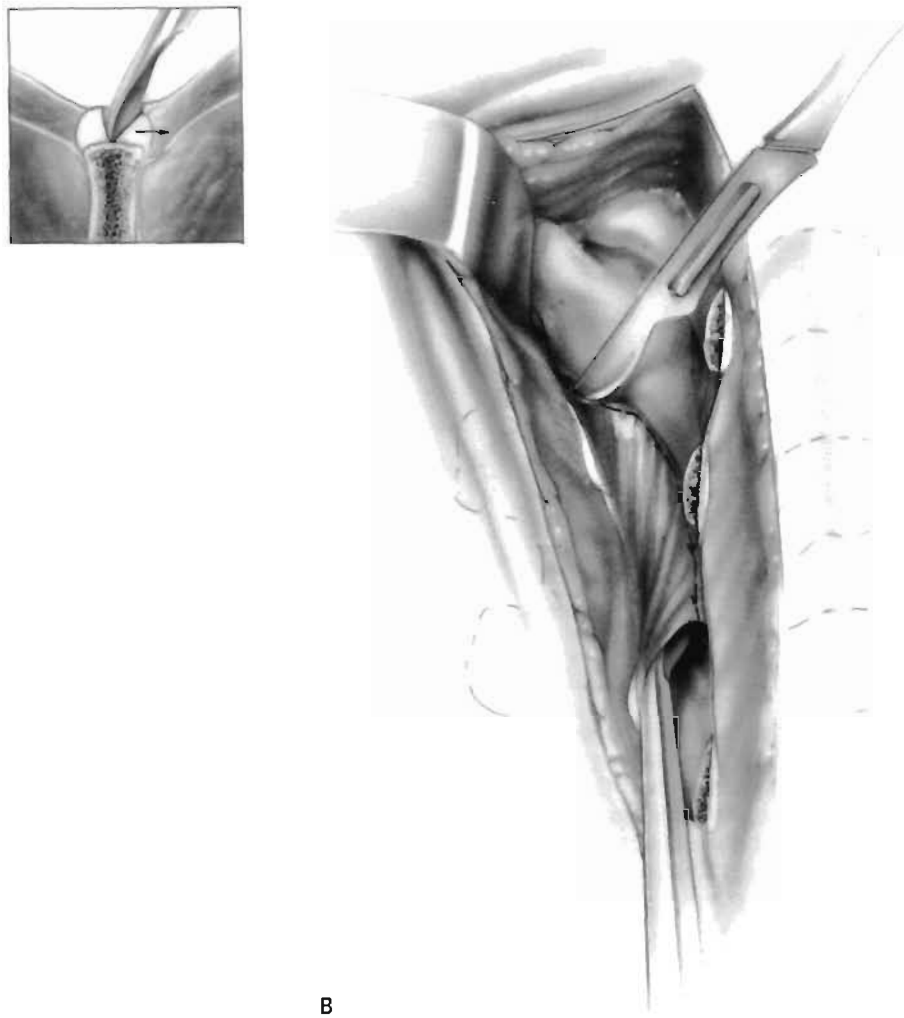
FIGURE 2-2. It is usually necessary to make this incision from the spinous process above the most proximal vertebra to be instrumented to the spinous process or of the most caudal vertebra to be instrumented. The incision should be a straight line between these two points so that the scar lies in the midline and will be nearly straight after correction of the curve. If, however, the curve is severe and the correction is not anticipated to approach 30 degrees, the incision can be made in a curved manner following the shape of the deformity. *(continued)*

FIGURE 2-3. The incision is deepened down to the tips of the spinous processes. It is important to identify and stay in the midline so that muscle is not cut, with consequent bleeding. The midline is identified by a thin line, which is actually the interspinous ligaments connecting the spinous processes. In severe cases of scoliosis with marked rotation, the muscles on the concave side are rolled up and over the midline, requiring that the knife (or cautery tip) be angled under it to reach the midline. After the apophysis of each spinous process is identified, they are split down to the bone with a knife or cautery.

◀ **FIGURE 2-2.** ***(Continued)***

If the fusion is to end in the region of L1 or L2, a separate incision can be used to obtain the iliac graft (see Fig. 2-151–2-157). If the L3 or lower vertebrae are to be fused, however, it is easier to extend the incision to the sacrum remaining in the midline (see Fig. 2-152).

After a slight cut partway through the dermis, the tissues can be infiltrated with a solution of adrenaline and saline (1:500,000). This is injected into the dermis to produce a *peau d'orange* effect. Sufficient volume should be injected **(A)** to swell the tissues. If desired, the same solution can be injected deeply. The needle follows the spinous process down to the lamina **(B)**, and 5 mL of the same solution is injected at each level on each side.



A

B

FIGURE 2-4. The exposure begins at the cranial end. The spinous process of the lamina above the one to be instrumented is exposed by pulling the cartilaginous tip of the spinous process off **(A)**, turning the elevator with flat surface against the spinous process, and sliding it down in the direction of the spinous process onto the lamina and the base of the transverse process. This is done to gain better exposure of the vertebra below. Care should be taken to follow the direction of the spinous process to prevent entering the muscle and creating unnecessary bleeding.

This procedure is then performed on the vertebra below so that the spinous process, the lamina, and the base of the transverse process of that vertebra are stripped of periosteum. These structures, however, are obscured by the muscle tissue on top of the elevator. The attachment of this muscle **(B)** to the caudal edge of the more superior lamina (the first one exposed) is not obvious. Using a knife (or cautery tip), these attachments are divided from the bone. The cut starts laterally or medially, but it should go from the tip of the spinous process to the lateral edge of the facet joint *(dotted line)*. Division of these attachments is aided by placing the tissue under tension with the elevator.

A

B

FIGURE 2-5. After the cut has been completed and the loose fatty tissue cleared from between the spinous processes, the elevator is placed in the cut that was made over the facet joint **(A)**. From here **(B)**, the elevator is drawn up the cephalad aspect of the transverse process. This should clear all of the tissue from the facet. The remainder of the transverse process is cleared to its tip. The very tip of the transverse process is obscured by the ligamentous attachment to the rib and, in most circumstances, can be left undisturbed provided that sufficient bone is exposed.

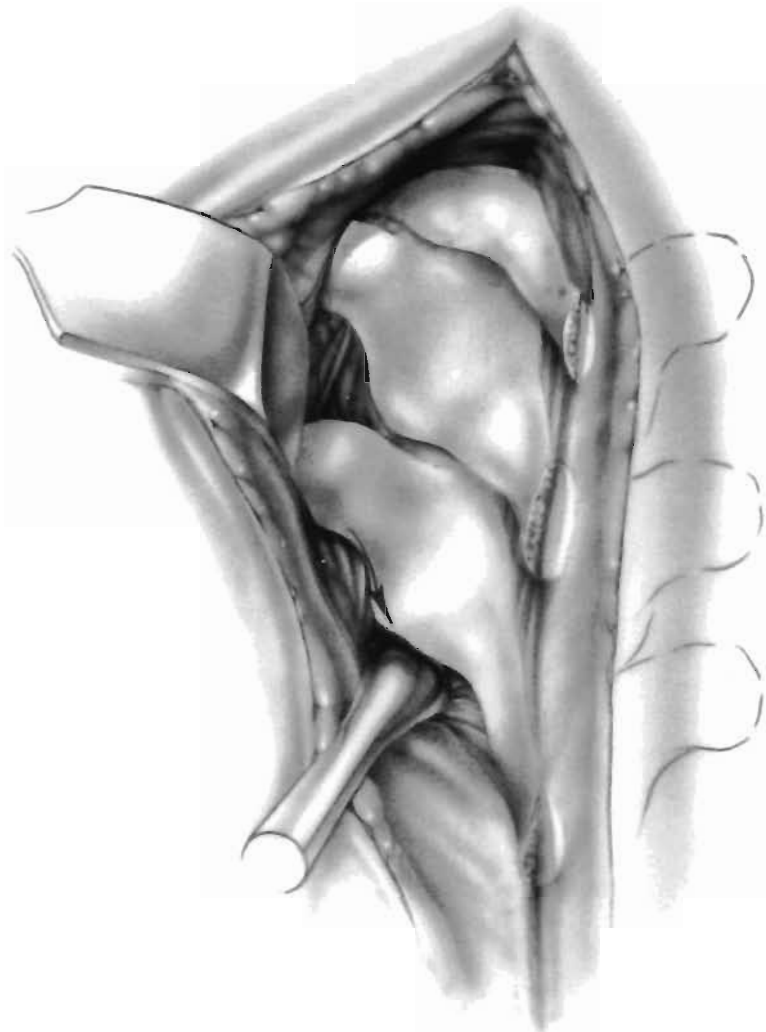


FIGURE 2-6. Before repeating these steps on the next vertebra, it is important to expose carefully the caudal edge of the vertebra just cleaned. This is accomplished by starting on the transverse process. With a small twisting motion of the elevator, clear the periosteum until the rounded edge of the bone can be seen. This is of particular importance in the region of the facet. If this is not accomplished, it will not be possible to see the facet clearly to cut the capsule, and the result will be shreds of soft tissue remaining on the bone. If a curette is used to remove the soft tissue from the facet joints, it should be used in a lateral to medial direction to avoid inadvertent penetration of the ligamentum flavum and possible spinal cord injury.

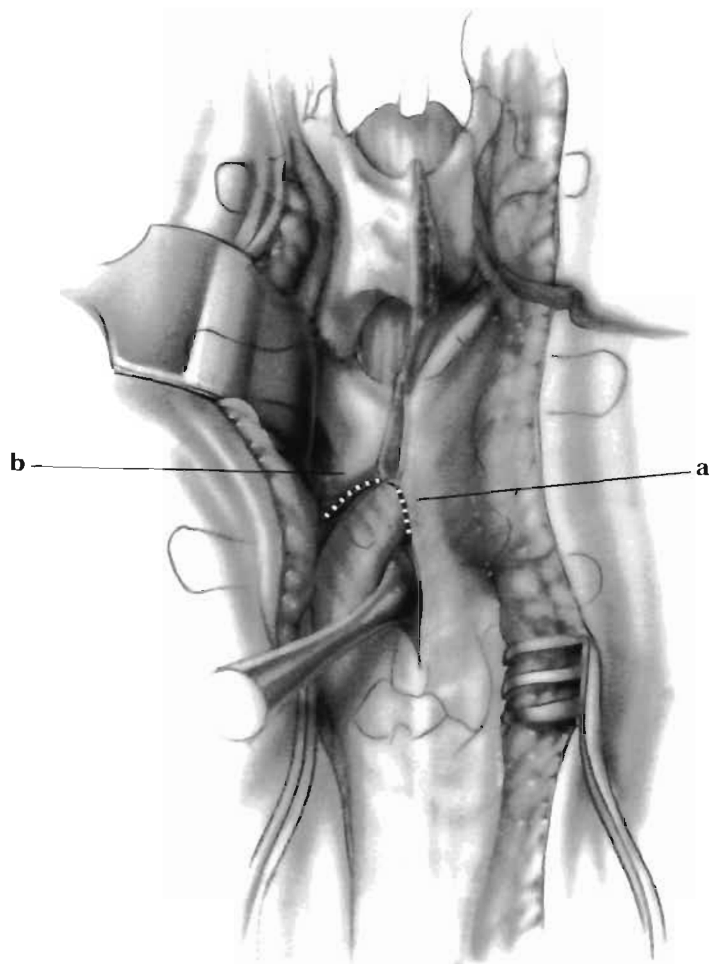


FIGURE 2-7. In the lumbar spine, the anatomy is different, and therefore the technique is different.

After reaching the lumbar spine, the spinous processes are noted to be farther apart. The space between is filled with a thick ligament that is not divided as easily as in the thoracic spine. Using the elevator to place the tissues under tension, this ligament is divided by cutting between the two spinous processes **(a)**. This cut should continue down to the lamina. With a little care, it is not difficult to avoid entering the spinal canal.

Although the anatomy appears different in this region, the principles are the same. Because the ligamentous attachments are on the caudal edge of the more cephalad lamina **(b)**, they are divided sharply as the elevator applies tension and continues the subperiosteal dissection of the lamina. This brings the dissection to the capsule of the facet joint.

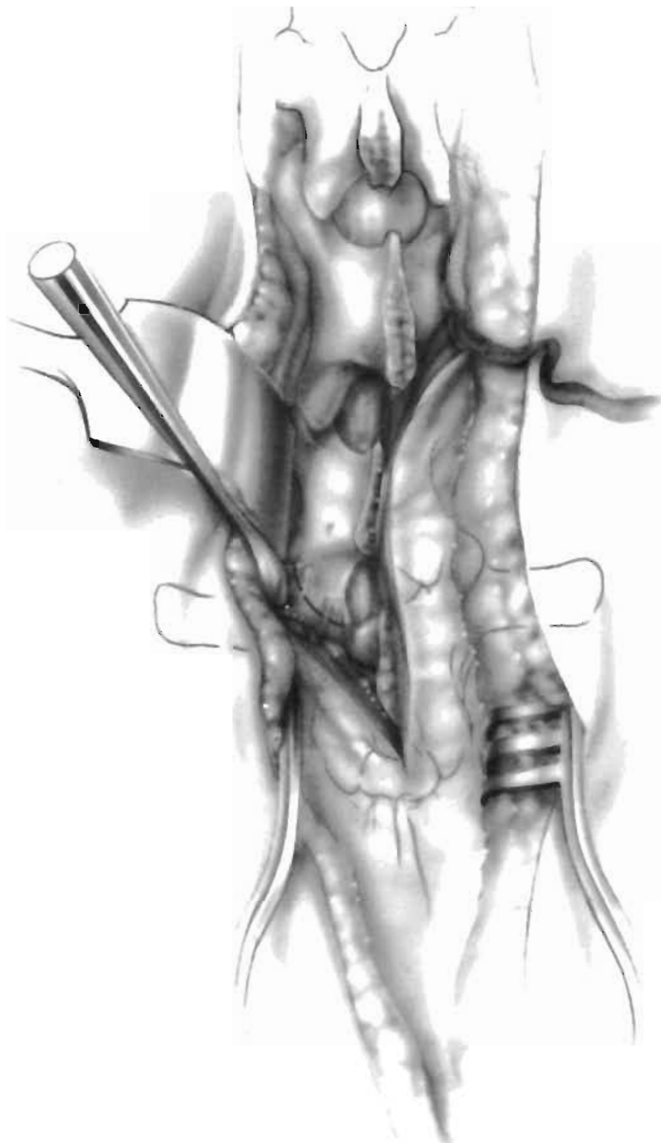


FIGURE 2-8. The easiest way to expose the facet joint is to follow the lamina out to the point where there is no more bone. Proceeding in a cranial direction from here is the inferior articular process, which in turn leads to the inferior facet. With the inferior articular process and the capsule of the facet exposed, a knife or electrocautery is used to divide the capsule, starting on the inferior articular process and going in a cranial direction across the facet capsule *(dotted line)*. At this point, the elevator can easily clean the capsule from both sides of the facet.

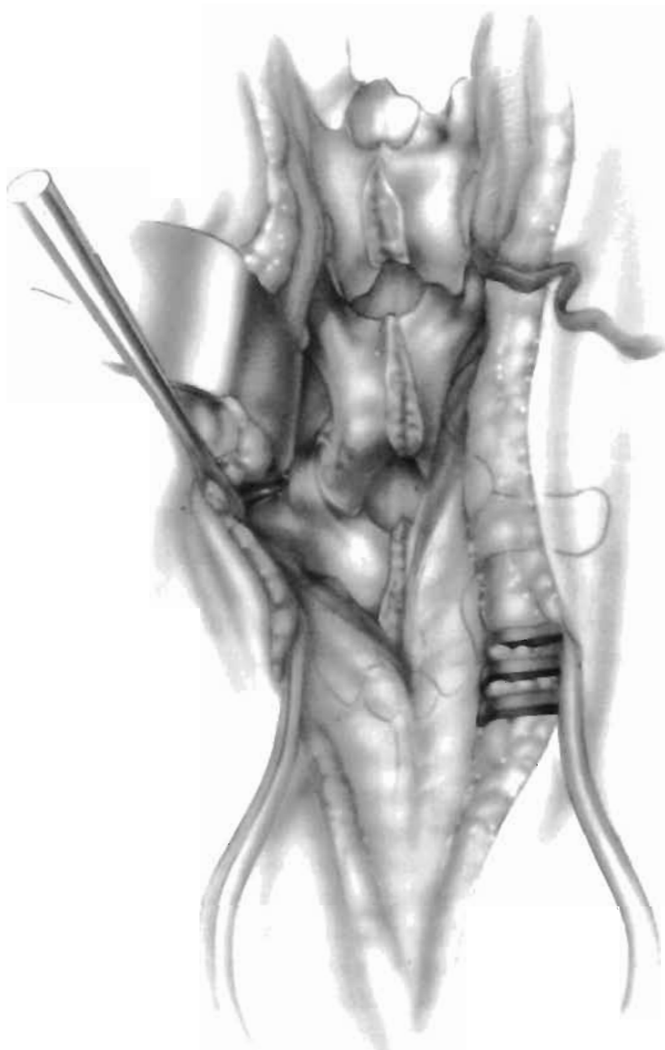


FIGURE 2-9. The transverse process is usually found just caudal to the level of the facet. By coming off the side of the inferior facet with the elevator, staying in contact with bone, the dissection follows onto the transverse process. Care should be taken with the elevator to pull laterally and upward to expose the transverse process.

After the transverse processes are exposed, a laparotomy sponge is packed into this area lateral to the facet joints and over the spinous processes. This not only tamponades venous bleeding but also stretches the tissues, making exposure and decortication easy when the surgeon returns to this area.

References

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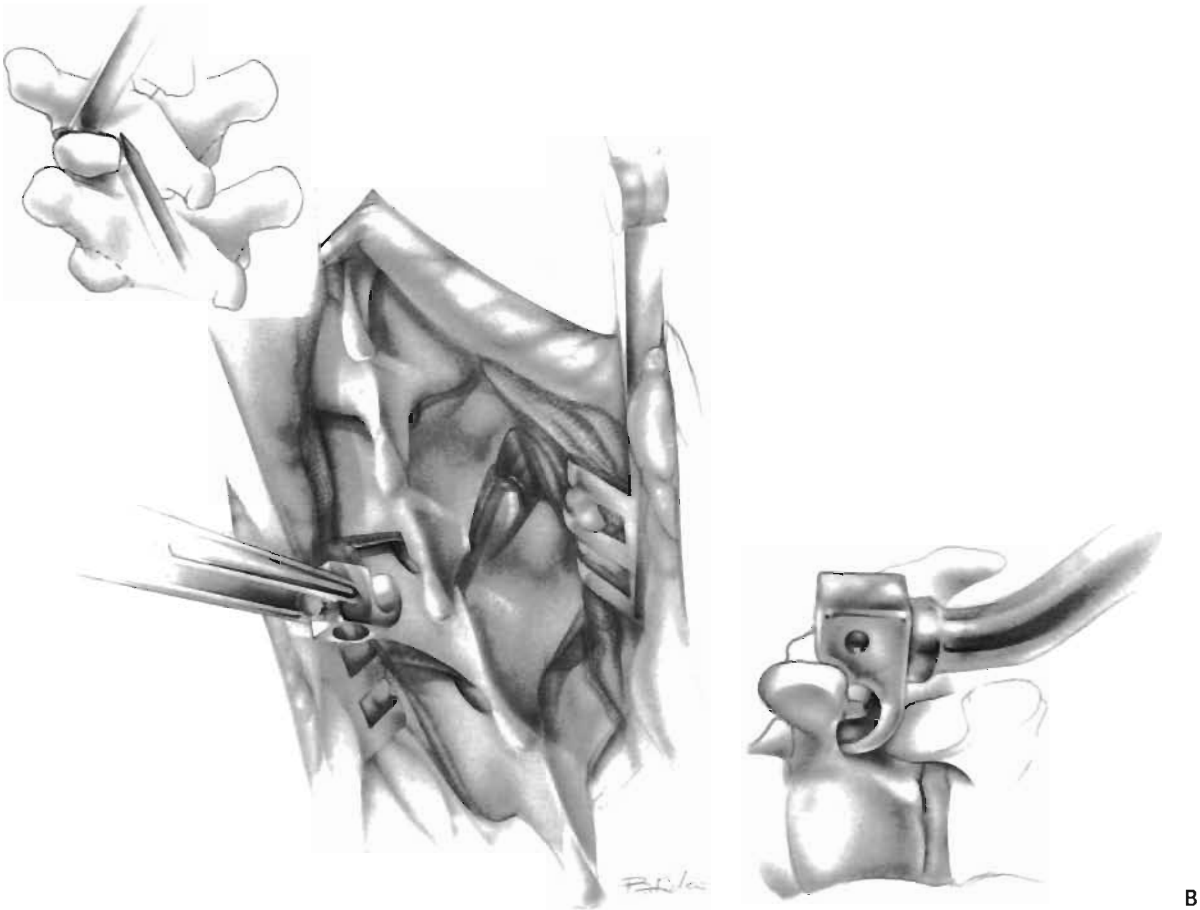
2.2 POSTERIOR SPINAL FUSION WITH HARRINGTON ROD INSTRUMENTATION FOR SCOLIOSIS

The Harrington rod was the first successful instrumentation for correction of scoliosis deformity. Although there are newer methods of instrumentation, the Harrington rod still remains in use. It has the longest follow-up of any technique and is the standard by which new techniques are compared.

The main advantage of the Harrington instrumentation is its simplicity and low cost: the insertion of two hooks and a rod. In light of newer methods of instrumentation, its disadvantages have become more apparent. The pure distraction force does nothing to affect rotation or sagittal contour directly. Various adaptations have been used to overcome these deficiencies: the use of a square end on the rod that fits into a square hole in the distal hook and the addition of sublaminar wires. These adaptations allowed the rod to be contoured and prevent its rotation into the scoliosis. The degree of correction in the sagittal plane, however, does not match what can be achieved with newer methods of segmental fixation using multiple hooks, sublaminar wires, and pedicle screws. In addition, the fixation is precarious enough to require postoperative immobilization.

The technique of Harrington rod placement is useful in learning the fundamentals of other related techniques, especially regarding hook placement and arthrodesis. In the technique initially used by Harrington, a compression rod was placed on the convex side of the curve. This offered increased stability and shortened the spine or at least resisted the stretching of the spine produced by the distraction rod. It is this distraction that, in some instances, is believed to be responsible for the rare spinal cord injury seen after Harrington rod instrumentation; however, the compression increased the lordosis that was usually present. Although not critically noted in the 1960s and early 1970s, this degree of thoracic hypokyphosis would not be acceptable by today's standards. Most surgeons never used the compression rod, finding it too difficult.

For Harrington instrumentation, the levels of fusion are selected according to the criteria proposed by King and colleagues (1) (Figs. 2-10 to 2-15). Results are reported in several articles (2-5).



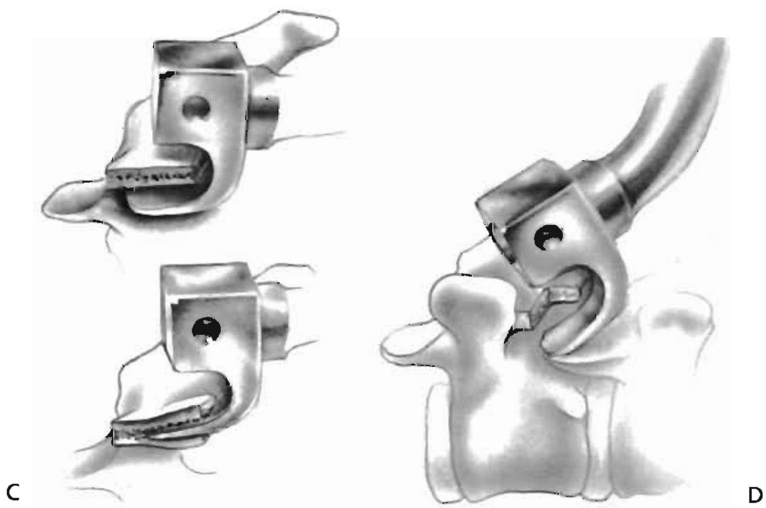


FIGURE 2-10. Placement of the infralaminar hook at the top of the curve on the concave side in the thoracic region **(A)** is begun by removing a small portion of the caudal edge of the facet joint and lamina of the selected vertebrae. This is done to allow the hook to move cephalad enough to be medial to the pedicle and within the confines of the spinal canal. This prevents its twisting out laterally. The notch in the lamina is made with a ¼-inch osteotome. Care should be taken to rest the hand holding the osteotome and, as much as possible, aim the osteotome away from the spinal cord. Provided that not too much bone is removed, the inferior facet blocks the osteotome from penetrating into the canal.

Hook placement begins with a #1251 hook on a hook holder and a pusher. This hook has a sharp edge that aids in penetration of the remaining ligamentum flavum. The hook **(B)** should be introduced so that it is medial to the pedicle. After placement **(C)**, it should be removed to be certain that it is under both cortices of the lamina and has not split the lamina. To accomplish this **(D)**, the introduction of the hook should begin with it tilted downward. It is useful to think of inserting it in such a way that it scrapes the cartilage off the inferior facet. When in place, it should be tested to be sure that it is medial to the pedicle; this can be done by pulling it laterally in an attempt to slide it out of the facet. This hook (or a #1253 hook) may be left in place because there is no danger that it will be pushed into the canal, and its presence serves as a reminder not to decorticate that lamina.

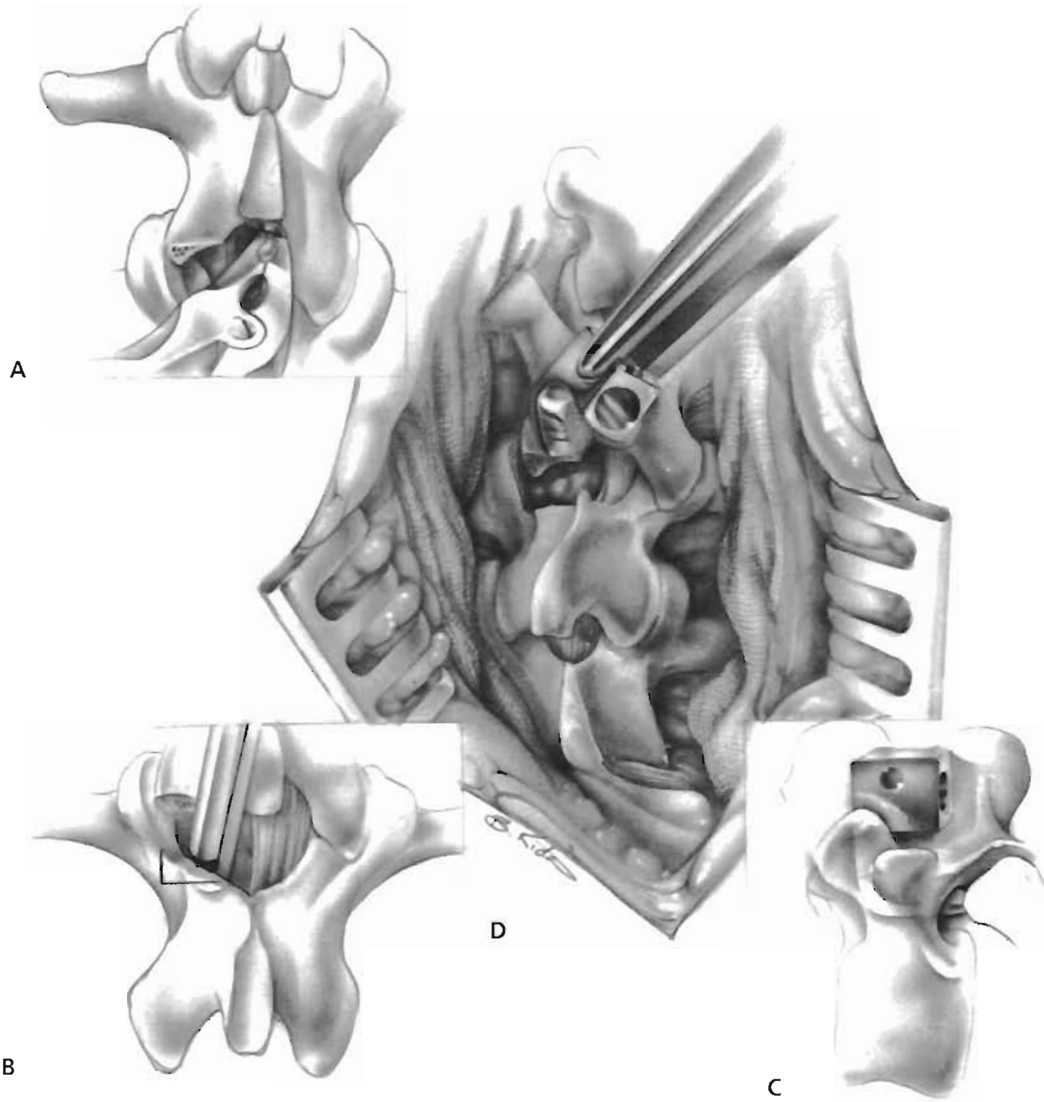


FIGURE 2-11. Placement of the distal hook in the lumbar region begins with gaining access to the spinal canal. This can be done most safely by nibbling away the ligament flavum in the midline cephalad to the selected vertebra. Safe entry into the spinal canal can also be obtained by using a small angled curette and releasing the ligamentum flavum attachment at the superior margin of the vertebral lamina. The caudal portion of the spinous process **(A)** and the adjacent portion of the superior facet can also be removed to improve access.

Next, the superior edge of the selected vertebra is squared off with a Kerrison rongeur. Only enough bone **(B)** to provide seating for the hook should be removed. Additional bone must be removed to allow the actual placement of the hook, and this bone should be taken from the facet and the lamina of the vertebra above.

At this stage, a #1254 hook, which is designed to fit on the collar end of the Harrington rod, is tried for fit. Like the thoracic hook **(C)**, it should lie medial to the pedicle within the spinal canal. This hook should be removed **(D)** because it could easily be pushed into the canal.

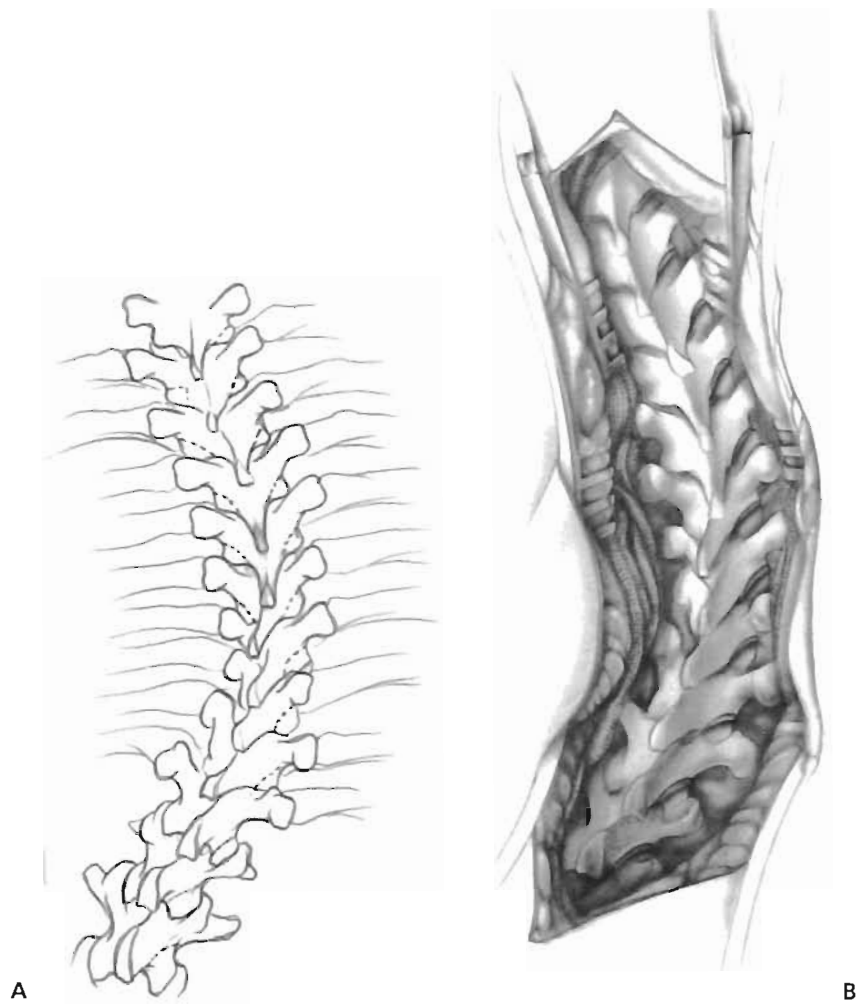


FIGURE 2-12. Before placement of the rod, all of the facets in the fusion area on both the concave and convex sides of the curve are excised. The thoracic facets are seen easily as that portion of the superior lamina that extends caudally to a smooth curving line drawn along the caudal margin of the transverse process to the caudal margin of the spinous process. This is indicated by the *dotted lines* in **(A)**. After removal of this portion of the superior facet, the cartilage of the inferior facet is seen **(B)** on the concave side of the curve. The cartilage of the superior facet joints is removed with a sharp curette in a lateral to medial direction. Great care must be exercised to avoid spinal canal penetration. After the facets are removed, complete decortication of the spinous processes, the laminae, and the transverse processes in the area that will lie under the rod is done. Those laminae that support hooks, however, should not be decorticated. Pieces of cancellous bone from the iliac crest should be packed into each facet.

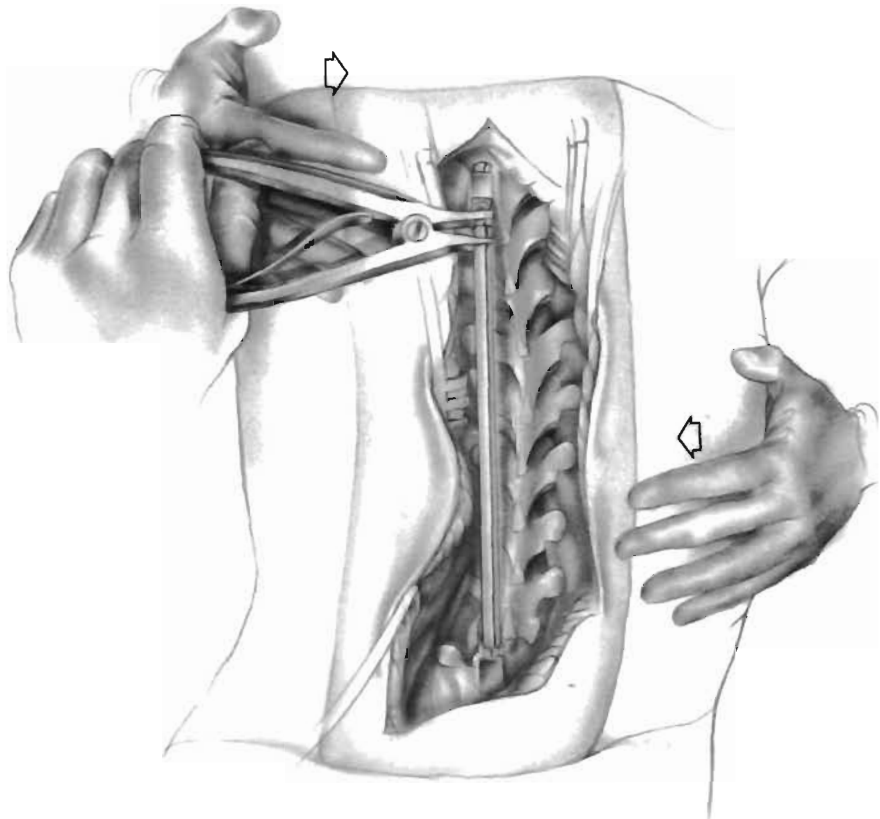


FIGURE 2-13. Both hooks are then placed and held firmly with a hook holder. The ratchet end of the rod is passed through the cephalad hook to the point where the distal collar end can be engaged in the caudal hook. At this point, the rod is ready to be distracted by use of the spreader. The spine is pushed straight by an assistant (arrows) while the distractor is used to force the superior hook along the ratchets of the rod.

At the completion of distraction, it is desirable to have as few ratchets as possible below the cephalad hook because this is the weakest part of the rod. This means that at the beginning of distraction, no ratchets may be visible below the hook and that, therefore, the Harrington spreader cannot be used for distraction. Although there is a special tool available to accomplish distraction in this situation, a small vise grip can be locked onto the rod far enough below the hook for the Harrington spreader to push against. After distraction is complete, the locking C ring is placed on the ratchet adjacent to the hook to prevent the rod from slipping.

FIGURE 2-14. At the completion of distraction, the remainder of the spine is decorticated, and the bone graft that is obtained from the iliac crest is carefully placed. Cancellous bone should be placed carefully in each facet. The surgeon must be careful so that when the muscle is pulled to the midline for closure, the bone graft is not dislodged.

Before wound closure, any bleeding from the muscle should be controlled. Any devitalized tissue resulting from the retractors or dissection should be débrided. Closure of the wound in three layers of running suture can be accomplished rapidly. The use of drains is at the surgeon's discretion.

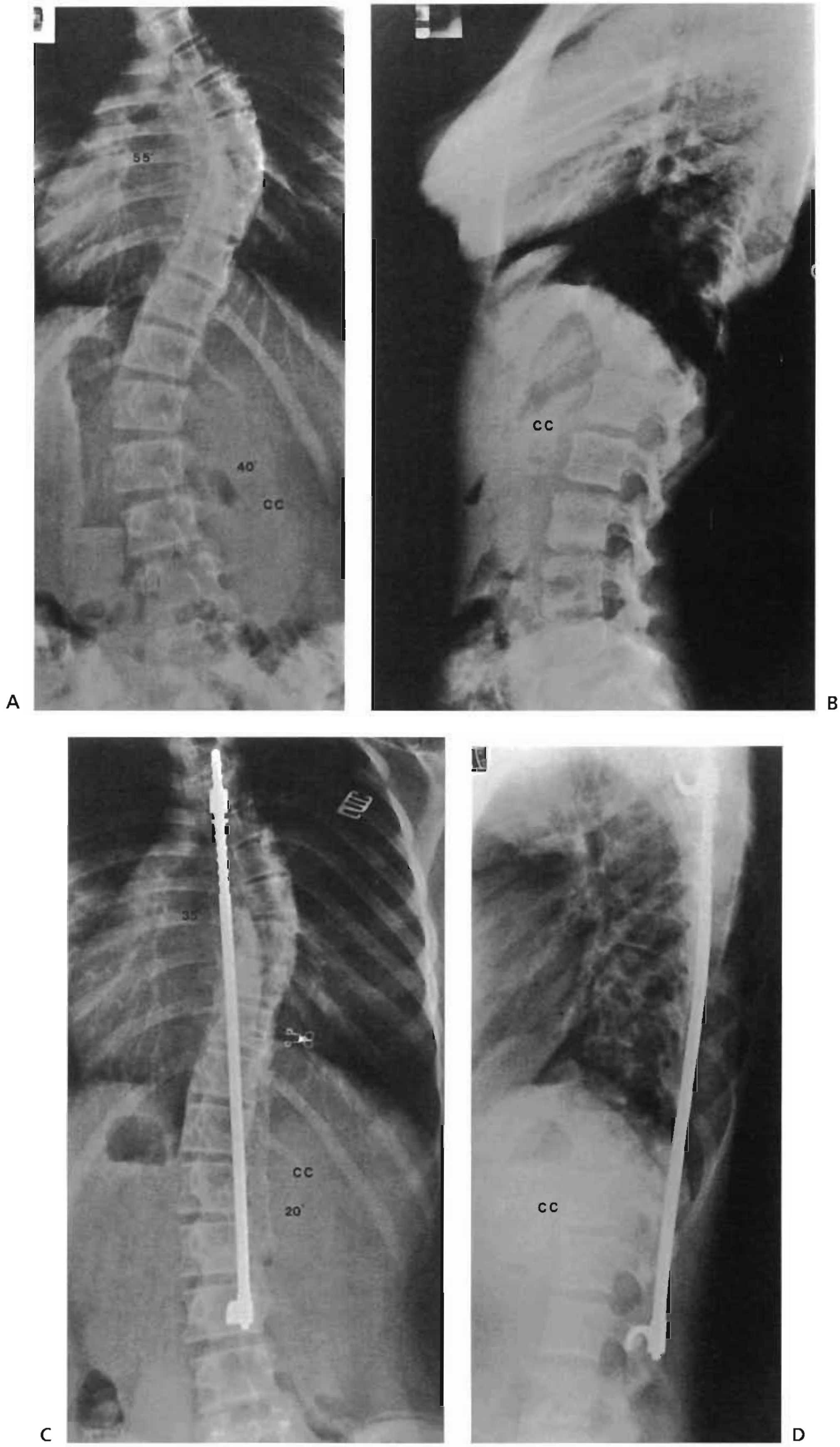


FIGURE 2-15. A comparison of the preoperative **(A, B)** and postoperative **(C, D)** radiographs of this 13-year-old girl demonstrates the correction of the scoliosis. The lack of correction of the hypokyphosis **(D)** is particularly noticeable on the lateral radiograph.

POSTOPERATIVE CARE

A properly placed Harrington rod may be more secure than is generally believed. The tension on the rod and therefore the force on the hooks decrease over the first hours and days. The likelihood that one of the lamina will break decreases; however, as the force of distraction lessens, there is a greater chance that a hook can be dislodged. In addition, there is no fixation of the vertebrae between the two hooks, and considerable motion can occur between these vertebrae. This can be demonstrated at the time of surgery. For these reasons, postoperative immobilization is considered necessary.

Initially, the patient is turned by "log rolling." Full mobilization is delayed until a suitable spinal orthosis is available or the patient has been placed in a cast. Pain is managed with morphine administered by a patient-controlled analgesia pump for the first 24 to 48 hours. Oral pain medication, supplemented by intramuscular medication, is then used. If a Foley catheter was used during surgery, it is best left in place until the morphine has been discontinued. Patients are followed at 3-month intervals with radiographs for the first year. Usually, the use of the cast or orthosis can be discontinued after 6 months. At 6 months, posteroanterior, lateral, and supine oblique radiographs are taken to assess the fusion mass. Six to 12 months after surgery, the arthrodesis should be solid and the patient allowed to return to full activities.

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2.3 HARRINGTON ROD INSTRUMENTATION WITH SUBLAMINAR WIRES FOR SCOLIOSIS

As the techniques of spinal fixation evolved in an effort to achieve better correction of both coronal and sagittal deformities, it was inevitable that the use of sublaminar wires would be combined with that of the Harrington distraction rod. This combined technique provides better correction of the sagittal contour and increased rigidity of fixation than use of the Harrington rod alone, but it does not offer a substantial increase in correction of the coronal deformity. Because this technique requires contouring of the rod, it is essential that a square-end rod be used so that the rod will not rotate into the deformity but rather pull the deformity to the rod, thereby gaining correction. The proximal hook should be placed medial to the pedicle, or a bifid pedicle gripping hook should be considered to prevent the hook from rotating out laterally. This technique is used widely by surgeons who have chosen not to embrace the newer posterior systems, such as the Cotrel-Dubousset, Moss Miami, and Isola instrumentation.

The criteria established by King and colleagues (1) determines the selection of the vertebrae to be fused (Figs. 2-16 to 2-19).

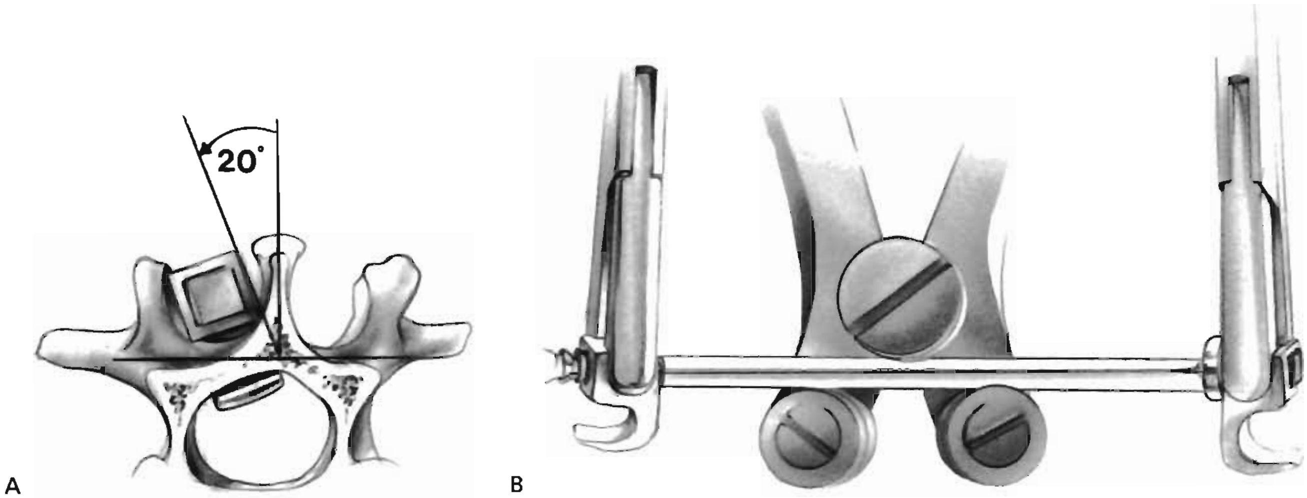


FIGURE 2-16. It is important that the rod is contoured so that it has the desired configuration when the distal square end is inserted in the square-end hook. Usually, the distal square hook sits with a 20-degree lateral tilt **(A)** when inserted under the lamina. An easy method to contour the rod is to hold it in a hook, which is held by a hook holder. The hook can then be inclined to the same degree of tilt that is observed **(B)** when it is inserted and the rod contoured in this position.

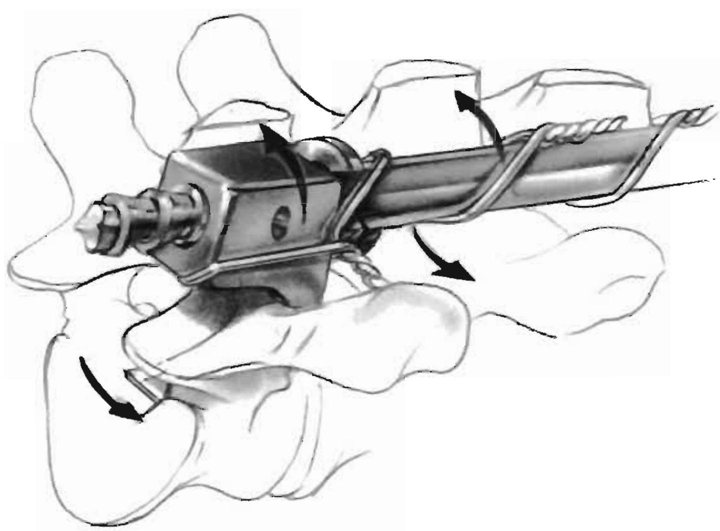


FIGURE 2-17. The technique for inserting the hooks is the same as for the Harrington rod, and the technique of passing the wires is described in the Luque technique. Wires should be passed around the laminae of all the vertebrae to be fused, including the most superior and inferior vertebrae into which the hooks are inserted. This provides additional stability for the hooks that are under different stresses from the Harrington technique.

The wires that pass around the rod tend to pull the rod toward the midline. This force, applied to the most dorsal aspect of the hook, tends to rotate the hook that is under the lamina in a lateral direction. The hook should be stabilized with a hook holder when tightening the wires. Although this force should be resisted by the pedicle, additional stability is obtained by passing the wire around the hook.

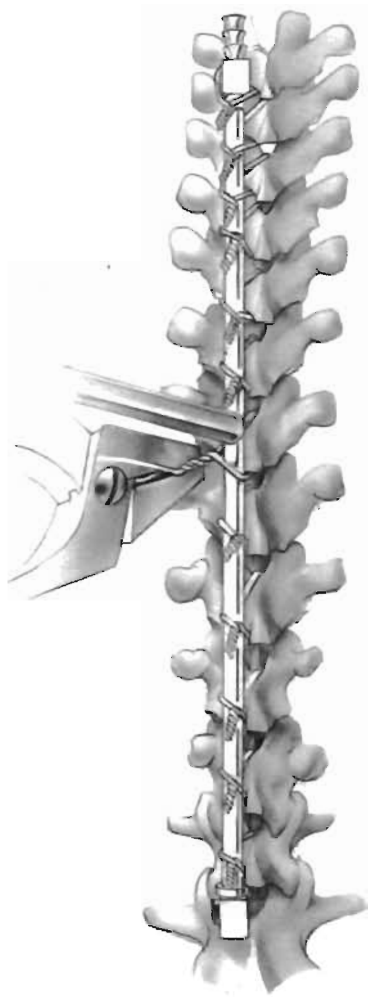
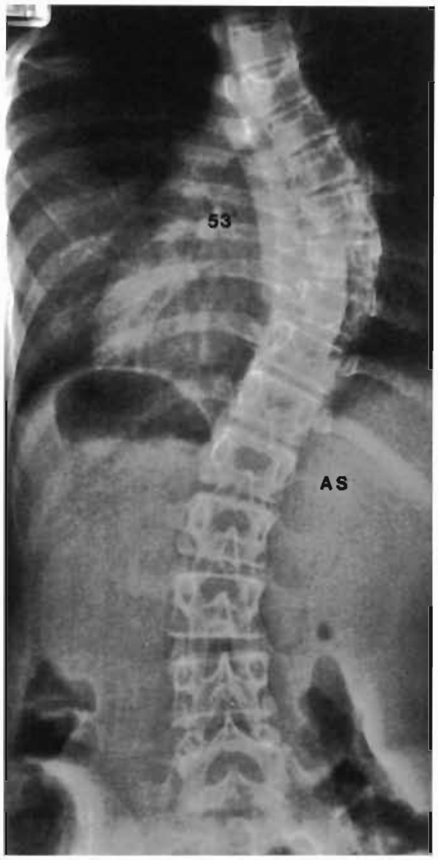


FIGURE 2-18. This technique can be accomplished fast enough to permit thorough facetectomy and decortication of the area that will lie under the rod without undue blood loss. The distraction is obtained before tightening the wires. The tightening starts at the ends and progresses toward the middle. In addition to an assistant pushing the spine straight, the rod is stabilized with a rod pusher.



A

B

C

FIGURE 2-19. Preoperative **(A)** and postoperative **(B, C)** radiographs of a 14-year-old-girl with a single curve illustrate the correction of the scoliosis and the preservation of the normal lumbar lordosis. Although moderately effective in correcting the thoracic hypokyphosis, it offers little if any additional correction of the rotational deformity compared with the Harrington rod used alone.

POSTOPERATIVE CARE

Postoperative care of these patients is similar to that of patients who have been treated using a Harrington rod. The need for immobilization in the postoperative period is not great, however. Our treatment consists of an Orthoplast jacket that is worn full-time for the first 3 months and for the next 3 months when ambulatory.

Reference

1. King HA, Moe JH, Bradford DS, et al. The selection of fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg [Am] 1983;65:1302.

2.4 INTERSPINOUS PROCESS SEGMENTAL INSTRUMENTATION (WISCONSIN INSTRUMENTATION) FOR SCOLIOSIS

Initial concepts of segmental spinal fixation used the spinous process for the segmental fixation (1,2). This technique, also known as the *Wisconsin technique,* was developed to provide a means of segmental spinal fixation that was as secure as the Luque method but did not entail the risk for passing wires in the spinal canal. The technique has the additional advantage of combining distraction with a lateral corrective force (3).

Disadvantages of this technique include the limited ability to correct sagittal plane deformity unless a contoured, square-end rod is used and the tendency of the rotational deformity to worsen with tightening of the wires around the Harrington distraction rod (Figs. 2-20 to 2-24).

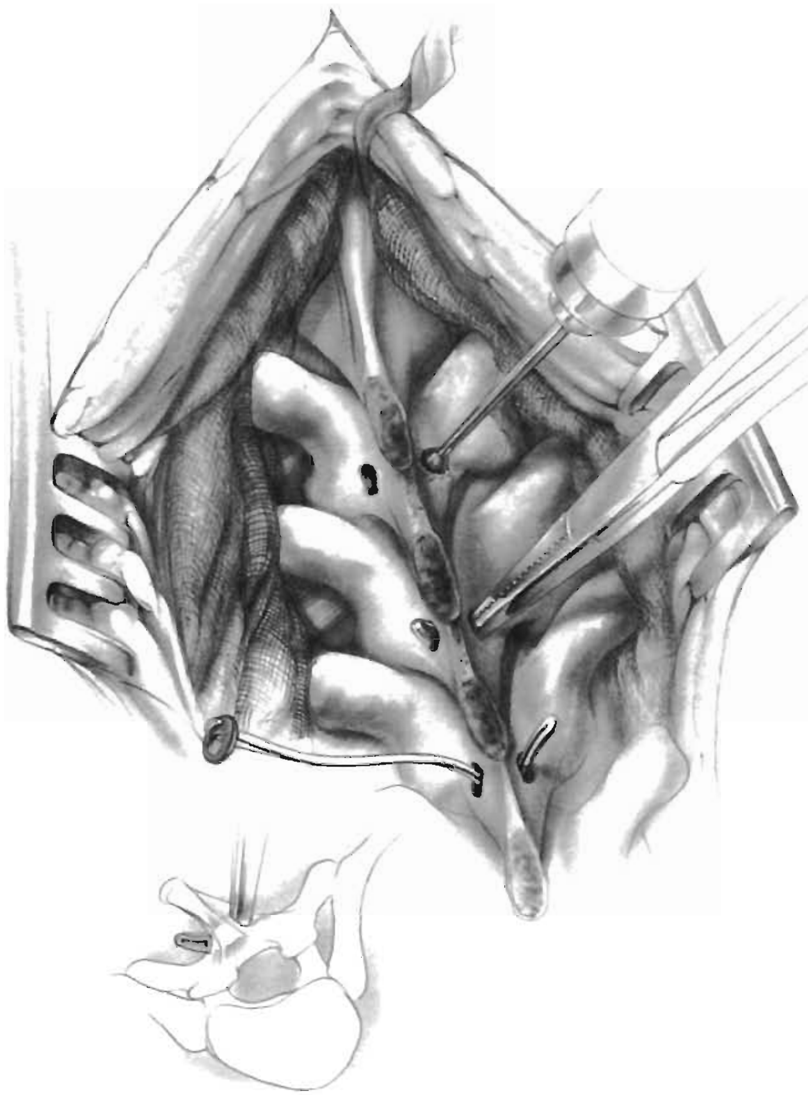


FIGURE 2-20. The spine is exposed as in the Harrington rod procedure. The levels for fusion are selected based on the needs of the particular case, and the two hook sites for the Harrington rod are prepared. The next step is to prepare the holes in the base of the spinous processes, through which will pass the button-wire implants. These holes can be prepared by the use of special curved awls that were designed for this purpose; however, we have found it easier to begin the holes on each side of the spinous process with a small air-driven bur. This provides excellent control. The two holes are then easily connected by passing a small curved hemostat or right-angled clamp or a large towel clip through each side. These instruments are less likely to penetrate the cortical wall of the canal than a sharp awl.

It is important to be at the base of the spinous process and to direct the holes as deeply as possible without entering the spinal canal. If the holes are placed too close to the tip of the spinous processes, there will not be sufficient strength in the bone. This technique is not suitable for a kyphotic spine because in this particular deformity, the spinous processes will thin and flatten out, providing little bone between the spinal canal and the tip of the spinous process.

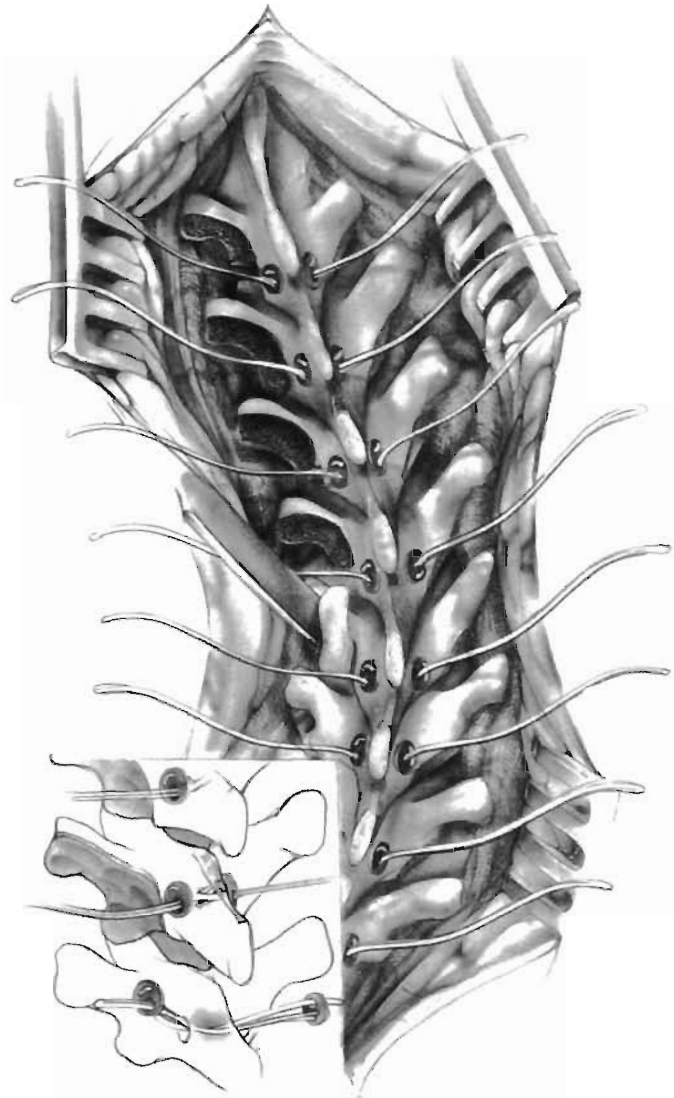


FIGURE 2-21. After the holes are made, the button-wire implants are placed. Two of these are passed through each hole, one from each side. Each button has a hole in addition to the one through which the wire is attached. The wire from the opposite side is passed through this extra hole. When these wires are pulled through and the buttons are firmly seated against the base of the spinous process, there is a wire loop projecting on each side of the spinous processes to be instrumented. At this point, all of the facets are excised, and the area of the spine that lies under the Harrington rod is decorticated.

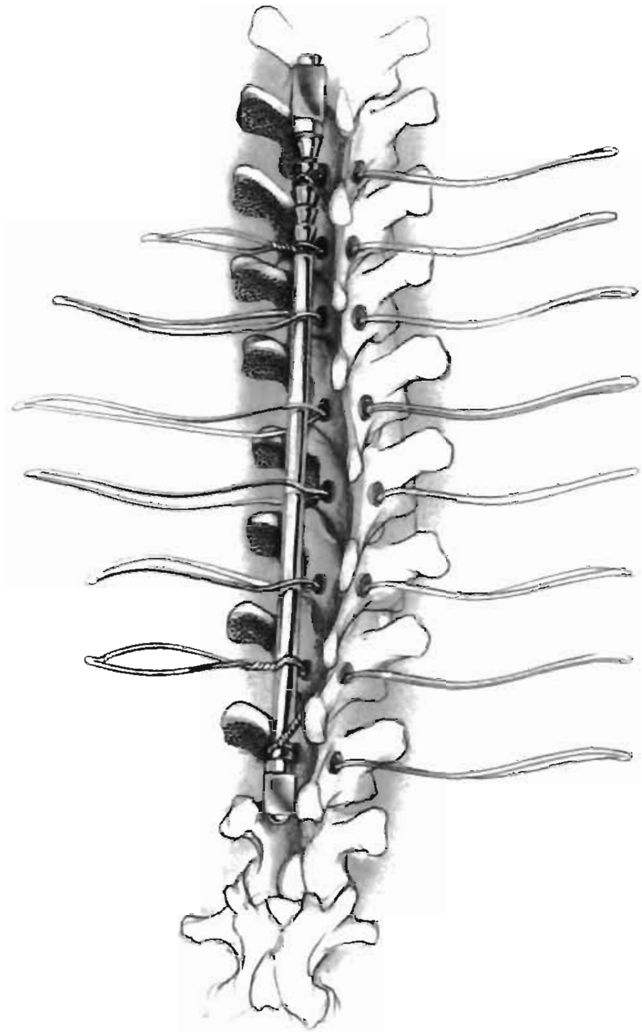


FIGURE 2-22. The hooks for the Harrington rod are put into their previously purchase sites, and the rod is placed into the hooks after being passed through the wire loops. The rod is then distracted. While an assistant uses manual pressure on the apical ribs to bring the spine to the rod, the wires are tightened around the rod, starting in those areas where the rod closely approximates the spine and working toward the apex of the curve. During the wire tightening, the hooks should be stabilized against rotation.

FIGURE 2-23. The contoured Luque rod can now be placed on the convex side after it is decorticated. It is contoured to give the estimated amount of correction that can be obtained. Kyphosis and lordosis can also be contoured in this rod, but this will be more of a bother than a help unless a contoured, square-end Harrington rod has been used on the concave side. An L configuration should be placed at one or both ends of the rod to keep it from sliding because it will not be locked in place by rigid cross-links. This rod then can be tightened by the convex (proximal to distal) technique.

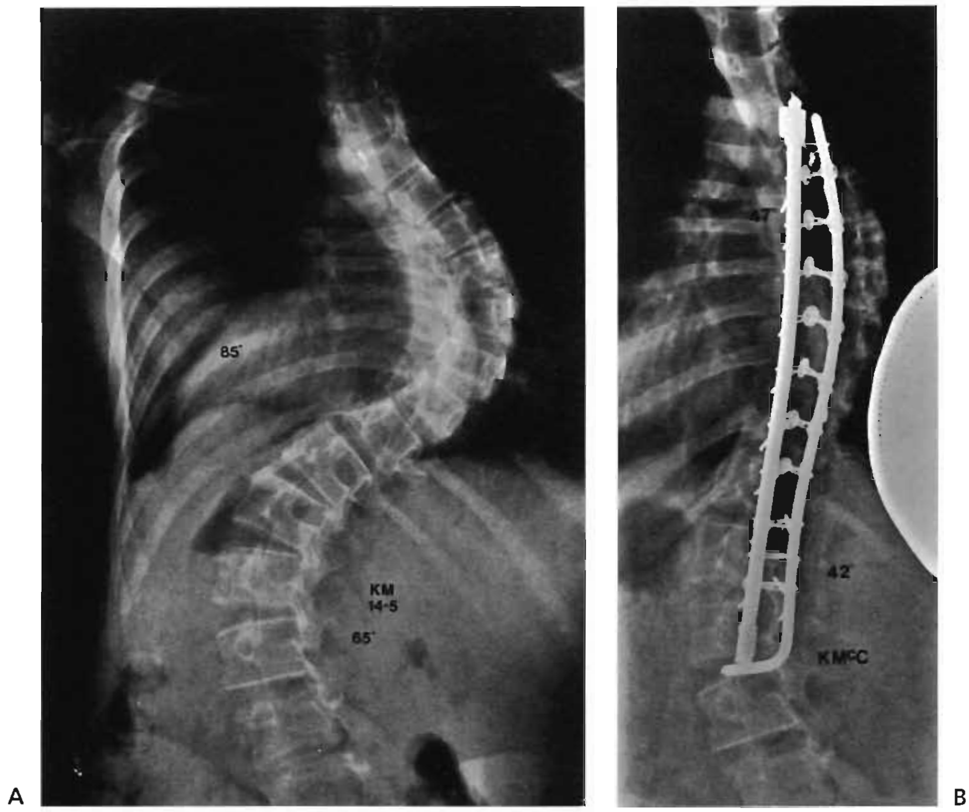


FIGURE 2-24. Radiograph **(A)** of a 15-year-old girl with severe rigid scoliosis. Anterior diskectomy and fusion were performed to obtain better correction. At the same operative session, posterior arthrodesis with interspinous process segmental spinal instrumentation was performed. This method is rapid, combines distraction with lateral corrective force, and is rigid, making it a reasonable choice for this situation. The results 2 years later are shown in **(B)**.

POSTOPERATIVE CARE

Postoperatively, patients are treated in the same manner as any stable spinal instrumentation would allow. Early ambulation or sitting with or without an orthosis is possible depending on the surgeon's choice.

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2.5 BILATERAL SUBLAMINAR SEGMENTAL INSTRUMENTATION (LUQUE INSTRUMENTATION) FOR SCOLIOSIS

The double L-rod method of segmental spinal instrumentation, popularized by Luque, introduced the first practical application of segmental fixation to the spine. The final evolution of the technique has resulted in a method of fixation in which two stainless steel rods are secured to the laminae of each vertebra in the fusion area.

These rods must be contoured to conform to the spine in its anticipated corrected position because the spine is moved to the rods and held there by wires to achieve correction. In addition, the rods can be contoured in the sagittal plane. Although this can be effective in maintaining or producing lumbar lordosis, it is less effective in correcting the hypokyphosis in thoracic scoliosis. Theoretically, better correction should be possible with this instrumentation because the geometric limitation of curve correction by distraction does not apply to lateral forces (1). Because the force of correction is shared by each lamina in the fusion area, this technique is ideal for those cases in which the bone is not of normal strength (e.g., neuromuscular scoliosis). The secure fixation produced by this technique lessens or obviates the need for postoperative immobilization.

This technique is more difficult to master than the Harrington rod technique. There is potential for neurologic injury with all of the wires in the spinal canal either through cord injury during wire passage or through inadvertent cord trauma during manipulation of the wires during the procedure or as they are secured to the rod (2). Many surgeons with wide experience in the technique report no complications using the wires. Reliance on the instrumentation rather than facetectomy, decortication, and bone grafting is a seductive trap that probably results in an increased incidence of late pseudarthrosis with this technique.

As with most other methods of instrumentation, the levels of fusion are determined by the upright (sitting) and bend or traction films. This technique finds its widest use in neuromuscular scoliosis; therefore, the usual criteria for fusion of neuromuscular curves apply. In these cases, the most common error is to fuse too short cephalad. In nonambulatory patients with neuromuscular deformities, it is the general consensus that the fusion should extend to the pelvis.

The rods are available in two diameters: $\frac{3}{16}$ inch (4.8 mm) and $\frac{1}{4}$ inch (6.4 mm). The smaller $\frac{3}{16}$-inch rods are flexible, and for that reason they are more forgiving and easier to contour. This same flexibility may be a disadvantage in gaining and maintaining correction, however, and in our opinion, this size of rod is rarely indicated.

The rods are secured to the spine with stainless steel wire, usually 16 gauge. Some surgeons prefer to use doubled wire to secure each rod to the lamina. Doubled 16-gauge wire is used at the most proximal and distal levels of fixation, and doubled 18-gauge wire is used at the intervening levels. The wire should be malleable and workable, so that it does not break with bending and twisting. It can be also obtained in precut lengths with a small bead on the end.

Although the original method is illustrated, the rods can be secured to a claw at the top on each side and pedicle screws or another claw on each side at the bottom. Wires are then used on all of the other vertebrae (Figs. 2-25 to 2-41).

FIGURE 2-25. Some surgeons prefer to prebend the rods based on the preoperative traction or bend film. Prebent rods (so-called unit rods) are also commercially available. We find it much easier, with the help of an assistant pushing the spine straight, to bend the rod after the spine is exposed. (Both French and in situ benders must be available in the operating room.) In this way, the rods can be bent, applied against the spine to check the fit, and adjusted in both the coronal and sagittal planes. Because correction improves after all the facets are excised, the rods are usually bent to gain slightly more correction than is apparent with an assistant pushing the spine straight. Because bone fragility varies in these patients, it is better to use the in situ benders and settle for less correction than to risk lamina failure and possible spinal cord injury. It should be possible to achieve correction equal to that seen on a forced bend film. At the completion of the surgery, the rods should lie in close contact with the laminae.

FIGURE 2-26. If the spine is not instrumented to the pelvis, an L is bent at one end of each rod. Initially, one reason for this bend was to keep the rod from slipping through the wire. This potential problem is obviated by the use of the Texas Scottish Rite cross-links. The bend makes it easier to control the rotation of the rod as the wires are being tightened. One of these bent ends is placed cephalad and one on the opposite side caudad. At the caudal end, the L may be passed through a hole in the base of the lumbar spinous process.

FIGURE 2-27. After the rods are contoured and before the next step, excision of the ligamentum flavum and of all the facets in the fusion area is performed. In the lumbar spine, there is sufficient room between the spinous processes to excise a portion of the ligamentum flavum without removal of bone. In the thoracic spine, however, the spinous processes overlap, obscuring the ligament. This overlapping portion of the spinous process can be removed with the same large rongeur or a bone biter. This is followed by excision of a small portion of the ligamentum flavum.

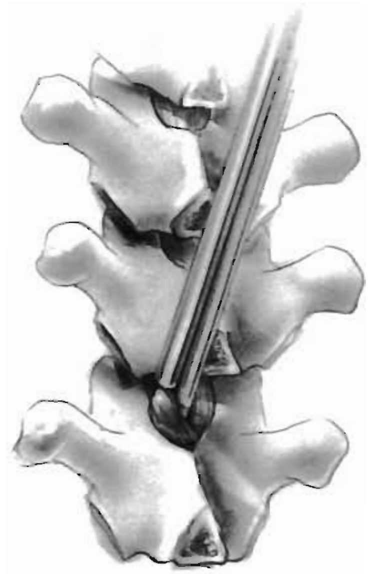


FIGURE 2-28. A large double-action rongeur is used to bite the ligament in the midline. It is usually possible with experience to bite through the ligamentum flavum with the large rongeur in a small area exposing the epidural fat. This hole then can be enlarged with a smaller and sharply angulated rongeur. A more cautious and time-consuming method is to take a small bite from the ligamentum flavum, thinning it out until the midline separation is found. This can be separated with a small dissector, and a Kerrison rongeur can be used to remove a portion of the ligament.

The removal of the ligamentum flavum should be sufficient to permit passage of the wire. Extensive removal of the ligament does little to make passage of the wire easier and only creates more bleeding and opportunity for bone graft to fall into the spinal canal. Any epidural bleeding encountered should be controlled with bipolar cautery or with a hemostatic agent such as Gelfoam or Surgicel. Because passage of the wire is easier and safer on the convex side of a curve, enlargement of the opening in the ligament in this direction is best.

FIGURE 2-29. The bending of the wires is crucial if their passage is to be atraumatic, and it may have some importance for safety. Pulling the wire through the canal is easier if no sharp bends are placed in the wire that is to be pulled under the lamina. The bend in the wire should be slightly longer than the width of the lamina so that the tip emerges on the other side. Care is needed to avoid creating a curve with too large a radius because this may impinge on the cord during passage.

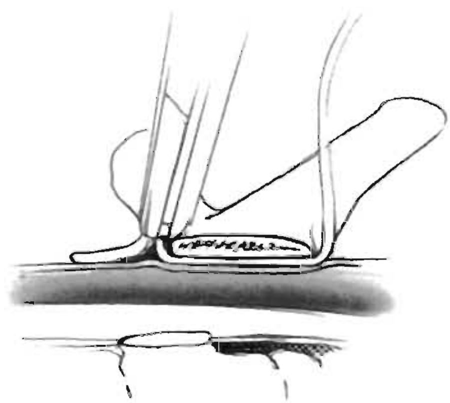


FIGURE 2-30. In situations in which the lamina is broad, it is better to bend only the tip, leaving the portion that is to be passed under the lamina flat. The wire can then be slid easily under the lamina without striking the spinal cord.

FIGURE 2-31. The wires are most easily passed from the caudal to cephalad direction. The wire must be controlled at all times. The wire should never be forced under the lamina. When the tip of the wire becomes visible at the cephalad end of the lamina, it is grasped with a large sturdy needle holder. Care must also be taken to avoid a Gigli saw effect, which may lead to laminar fracture. As it is pulled through, a gentle upward force is maintained on the caudal end of the wire to help straighten the bend and ensure that it does not impinge on the cord and that it rests "flat"against the undersurface of the lamina. During the remainder of the procedure, care must also be taken to avoid inadvertent pushing of the sublaminar loops into the canal.

If both sides of the spine will be secured with a rod, as is usual in paralytic curves, a double segment of wire, the bent end cut off after passage, may be passed and the two resulting pieces secured on opposite laminae. (In these illustrations, passage of a single wire is shown for clarity.) Great care must be taken to avoid crossing the wires under the lamina in the spinal canal. Double wires are often used on each side at the top and bottom of the rods, where the stress may be greater.

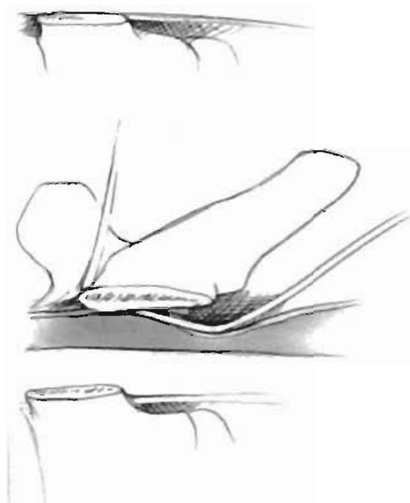


FIGURE 2-32. After the wire is drawn under the lamina, it must be secured in such a way that, if accidentally hit, it will not be forced into the spinal canal. No matter how careful the operating team, it is difficult to avoid hitting the wires during the course of the surgery. The amount of force necessary to push a wire in against the spinal cord is so slight that it can occur without the surgeon being aware.

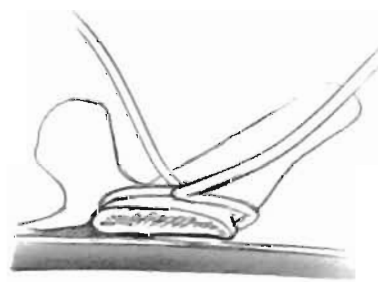


FIGURE 2-33. The best way to secure the wires is by bending each end of the wire securely over the lamina and then over the edge of the wound. Wire organization is crucial to the success and speed of the operation. As the wires are passed, the infralaminar wires are organized laterally while the cephalad supralaminar portion is organized medially (see Fig. 2-37).

If complete decortication of the spine is to be performed, it must be done at this time, before the rods are wired in place. There are two major problems with doing a complete decortication, as desirable as it is, of a paralytic spine at this stage: the bleeding may be excessive, and there is increased risk for neurologic injury when moving all of the wires from side to side. In most cases, therefore, the rods are wired in place at this point, and decortication of the accessible bony surface is done as the final step before closure. This highlights the importance of previous complete excision of all facets, which will be inaccessible at this point. In addition, the closer the rods lie against the lamina and base of the spinous process, the more bone is available for decortication lateral to them.

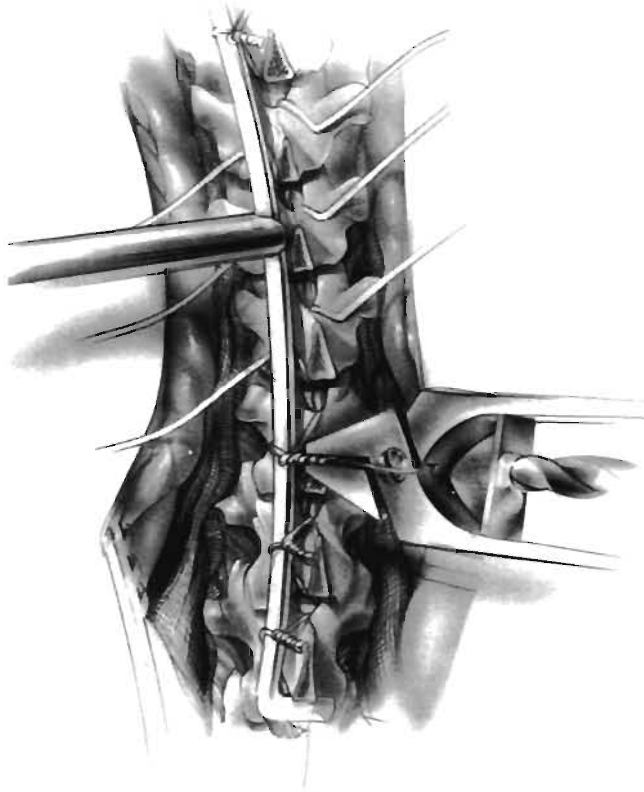


FIGURE 2-34. The technique of tightening the wires is important. The wires should not be used to pull the spine to the rod. Rather, an assistant pushes the spine straight while the rod is stabilized with a rod holder or pusher. The wires are then tightened sequentially, holding the correction that is gained.

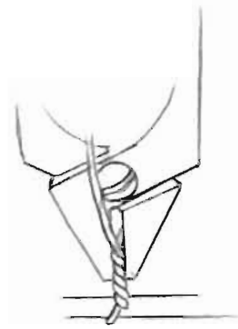


FIGURE 2-35. It can be difficult to determine when the wires are tight enough. As the wires are tightened with the wire twister, the twists are at an angle of about 45 degrees to the axis of the wire.

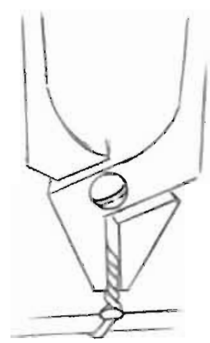


FIGURE 2-36. When the newest twist, the one closest to the rod, changes direction to lie at 90 degrees to the axis of the wire, it is as tight as it can be made without risking breakage. During the tightening, careful inspection of the L segment is necessary to be sure that it is not rotating. This segment should be stabilized with a rod holder.

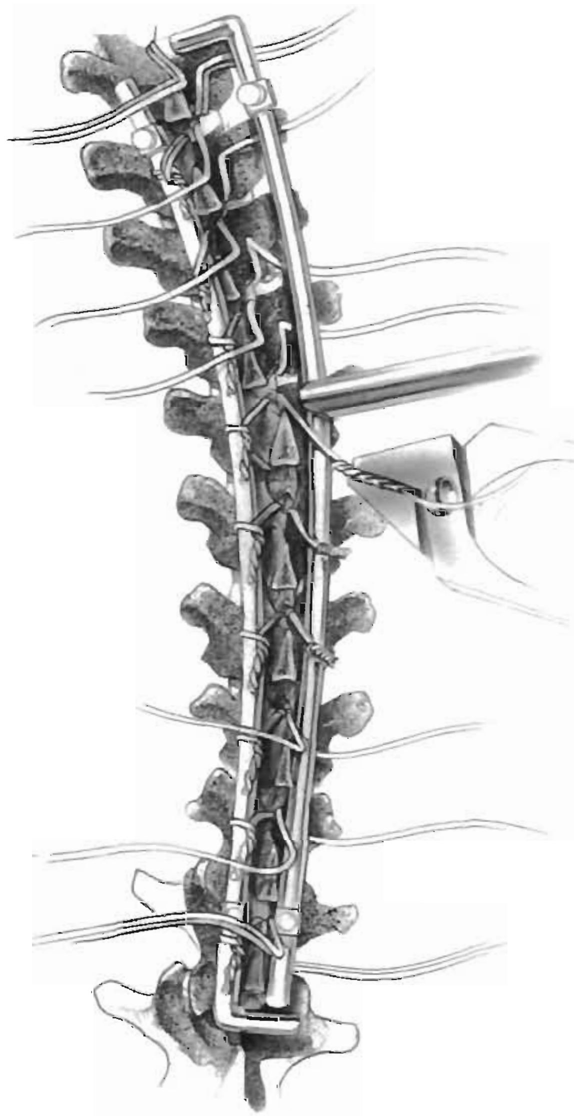


FIGURE 2-37. Two techniques for rod insertion are recommended: convex rod technique and concave rod technique (3). Note how the wires are organized so that the caudal end is lateral and the cranial end is medial to the rod. This helps to push and secure the rod to the base of the spinous process. In the usual paralytic C curve, we use a simpler technique, first wiring in the concave rod completely and then wiring in the convex rod. The principle is to insert the rods and tighten the wires in the manner that most gradually applies force to the spine and thereby corrects the curve. Therefore, the wires tightened first are those in which the rod is already in close contact with the lamina. On the concave side, these are the end wires progressing toward the apex of the curve. On the convex side, the wires at the apex of the curve are tightened first, alternately progressing toward each end.

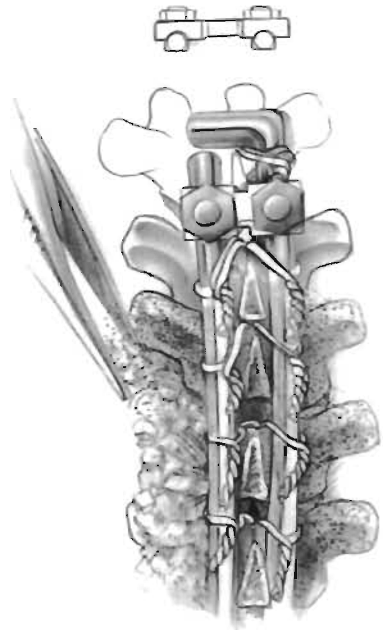
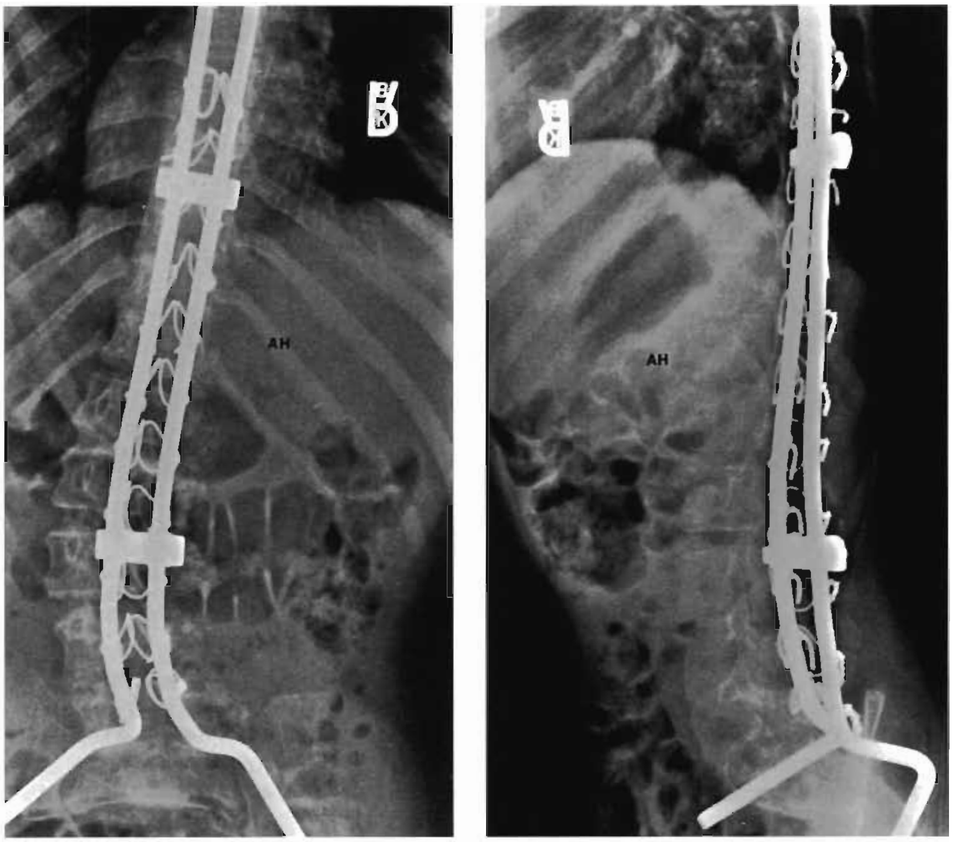


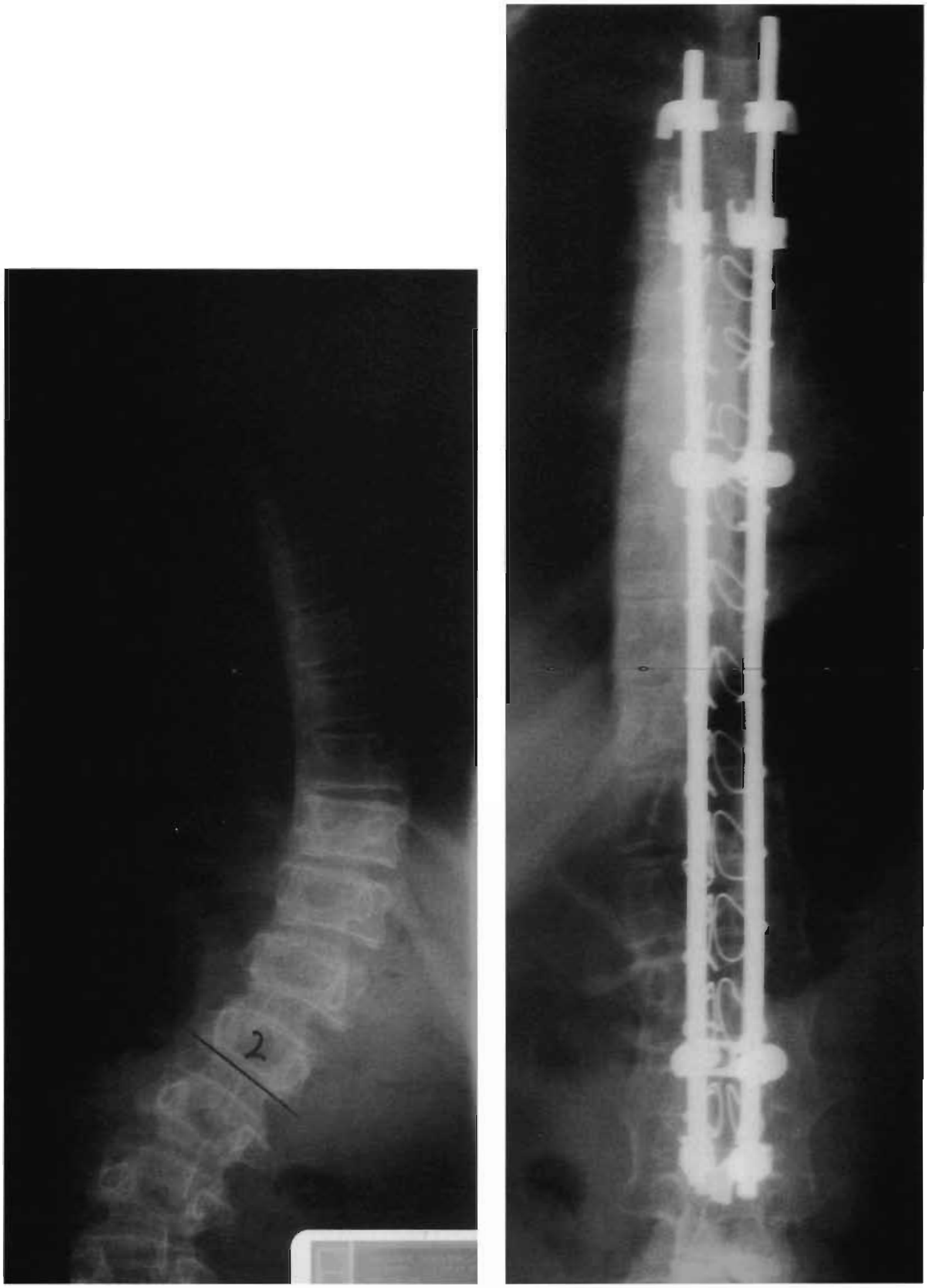
FIGURE 2-38. After all of the wires are tightened and retightened once, they are cut, leaving three to four twists, and bent over the rod. As they are bent, they are twisted in the direction of the twist to prevent their loosening. Two cross-links are secured to the rods. This illustration shows the Texas Scottish Rite cross-link plates secured to the I bolts that were placed on the rod at the time of insertion (see Fig. 2-37), and all of the exposed cortical surface is decorticated. Bone graft is added, and the wound is closed.



A B

FIGURE 2-39. The postoperative anteroposterior **(A)** and lateral **(B)** radiographs of a 12-year-old girl with spastic quadriparesis demonstrate the use of Luque rods with Texas Scottish Rite cross-links and fixation to the pelvis by the Galveston technique. Note the failure of the instrumentation to derotate the lumbar spine, although the lumbar lordosis is well preserved.

The Galveston technique of pelvic fixation illustrated here has largely replaced the original technique described by Luque in which the bent segment of the rod was passed transversely through both tables of the ilium.



A B

FIGURE 2-40. The next evolution of the Luque fixation was to gain further stability of the rods by the use of hooks at the top, bottom, and sometimes neutral vertebra between two curves. **A:** The preoperative sitting radiograph of this 13-year-old boy with spastic quadraparesis demonstrates a typical curve. L5 was parallel with S1, which led to the decision to fuse only to L5. **B, C:** Two years after surgery, the fusion is solid, and the patient has maintained good sitting balance. (*continued*)

C

FIGURE 2-40. *(Continued)*

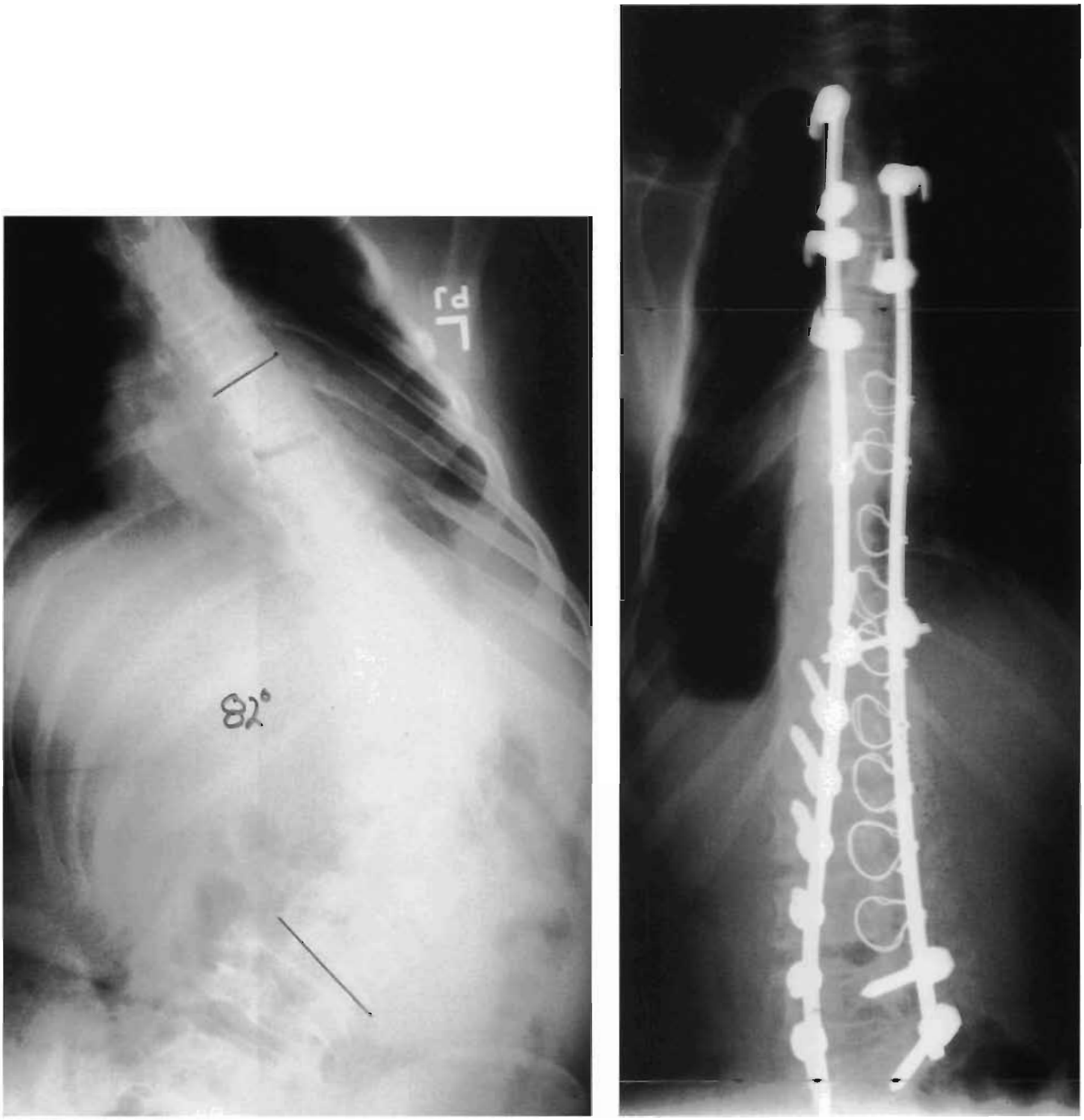
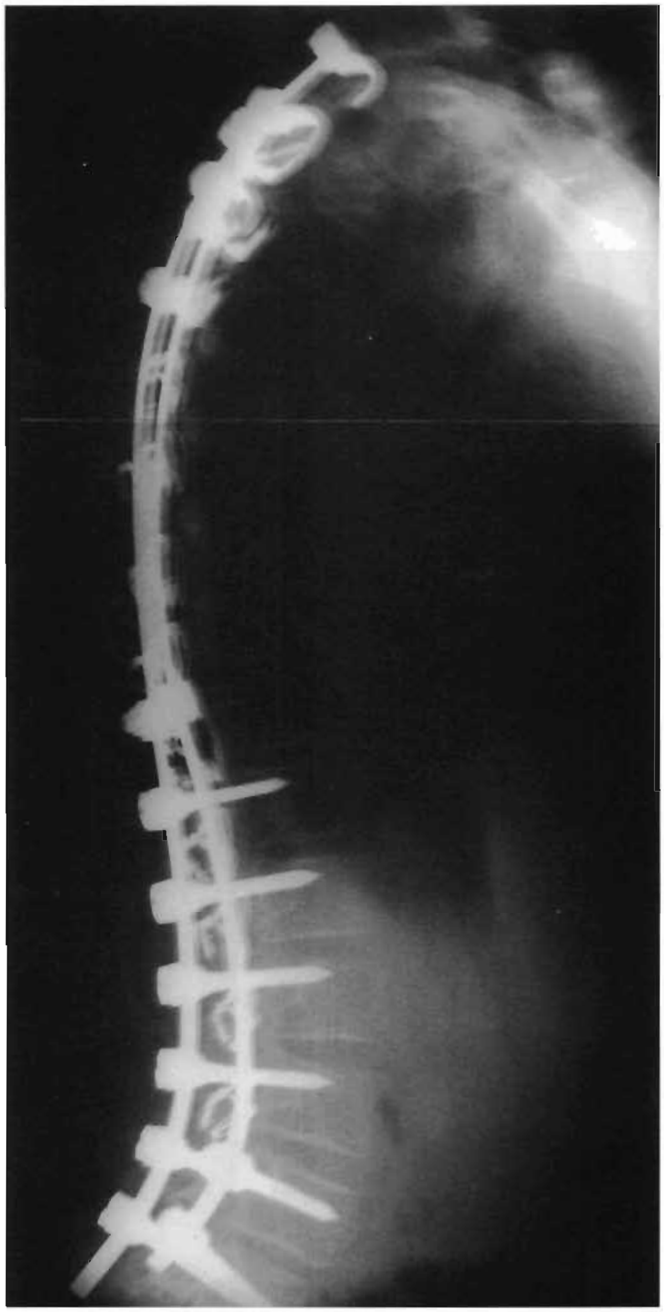


FIGURE 2-41. The use of pedicle screws in the lumbar spine to gain even better control of the deformity is demonstrated. **A:** Preoperative sitting radiograph shows the curve. **B, C:** Radiographs 4 months after surgery. Instrumentation to L5 and fusion to the sacrum were accomplished. The patient has maintained sitting balance at 2 years after surgery. *(continued)*



C

FIGURE 2-41. ***(Continued)***

POSTOPERATIVE CARE

Except in cases of unusually soft bone, no postoperative immobilization is required. Most of the patients in whom this technique is used poorly tolerate casts and orthoses. Early mobilization is possible with most patients, beginning with sitting on the first or second postoperative day. Although parents are often concerned about how they may lift and handle their children after surgery, they can be reassured that no changes in their usual routine are necessary.

References

1. Schultz AB, Hirsch C. Mechanical analysis of techniques for improved correction of idiopathic scoliosis. Clin Orthop 1974;100:66.
2. Wilber G, Thompson GH, Shaffer JW, et al. Postoperative neurological deficits in segmental spinal instrumentation. J Bone Joint Surg [Am] 1984;66:1178.
3. Allen BL, Ferguson RL. The Galveston technique for L rod instrumentation of the scoliotic spine. Spine 1982;7:276.

2.6 GALVESTON PELVIC INSTRUMENTATION

The foremost advantage of this method is the secure fixation it provides in all planes. The rods can be contoured at the operating table and do not require prebending with special instruments or techniques. The main disadvantage is the difficulty in bending the rods to fit properly. This can be overcome in large part by understanding the proper technique and by experience. Both are necessary. A theoretic disadvantage is that the instrumentation extends to an area outside the fusion area. The motion that results is reflected in the loosening evidenced by the "windshield-wiper" effect seen with the original Luque method. This has not proved to be of any clinical consequence (Figs. 2-42 to 2-52).

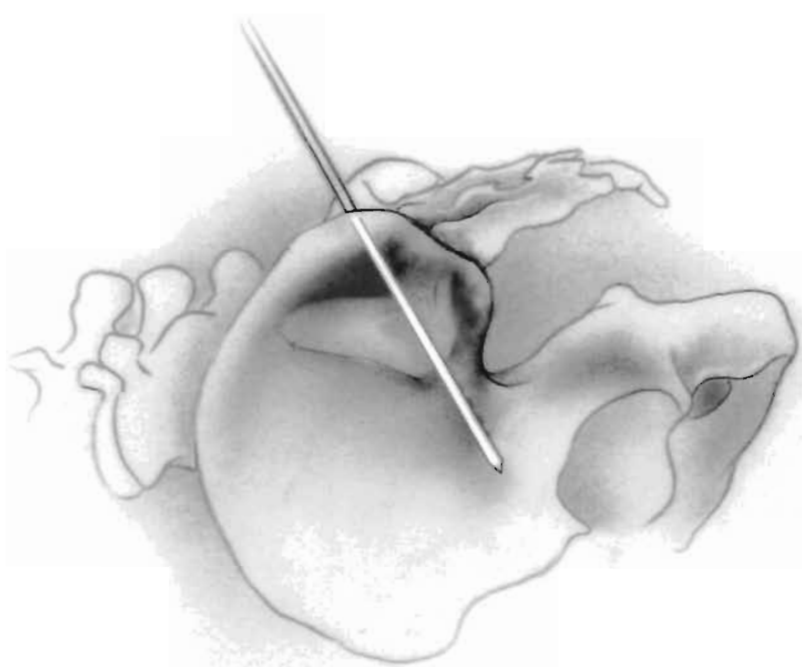


FIGURE 2-42. In the Galveston technique, the segment of the rod that is in the pelvis passes between the two tables of cortical bone in the thickest portion of the ilium, the transverse portion just cephalad to the sciatic notch (1).

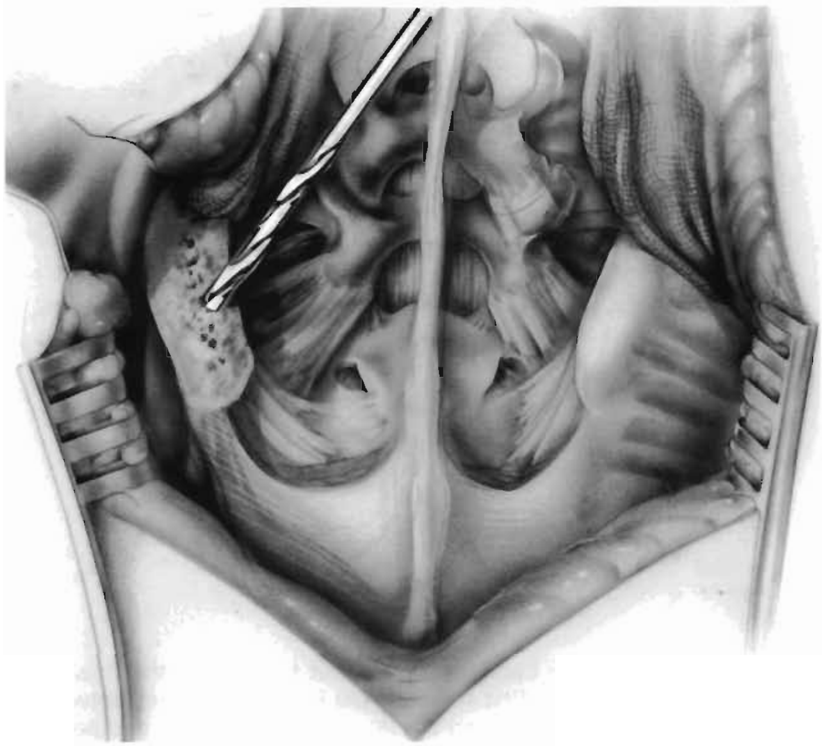


FIGURE 2-43. From the midline incision, both iliac crests are exposed. Unlike the exposure for obtaining a bone graft from a midline incision, this entire dissection is best carried out deep to the paravertebral muscles so that the rod can lie in contact with the bone and be covered with the muscle. Elevation of the muscle is aided by a transverse cut at the caudal extent of the muscle. The periosteum over the posterior crest is incised, and the posterior crest and the outer table of the ilium are exposed. The sciatic notch should be visible because it serves as a guide to the pelvic segment of the rod. The bone graft can be obtained from the more cephalad portion of the ilium, where it will not interfere with the purchase of the rod. In most cases in which this technique is used, however (e.g., paralytic scoliosis), the ilium is very thin, and what little bone is harvested does not make this worthwhile. After the area is exposed, a drill of correct size for the rod is used to drill the path for the rod.

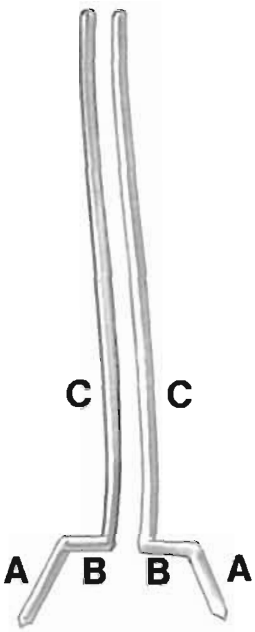


FIGURE 2-44. It will take two bends and one twist to produce the finished rod that consists of three segments. The first segment **(A)** is that which lies between the two cortical tables of the ilium and is called the *iliac segment*. The second part of the rod **(B)** runs from the ilium transversely to the area adjacent to the sacral spinous process and is called the *sacral segment*. The last segment **(C)** is that fixed to the spinal vertebrae and is called the *spinal segment*.

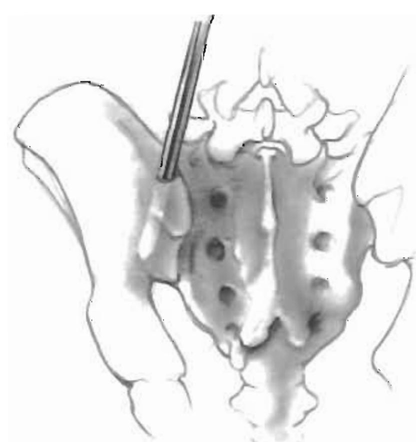


FIGURE 2-45. The hole for the iliac segment is made with a drill. The hole is started slightly cephalad to the posteroinferior iliac spine, and the drill is directed between the two tables of the ilium to pass just cephalad to the sciatic notch. The depth of the hole varies between 6 and 9 cm, depending on the size of the child. If desired, a guide pin can be inserted in this hole to be used with a special jig to aid in bending the correct contours into the rod (see Fig. 2-50). After a little experience, however, it is easier simply to bend the rods and make minor adjustments with the rod in place.

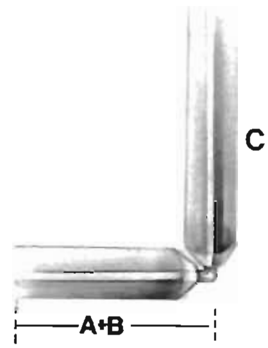


FIGURE 2-46. The depth of the hole should be noted; it is usually about 7 to 8 cm. This is the length of the iliac segment of the rod **(A)**. In addition, the distance from the hole to a point adjacent to the sacral spinous process should be noted. This is usually 2 to 2.5 cm **(B)** and represents the sacral segment of the rod. **C:** The spinal segment of the rod. The rod is now bent with two tube rod benders to place a 60- to 80-degree bend in the rod at a distance from the end of the rod that is equal to the length of both the iliac and the sacral segments of the rod. On the concave side of the curve, the rod fits better if the bend is less (i.e., about 60 degrees). On the convex side, 80 degrees is usually correct.

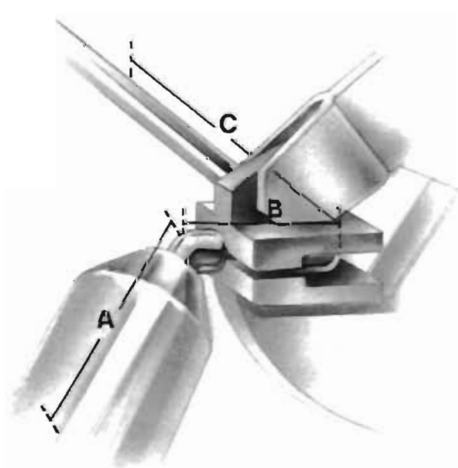


FIGURE 2-47. The next step is to place the bend that separates the iliac segment from the sacral segment. With a tube bender on the iliac section and a rod clamp on the sacral segment, a bend is placed that allows the rod to reach the sacral lamina when the iliac segment is inserted. In calculating the measurement with the bend, it should be remembered that the bend in the rod itself accounts for at least 0.5 cm. In addition, although the technique for bending the opposite rods is identical, the rods will be mirror images of each other.

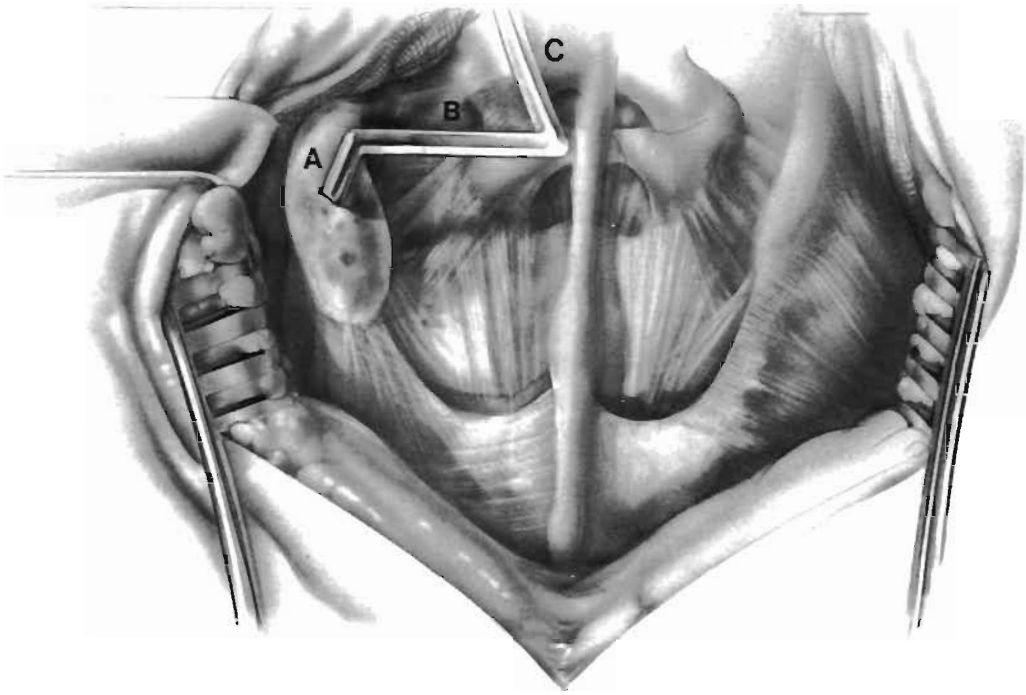


FIGURE 2-48. The three sections of the rod are now formed. At this point, the rod cannot be placed.

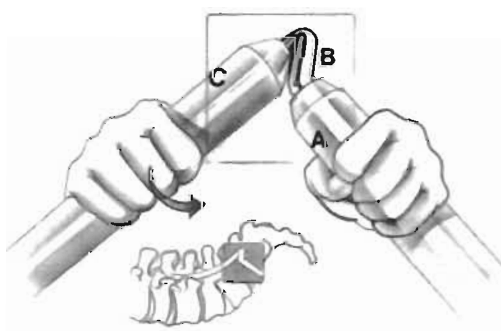


FIGURE 2-49. The last step **(B)** is to place a twist in the rod in the sacral segment. This allows the rod to conform to the sacral inclination. Although this can be done to some extent by bending lordosis into the rod, it is usually difficult to bend in sufficient lordosis close enough to the junction of the sacral and spinal sections to have the rod lie on the sacral lamina. This twist is created by placing a tube rod bender on the spinal **(C)** and iliac **(A)** segments. The benders are brought toward each other. This produces a more ventrally directed spinal section, which conforms better to the sacrum. The amount of twist to be placed must be estimated because the rod cannot be placed at this point.

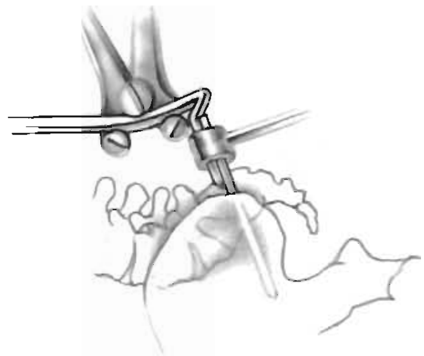


FIGURE 2-50. Finally, the desired spinal contours are bent into the rod. It is best to start with lordosis because it will not be possible to place the rod in the iliac hole and next to the spine until this is done. Although a rod guide can be used with a pelvic guide pin in the iliac hole and the double-rod guide, this technique usually results in a less than perfect fit and, after a short learning curve, is easily omitted.

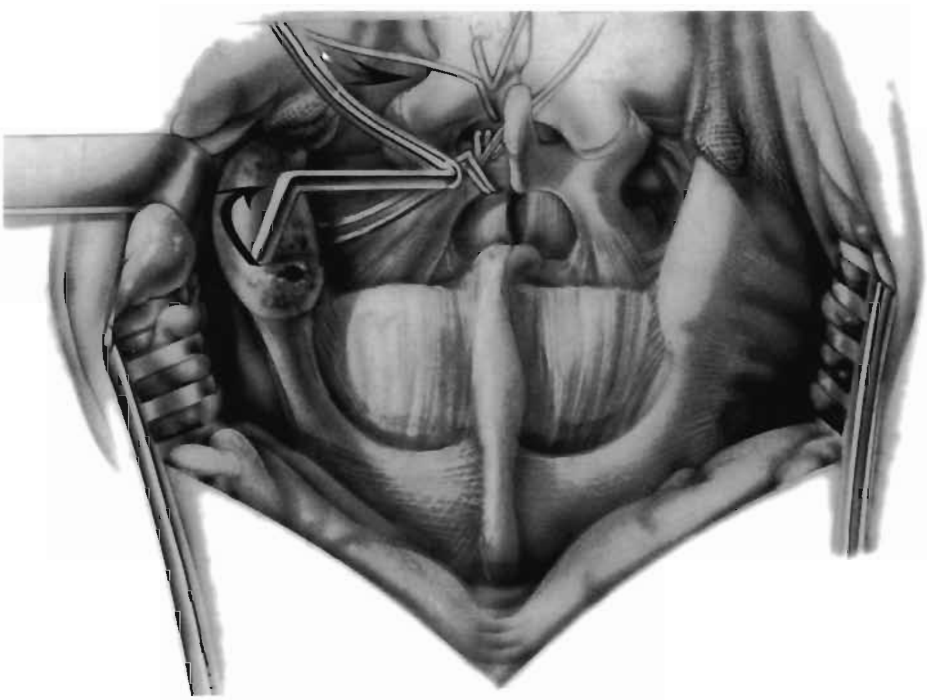


FIGURE 2-51. After the rod is contoured and the proper fit of both rods is ensured, the facet excision, any desired decortication, and passage of the sublaminar wires is completed. The rod can be inserted and wired into place.

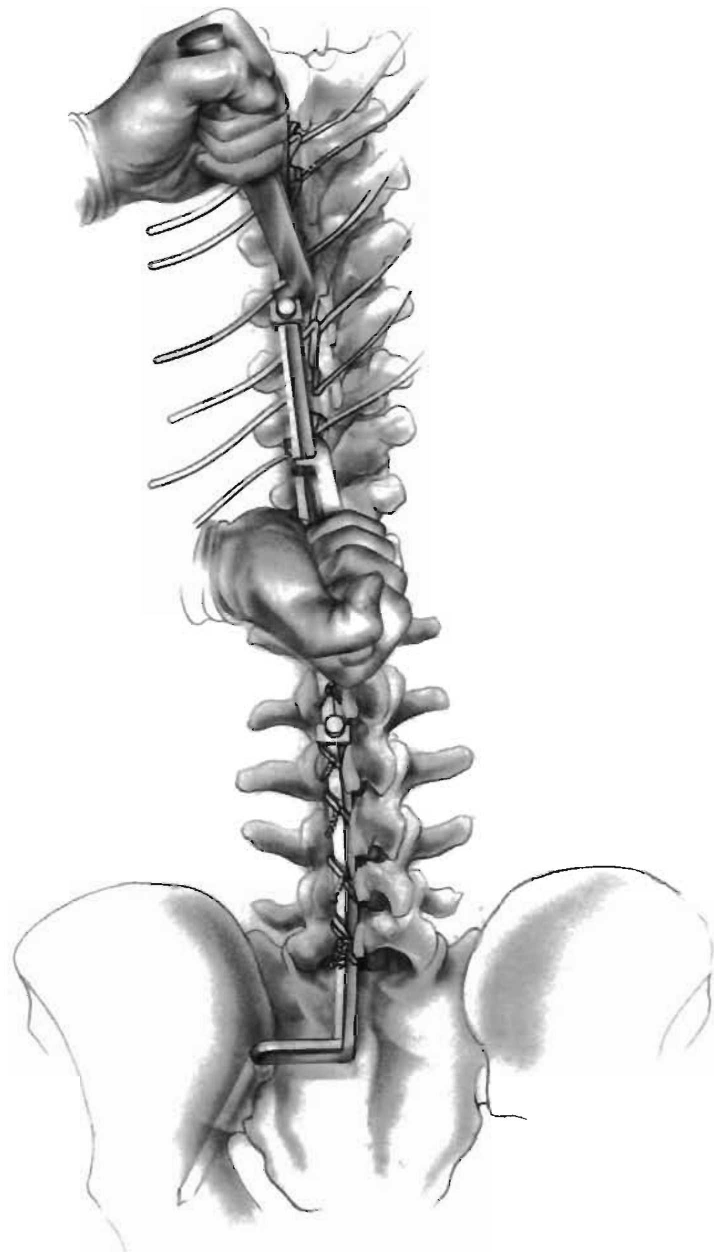


FIGURE 2-52. After the rods are in place, and even after some of the wires have been tightened, it is possible to make adjustments in the spinal segment with a pair of rod benders. The rod benders supplied with the Cotrel-Dubousset instrumentation are ideal because of their slim contours. After the first rod is in place, consideration should be given to placing the second rod. It is likely that after tightening some of the wires on the spinal segment of the first rod, the contour of the spine will have changed. The contour of the spinal segment of the second rod may need to be adjusted. After all adjustments are made, the cross-links are secured.

POSTOPERATIVE CARE

In general, postoperative immobilization is not used. Most of the patients in whom this pelvic fixation is used have spinal deformity because of neuromuscular disease and therefore are not good candidates for immobilization. The fixation is rigid, but the iliac segment becomes loose with time because of the motion between the ilium and the sacrum. It is doubtful that cast immobilization would prevent this motion. When the instrumentation extends to the pelvis, it is generally recommended that family members or caretakers lift the patient under the back and buttocks to avoid undue stress at the lumbosacral junction caused by lack of control of the lower extremities. Six months after surgery, usual activities and handling of the patient can resume.

References

1. Allen BL, Ferguson RL. The Galveston technique for L rod instrumentation of the scoliotic spine. Spine 1982;7:276.

2.7 DUNN-McCARTHY PELVIC FIXATION

An alternative to the Galveston type of pelvic fixation is that described by McCarthy and associates (1). In this technique, the ends of the Luque rods are prebent to fit over the sacral ala in the manner of large alar hooks. This technique may be indicated particularly when the pelvis is very thin or small. It is mechanically at its best in the correction of kyphosis and is contraindicated in lordosis.

The end of the rod that is to fit over the sacral ala must be bent before the operation. The tight bends necessitate that the rods be heated over a flame to soften the metal before bending. Bends of two different dimensions can be made, one at each end of a long Luque rod. The end that fits the least well can be cut off at surgery and discarded. It is necessary that the rods be bent so that they are mirror images of each other (Figs. 2-53 to 2-55).

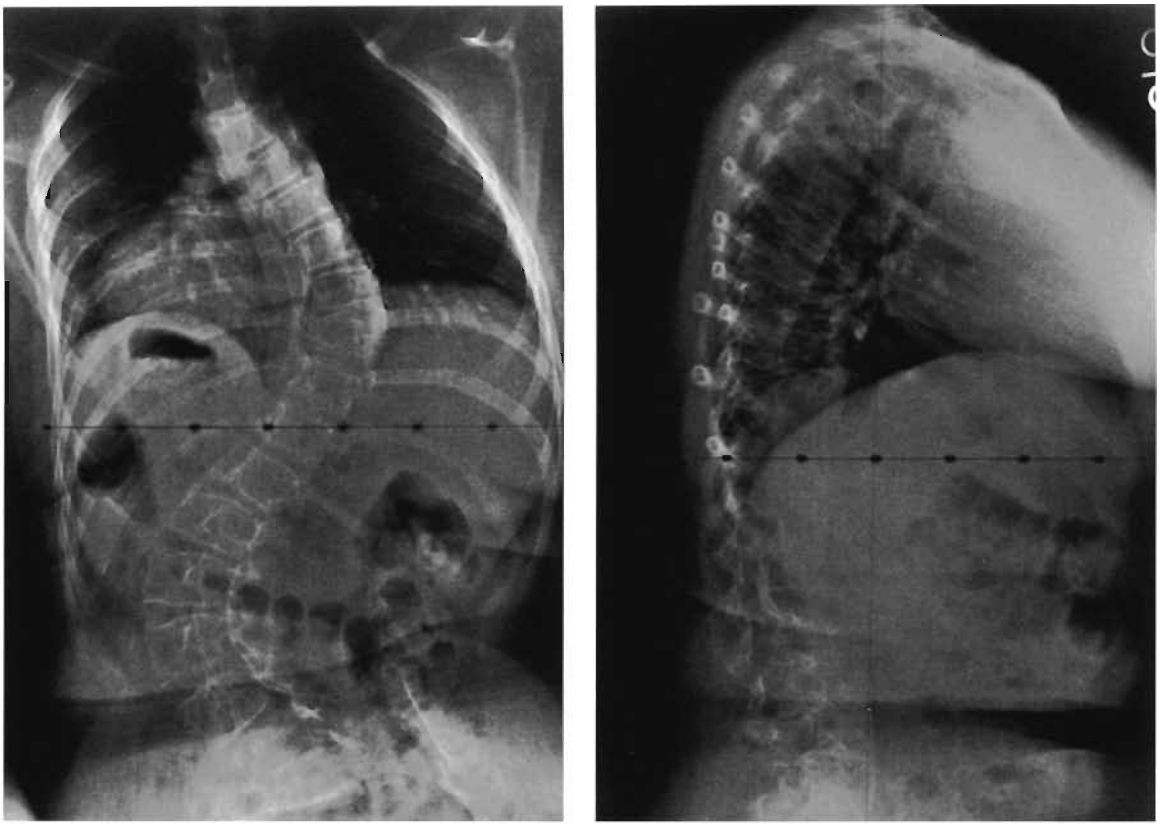

A B

FIGURE 2-53. Measurement from the preoperative radiographs aids in achieving the correct dimensions of the bends. The first consideration is that the midportion of the sacral ala is lateral to the midportion of the lamina. This amount of lateral offset in the rod **(A)** can be estimated by measuring the distance from the midportion of the L5 lamina to the midportion of the sacral ala. In the typical patient, this is about 1 to 1.5 cm. The width of the segment that is to go over the sacral ala **(B)** is measured from the lateral radiograph of the pelvis. This width is also usually between 1 and 1.5 cm. When this procedure is used in the bifid myelodysplastic spine, careful preoperative planning is necessary to be sure that the rod lies in the desired position.

At surgery, the sacral ala is cleaned as it would be for lumbosacral arthrodesis. It is important that the hook portion of the rod pass anterior to the alae, thus necessitating that the dissection be carried out slightly more anterior than usual. Before seating the rod, it should be possible to pass a finger around the front of the alae.

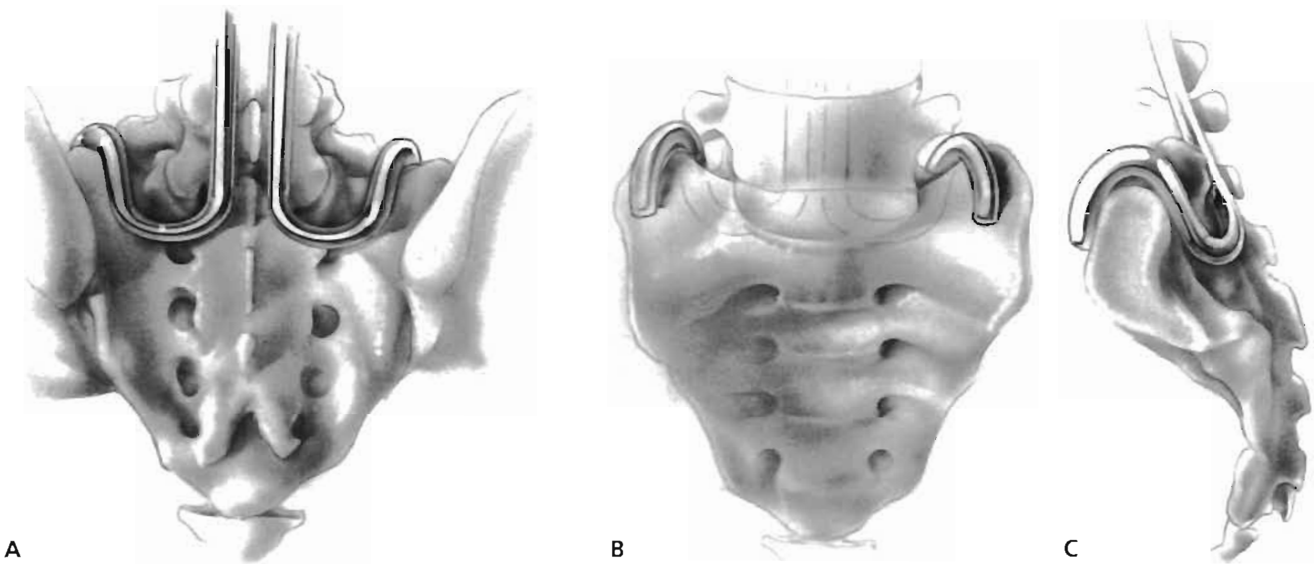
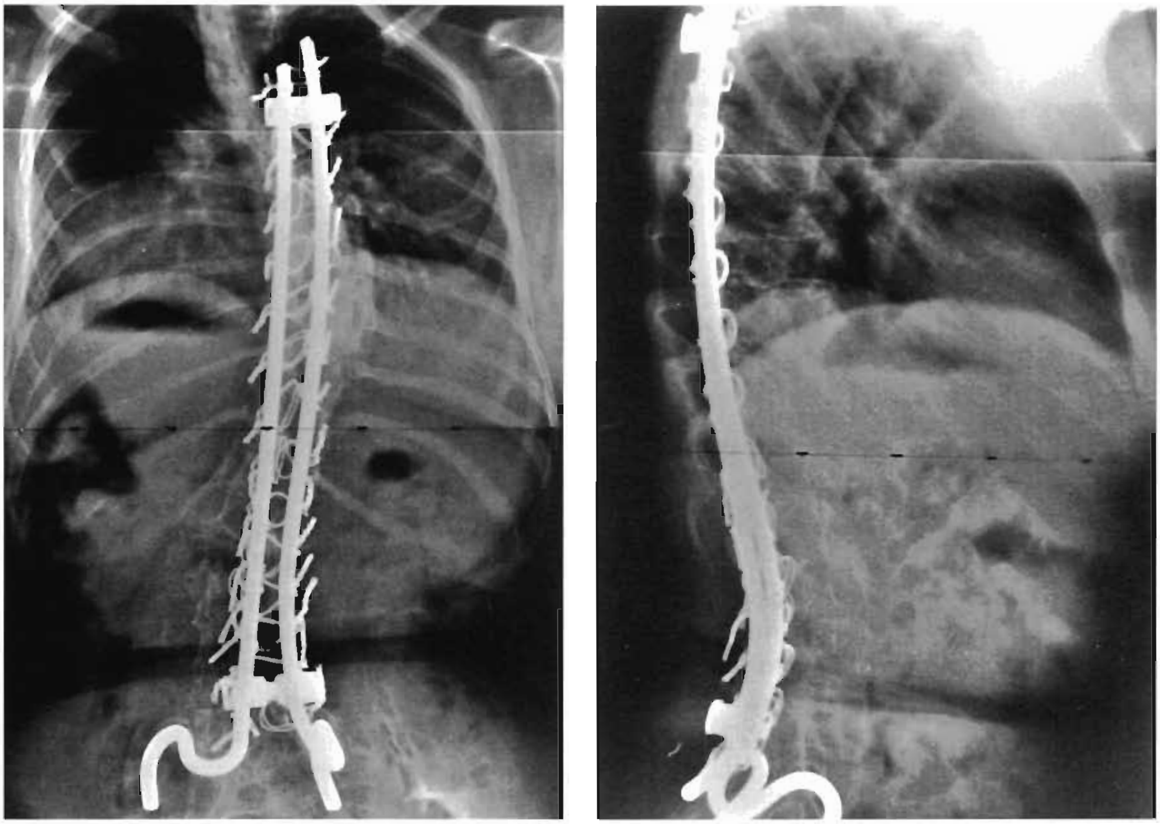


FIGURE 2-54. The prebent portion of the rod is hooked on the ala like a giant sacral hook. It does not penetrate the cortex. It is possible to make minor adjustments to the rods during surgery, but it is not possible to bend all of the necessary curves into the rod in the operating room. Contouring lordosis into the sacral segment of the rod positions it more firmly against the sacral alae. Use of the Texas Scottish Rite cross-links on the spinal segment of the rods prevents movement of one rod in relation to another and provides a rigid construct. The rod is held in place over the sacral alae by the sublaminar wires.



A B

FIGURE 2-55. Anteroposterior **(A)** and lateral **(B)** radiographs after posterior arthrodesis and instrumentation with the Dunn-McCarthy technique. (Courtesy of Richard McCarthy, M.D., Little Rock, AR.)

POSTOPERATIVE CARE

This fixation is as rigid as the Galveston fixation and therefore may or may not require immobilization, depending on the surgeon's choice and the circumstances.

Reference

1. McCarthy RE, Dunn H, McCullough FL. Luque fixation to the sacral ala using the Dunn-McCarthy modification. Spine 1989;14:281.

2.8 SACRAL SCREW FIXATION TO THE SACRUM

Sacral screw fixation is a method of fixation to the sacrum that has its most use in treatment of spondylolisthesis when fixation is required and in the occasional case of scoliosis that requires fixation to the pelvis. The technique may vary a bit depending on the instrument system used, but the point of insertion and the path of the screws are the important parts of the technique.

The screws may be placed at S1 and be directed either medially into the body of the sacrum or laterally into the ala. Additionally, a screw may be started at S2 and directed lateral into the ala. This latter placement is most often used in conjunction with a medially directed S1 screw (Figs. 2-56 to 2-59).

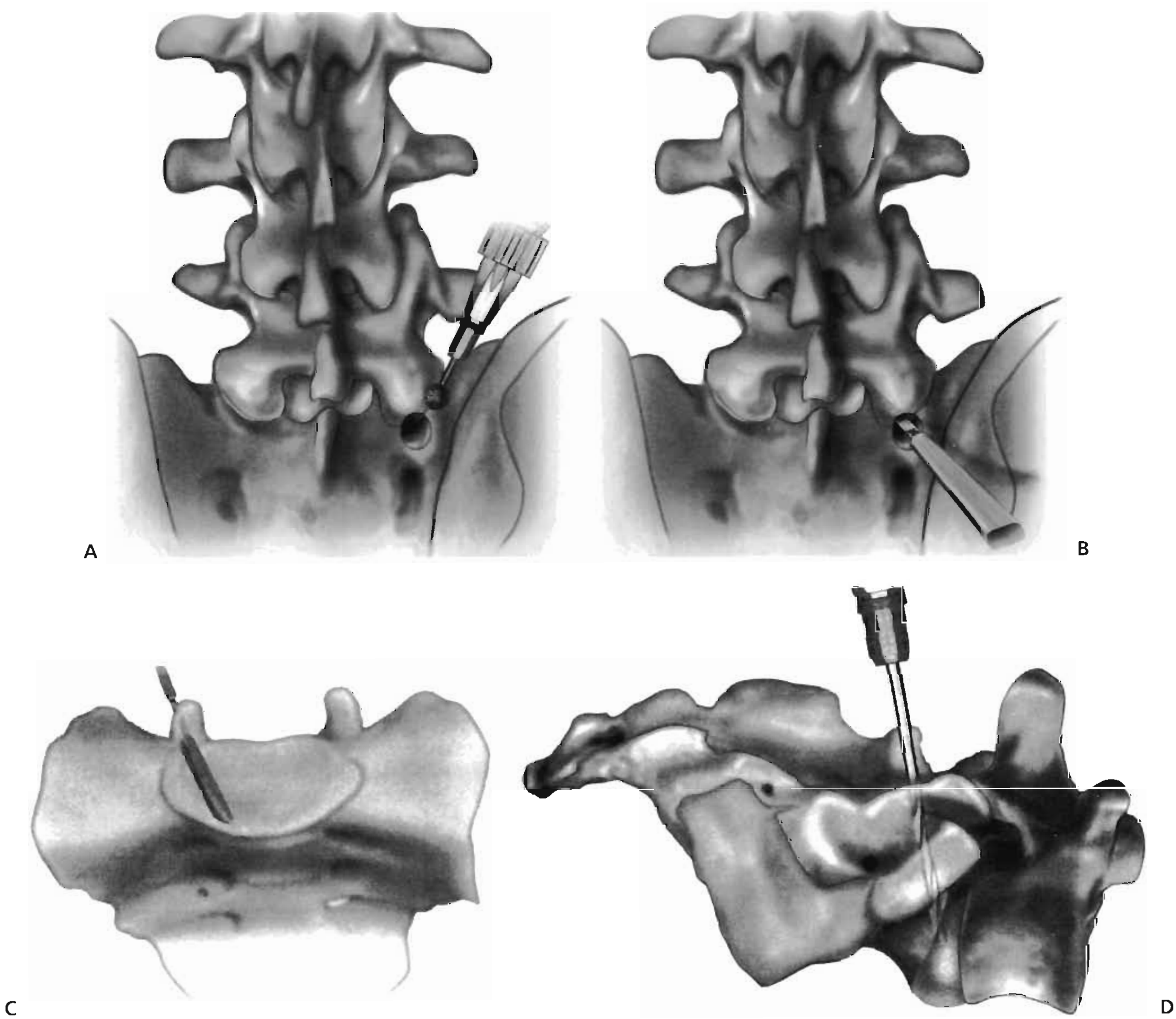


FIGURE 2-56. The S1 pedicle is the largest in the body and thus allows a good deal of variation in the starting point and angle of passage. A good starting point is on the prominence at the base of the S1 facet **(A)**. Use a motorized bur to remove the cortical bone and expose the cancellous bone of the pedicle.

The same probe that is used for the pedicle screws is used to open the path in the S1 pedicle. It is directed about 20 degrees medial to enter the main portion of the sacral body **(B, C)**, and 10 degrees cephalad to aim toward the sacral promontory **(B, D)**. The amount of tilt in the cephalad direction will depend on the position of the sacrum or, more particularly, on the plane of the S1 end plate. It is often best to determine this plane with a lateral radiograph because the angle can vary considerably, depending on the position of the patient, the amount of lordosis, and any deformity.

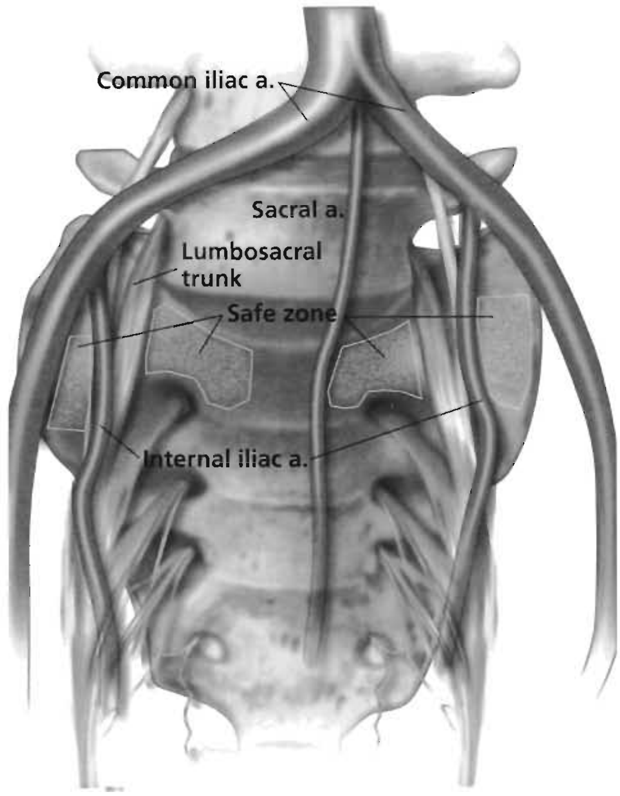
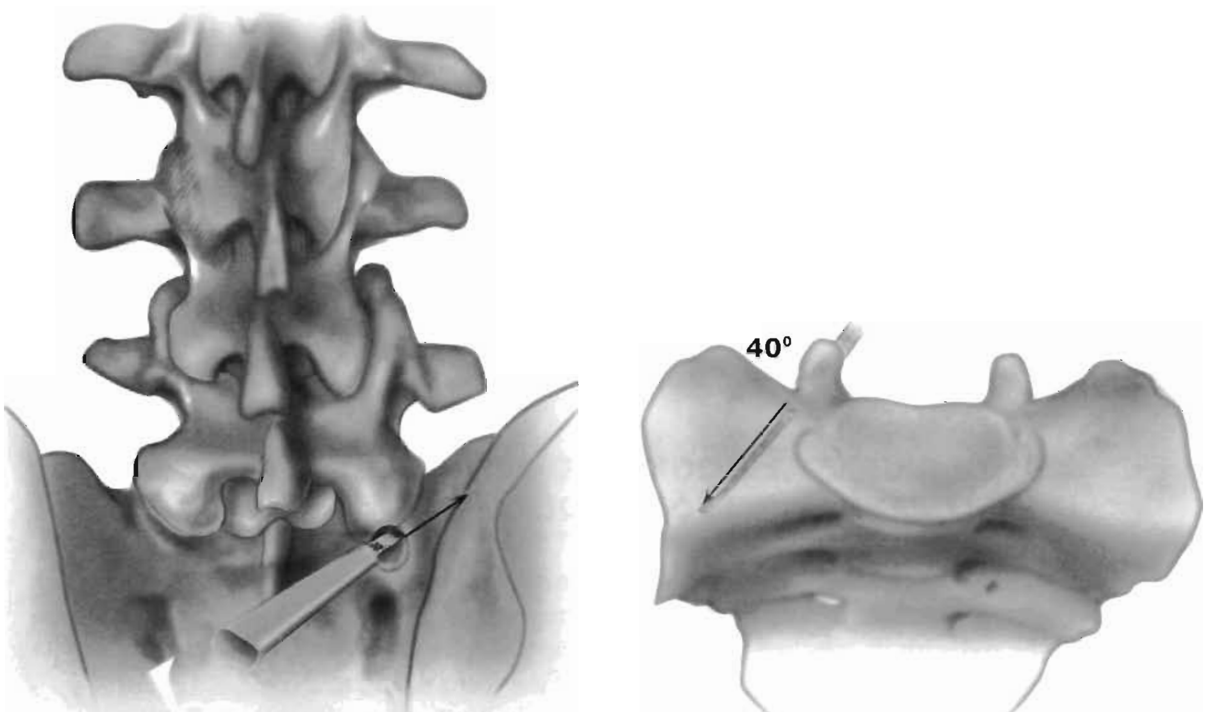


FIGURE 2-57. Because such large forces are placed on sacral fixation, many surgeons prefer bicortical fixation in the sacrum. The medial sacral screw is the only screw that can be safely used for bicortical purchase by penetrating the anterior cortex. This may be achieved in two ways: by crossing the end plate of the S1 vertebra into the disk or by penetrating the anterior cortex of the sacrum in a safe zone.

The path for the screw can be made either with a drill or probe. If bicortical fixation is desired, a drill is started and, when in the cancellous bone, pushed carefully until the anterior sacral cortex is felt. It can then be carefully drilled through the cortex.



A B

FIGURE 2-58. To place an S1 screw in the ala, remove the bone or start the drill on the medial side of the base of the S1 facet **(A)**. Direct the drill about 35 to 40 degrees lateral and parallel to the sacral end plate **(B)**. Advance the drill to the anterior cortex of the ala by carefully pushing it until the cortex is encountered. The length of the screw is then measured with a depth gauge.

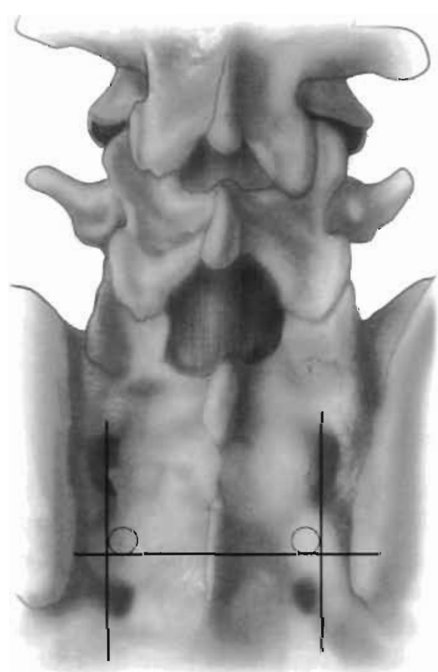


FIGURE 2-59. The starting point for the S2 alar screw is medial to a line connecting the S1 and S2 foramina and about two thirds of the way down from the edge of the S1 foramen to the superior edge of the S2 foramen. This screw is directed about 40 to 45 degrees lateral. Aligning an S1 medial screw with a lateral S2 screw to accept a straight rod takes considerable thought and experience and is not often used.

2.9 SEGMENTAL HOOK AND PEDICLE SCREW INSTRUMENTATION FOR SCOLIOSIS

When the Cotrel-Dubousset spinal instrumentation was introduced in the early 1980s, it presented several new concepts, the most important being that rotation of the rod with its attached hooks rotated the vertebrae and is integral to the correction of the apical vertebral rotation and of the scoliosis and to the restoration of the normal sagittal curves (1). The question of how much rotation is actually corrected, where it occurs, and the role of rotation versus translation or correction of torsion remains a matter of continuing debate (2–7). The concept of scoliosis as a torsional deformity, first described by Perdriolle and Vidal (8) and more recently by Asher and Cook (9), is appealing. It is clear that these and similar methods of spinal fixation produce better correction in both the frontal and sagittal planes.

All of these methods of segmental fixation share common attributes. There are multiple hooks, pedicle screws, and sublaminar wires that can be on the same rod. These can be distracted, compressed, and rotated independently of any other. Two rods can be used and linked together for a stronger and more rigid construct, without the need for postoperative immobilization.

Despite the variations among surgeons (10-16), there are some basic principles that remain constant and have stood the test of time and changing instrumentation. To understand these principles, it is important first to understand the definition and importance of different vertebrae within a curve and the various curve patterns.

DEFINITIONS

The Center Sacral Line

The central sacral line has replaced the "stable zone" described previously by Harrington. As defined by King and colleagues (17), the center sacral line is a vertical line drawn through the center of the sacrum perpendicular to a horizontal line between the top of the iliac crests. It is measured on a standing anteroposterior radiograph, and the iliac crests must be level. If a leg-length discrepancy is present, a lift should be used to balance the pelvis before the radiograph is taken.

The Apical Vertebra

The apical vertebra is determined on the standing anteroposterior radiograph. It is the vertebra that lies at the apex of the curve. It is usually the most horizontal vertebra in the curve, the most rotated and deviated from the center sacral line, and the most wedged. In thoracolumbar and lumbar curves, the apex of the curve actually may be a disk space. In this instance, the vertebra below is termed the apical vertebra.

The End Vertebra

The end vertebrae are identified on the standing anteroposterior radiograph as the most tilted (toward the concavity) vertebra at each end of the curve. They are the sites of the measurements for the Cobb angle. Usually, but not always, the center sacral line passes through these vertebrae.

The Intermediate Vertebrae

This term was introduced with the description of the use of the Cotrel-Dubousset instrumentation and is a useful descriptive term for vertebrae that are important for hook placement. The intermediate vertebrae are determined on the supine maximal right-side or left-side bending radiograph, which is toward the convexity of the curve. These vertebrae are the upper and lower vertebrae of the most rigid segment of the curve. This region is that segment of the spine where the concave apical region disks do not neutralize on side bending radiographs toward the curve convexity.

The bending film toward the concavity determines the mobility in the compensatory curves, which is a factor of considerable importance in the choice of procedure, levels, and hook sites. On the bending films, it should be noted which disk spaces open and close.

Spinal Segments

A spinal segment is two or more adjacent vertebrae. It is an important concept in the current thinking about how to correct spinal deformity. The terminology can be used in two ways. The first is segmental mobility, which is most often used to describe the motion between two adjacent vertebrae. The second is to think of certain areas of the spine as segments.

Junctional Zones

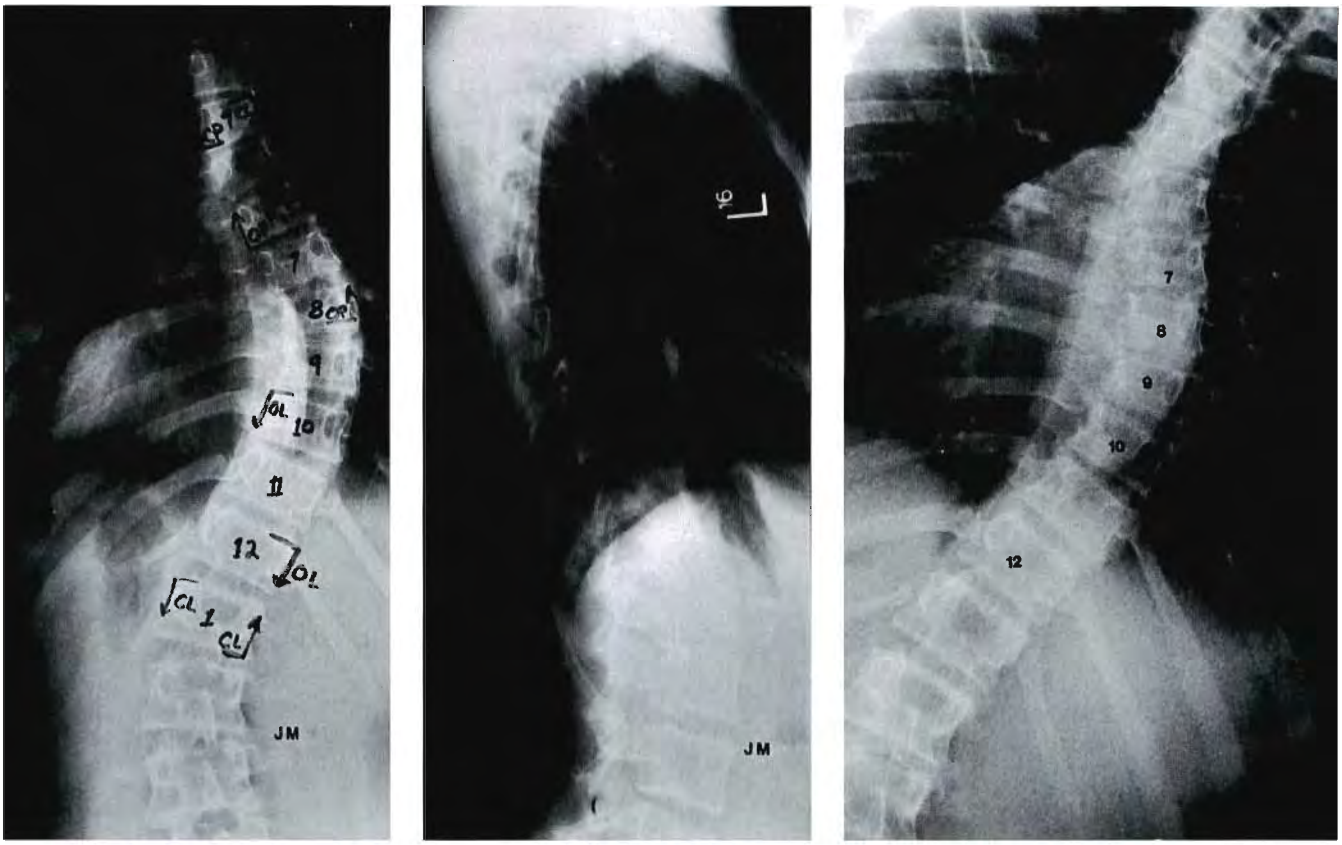
Junctional zones are those areas of transition between one spinal segment and another. The thoracolumbar junction at T12 and L1 is an example. Other examples include the transition between one coronal deformity and another, such as between a right thoracic and left lumbar curve, and the area between the instrumented and uninstrumented segment of the spine (18).

PRINCIPLES OF INSTRUMENTATION

In the planning of the instrumentation, several principles are important.

- The deformity must be considered in all three dimensions: coronal (the scoliosis), axial (the rotation), and sagittal (the alteration of normal lordosis and kyphosis). This is evaluated on upright anteroposterior and lateral radiographs and supine maximum right-side and left-side bending radiographs.
- All vertebrae that are a part of any of the deformities should be instrumented.
- Consideration must be given to the mobility of the segments that will not be included in the instrumentation. Because most curves cannot be corrected completely, the response of these uninstrumented segments after instrumentation of the adjacent segments determines ultimate spinal balance. Two general rules can be derived from these observations: the end vertebra that is instrumented should be intersected by the center sacral line, and the end vertebra should be mobile, with its end plate coming horizontal to the pelvis and its rotation correcting to neutral on the bending radiographs.
- Forces should be applied to open closed disk spaces and close open disk spaces.
- Posterior compression forces produce relative lordosis and tend to correct kyphosis. Compression forces should be applied in the regions of abnormal kyphosis.
- Distraction forces produce relative kyphosis and tend to correct lordosis or hypokyphosis. Distraction should be applied across segments that are in abnormal lordosis.
- In general, the concave side of the spine can be considered to be in relative lordosis and the convex side in relative kyphosis.
- All sagittally abnormal areas must be included in the instrumented area of the spine.
- The distal instrumented level must achieve axial neutralization on bending radiographs.
- Instrumentation should never end on an apical zone in either the coronal or sagittal plane.
- The proximal extent of the instrumentation must extend beyond any high thoracic kyphosis in the sagittal plane and must not cause upper thoracic imbalance in the coronal plane. The structural nature of an upper thoracic curve must be taken into consideration on the posteroanterior and side bending views, to include this area in the instrumentation, when the curve in the T1 or T2 to T5 area is structural.

Considerable controversy exists regarding whether the King rules can be applied to selection of instrumentation levels with the currently used posterior spinal instrumentation systems (Figs. 2-60 to 2-75).



A, B C

FIGURE 2-60. Preparation of the patient and exposure of the spine are the same as for Harrington instrumentation. Preplanning of hook placement is essential, however. This can be marked clearly on the preoperative radiograph **(A)** to guide both the surgeon and the nurse.

Selection of levels for fusion follows many of the principles outlined by King and colleagues (19). Experience has demonstrated, however, one important exception related to selective fusion in the type II curve. The guidelines proposed by King and colleagues (19) frequently have been noted to produce decompensation of the spine to the left when only the right thoracic curve is corrected in a type II curve. There is no universal agreement on the proper selection of the most inferior vertebra to be instrumented when treating a type II curve with Cotrel-Dubousset instrumentation, although the most important consideration is probably the rotation of the lower vertebra. The lower vertebra to be instrumented should rotate into the curve, and the vertebra that begins to rotate into the compensatory curve must not be instrumented.

The use of the instrumentation is demonstrated on a single thoracic curve. The end vertebrae are selected on the criteria of King and colleagues (19). The cephalad end vertebrae **(B)** should extend beyond the hypokyphosis seen on the lateral radiograph. The intermediate vertebrae **(C)**, which define the most rigid spinal segment, are determined on the bending radiograph, and two hooks are placed on either side of this segment. On the convex side of the curve, the end vertebrae are instrumented, as is the apical vertebra.

The lower hook on the convex side of the curve is the most frequent to dislodge. To help secure this, a "claw" configuration, as shown here, can be used to lock it in place securely. Dislodgment is not a problem with pedicle screws.

In the original use of this instrumentation, a claw configuration was recommended at the top of the curve on both sides. There is wide variation in this among surgeons. Although the claw configuration using the transverse process of the most cephalad vertebra and the pedicle of the vertebra below is recommended for the top vertebra on the convex side, some surgeons vary this configuration. This claw can be constructed with the down-going hook on the transverse process or over the superior lamina of the most cephalad vertebra with the up-going pedicle hook on the next caudal vertebra. A simple laminar hook in compression on the top vertebra may also be sufficient at the top on the convex side of the curve.

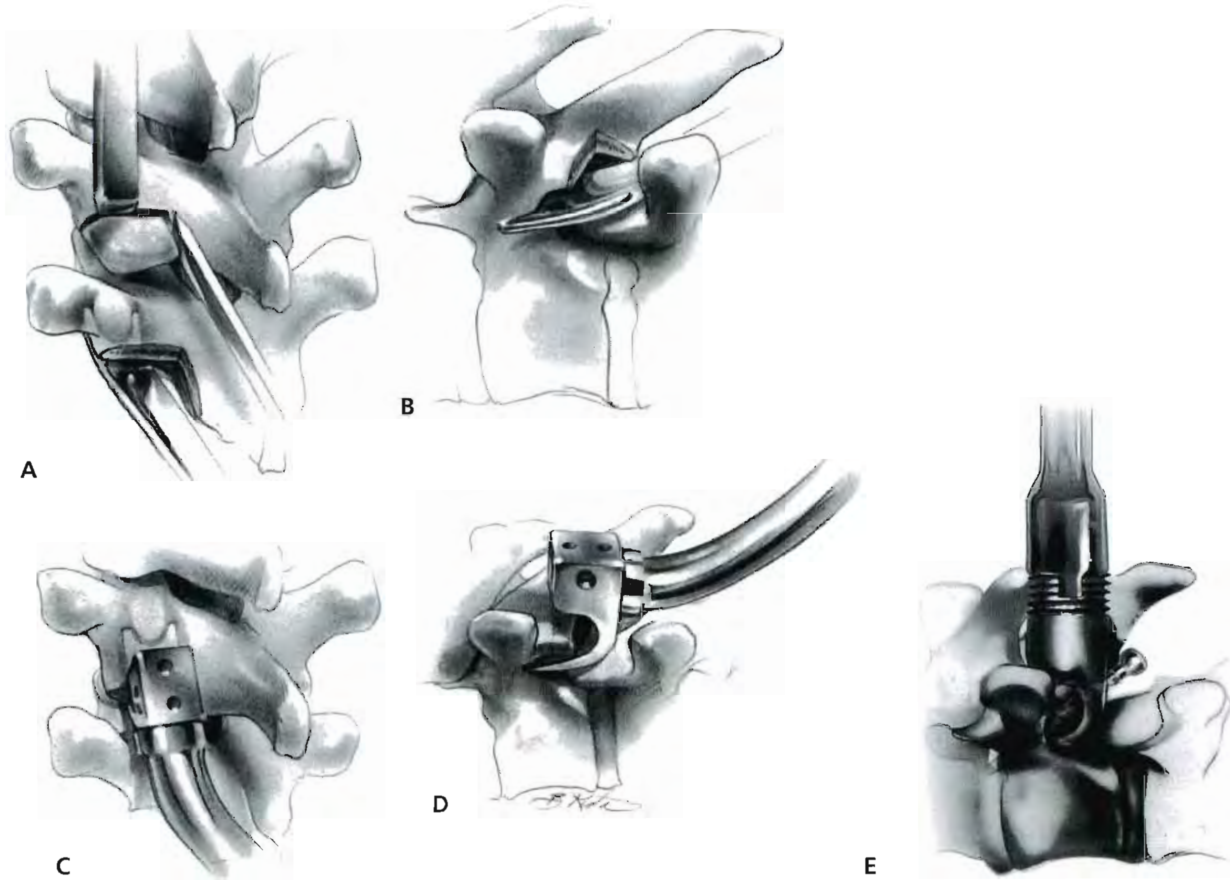


FIGURE 2-61. Pedicle hooks are used only in the thoracic spine and always face cranially. It is necessary to remove a portion of the lamina to allow the hook to extend far enough cranially to engage the pedicle. In addition to being fixed in a semirigid way to the vertebra, the strength is increased over that of the sublaminar hook. The preparation for this hook is essentially the same as illustrated in Figure 2-10 for a sublaminar hook. First, a portion of the lamina is removed **(A)**. Most instrumentation sets that use pedicle hooks come with a tool called the *pedicle finder.* This tool is slid under the lamina to feel for and identify the pedicle **(B)**. This is dangerous unless there is something to prevent the tool from sliding into the canal. As the surgeon pushes cranially, the tool may slip off of the pedicle medial and strike the spinal cord. The pedicle can just as easily and much more safely be identified with the pedicle hook itself. The pedicle lies at the junction of the transverse process and the center of the lamina. For more detail, see Figures 2-64 and 2-65.

With the hook held in a hook holder (not shown) and a pusher, the hook is inserted under the lamina with the same precautions as the sublaminar hook **(C)**. The hook should come to rest against solid bone. It should not come flush against the lamina **(D)**. If it does, either not enough bone has been removed or the hook is medial or lateral to the pedicle. When on bone, the hook is moved side to side. It should move neither medially nor laterally, indicating that it is engaged on the pedicle. The pusher is now struck with a mallet to drive the prongs of the hook into the pedicle, fixing it into place.

The AO spinal system allows for even more rigid fixation of the pedicle hook by use of a screw that passes through a hole in the base of the hook and into the pedicle. The screw is placed with the aid of a jig placed in the hole in the screw. A hole of a predetermined depth is drilled into the pedicle, and the 3.2-mm screw is inserted, locking the hook to the pedicle **(E)**.

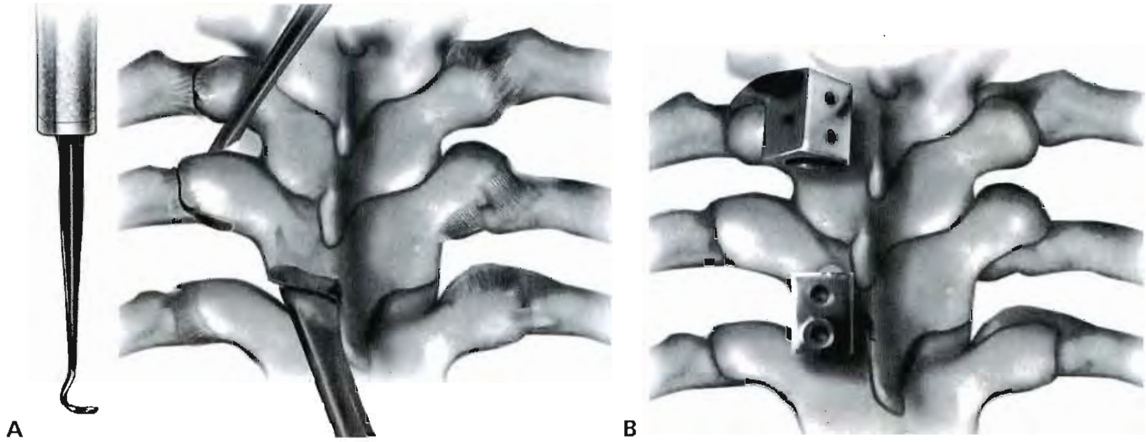


FIGURE 2-62. The classic claw configuration consists of a transverse process hook cephalad and a pedicle hook in the same vertebra or the one below. The transverse process hook is inserted as close to the base of the transverse process as possible. First, the transverse process instrument is used to cut the costotransverse ligaments by passing it between the transverse process and the rib **(A)**. This allows easy seating of the transverse process hook. The final claw configuration is shown in **B**. The transverse process hook can be replaced by a supralaminar hook. On the convex side of the spine in which the top hook will be in compression, a single supralaminar hook may suffice to replace the claw.

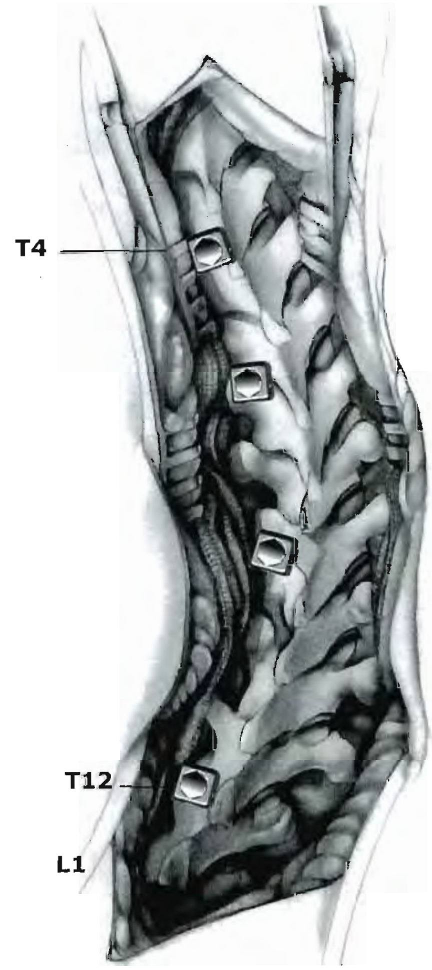


FIGURE 2-63. The hooks have been placed on the intermediate vertebrae on the concave side. Hooks placed in the lumbar region and hooks facing caudally cannot engage the pedicle, and therefore laminar hooks are used in these areas in the same manner as Harrington distraction hooks. Lumbar hooks can be used in the thoracic spine, and vice versa. Their use is dictated by which type of hook fits best. In this regard, it should be observed that a lumbar hook with its deeper blade placed on a small thoracic lamina can be pushed into the canal when the rod is rotated.

It is also possible to use sublaminar wires on the intermediate vertebrae. This technique is usually used with a translating maneuver rather than a rotation maneuver.

Notice that the facets have been excised on both sides and the convex hook sites at T4, T8, T12, and L1 have been prepared. Excision of all of the facets is best done before any correction because it will increase the mobility of the spine. Decortication of the spine is performed on each side before rod insertion on that side. The bone graft should be placed beneath the rod and in each facet.

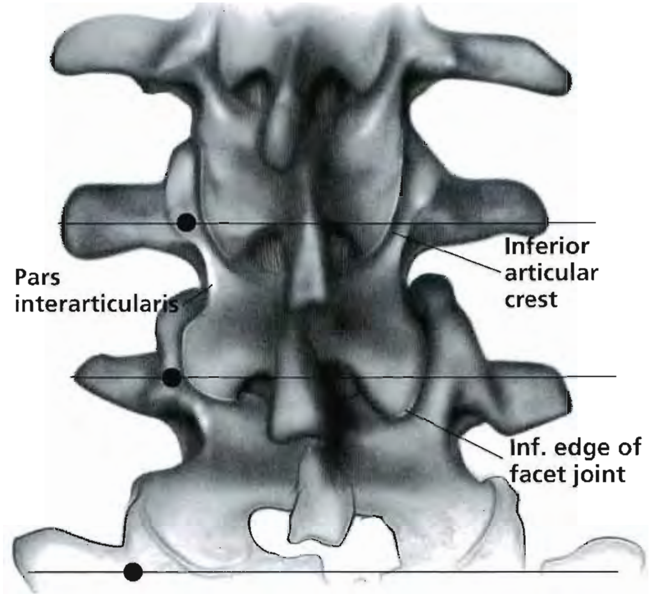


FIGURE 2-64. Most surgeons limit their use of pedicle screws in routine scoliosis surgery to the lumbar vertebrae, T11, or T12. Although there are many variations of the technique to insert pedicle screws, the principles are the same, and the method shown here is but one of many that work. The first task for the surgeon is to identify the point on the posterior surface of the bony spine under which the pedicle lies. The features of the posterior surface anatomy of the lumbar vertebrae are the transverse process, the inferior edge of the superior facet, and the articular crest that extends from this last landmark and represents the area of the pars interarticularis. The pedicle lies beneath the point at the inferior base of the superior articular facet just lateral to the articular crest intersected by a horizontal line that bisects the transverse process.

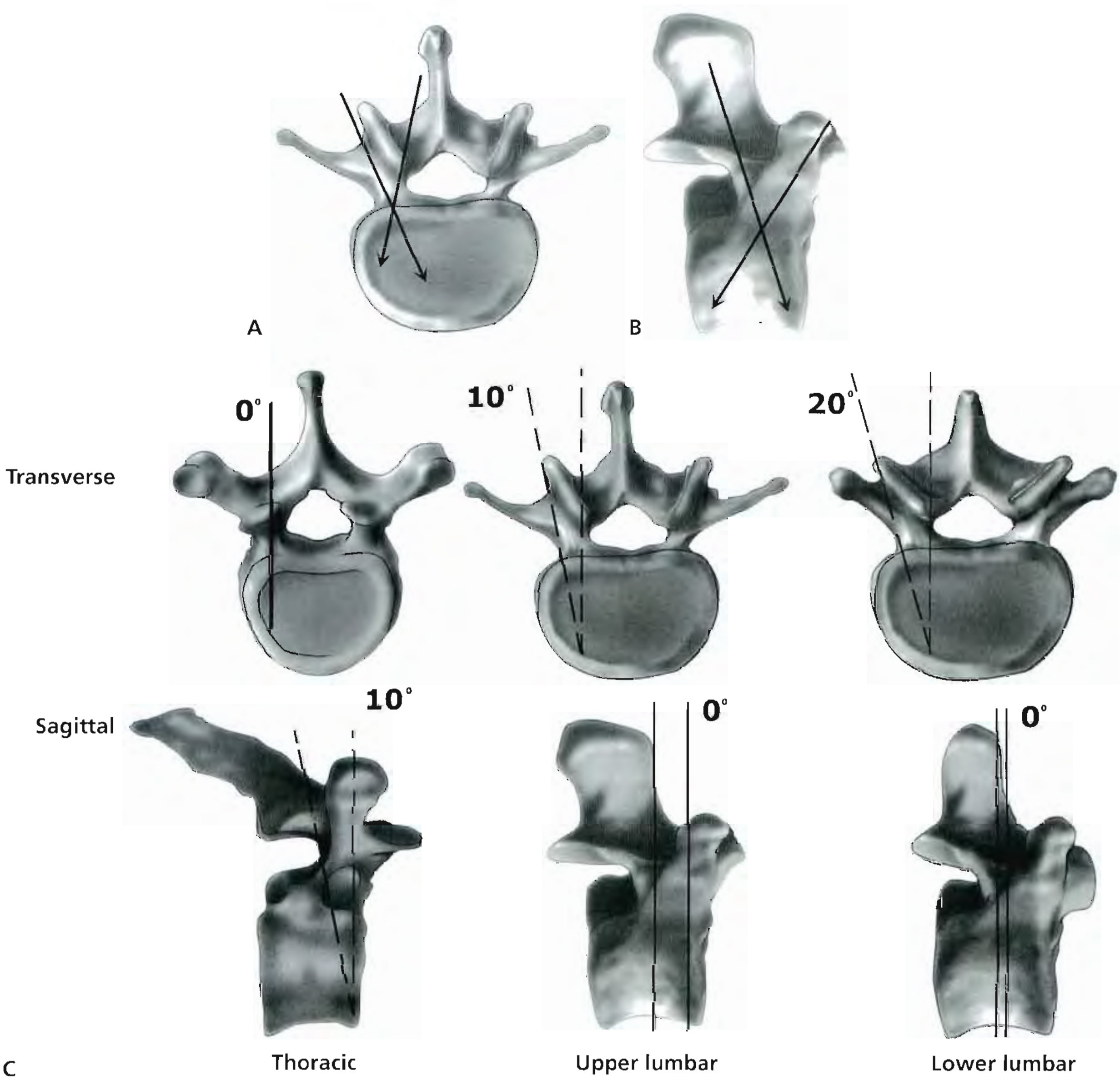


FIGURE 2-65. The second task of the surgeon, having determined the starting point for the pedicle screw, is to decide at what angle it should be directed. It is this task that is the most difficult in dealing with spinal deformity. In addition to understanding the differences in both sagittal and transverse pedicle angles, the surgeon needs to be able to evaluate the alterations produced by the lordosis and rotation in the spine.

Study of the cross-section of the vertebral body demonstrates that there are several points at which a screw may start and still pass within the pedicle, depending on what angle it takes **(A, B)**. This ameliorates to some extent the difficulty posed by the deformity. A more detailed description of the pedicle anatomy and other considerations is given by Zindrick (20).

C: Changes in the angles in both transverse and sagittal planes that the screw needs to follow to remain with in the pedicle of the various vertebra. These are approximations and may vary. More difficult, however, is also to judge the angle of the pedicles with the effects of lordosis and rotation on the vertebra. (Adapted from Zindrick MR. Pedicle screw fixation. In: Weinstein SL, ed. The pediatric spine: principles and practice. New York, Raven, 1994:1683.)

FIGURE 2-66. After identifying the insertion point, a 5-mm power bur is used to remove the cortex and enter the cancellous bone. A rongeur is used to remove the prominent facet. This may be done either before or after the hole is made with the bur. Using a circular motion, the bone at the starting point is removed until cancellous bone is exposed.

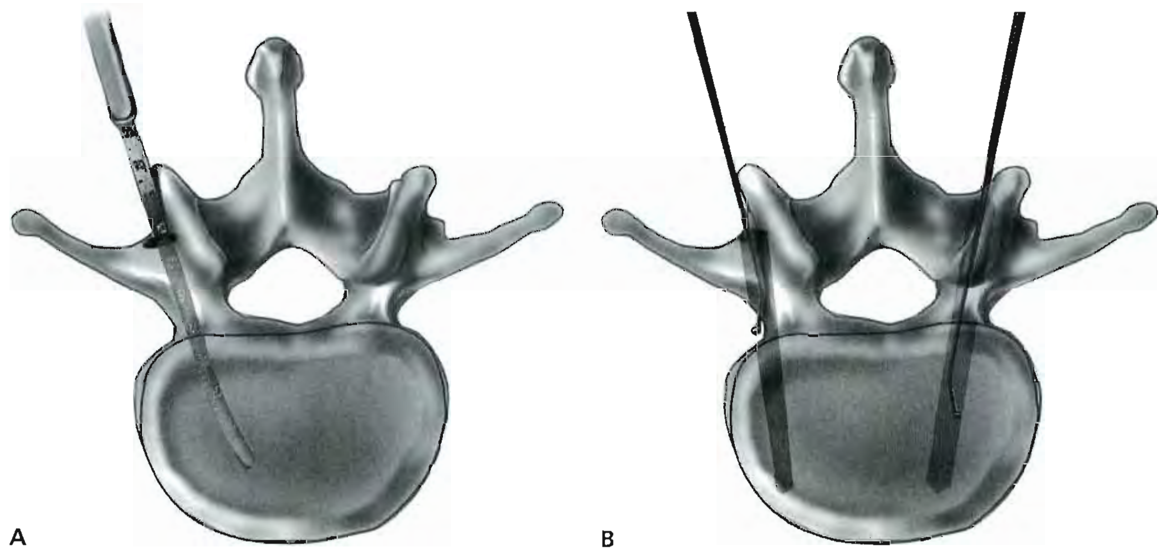
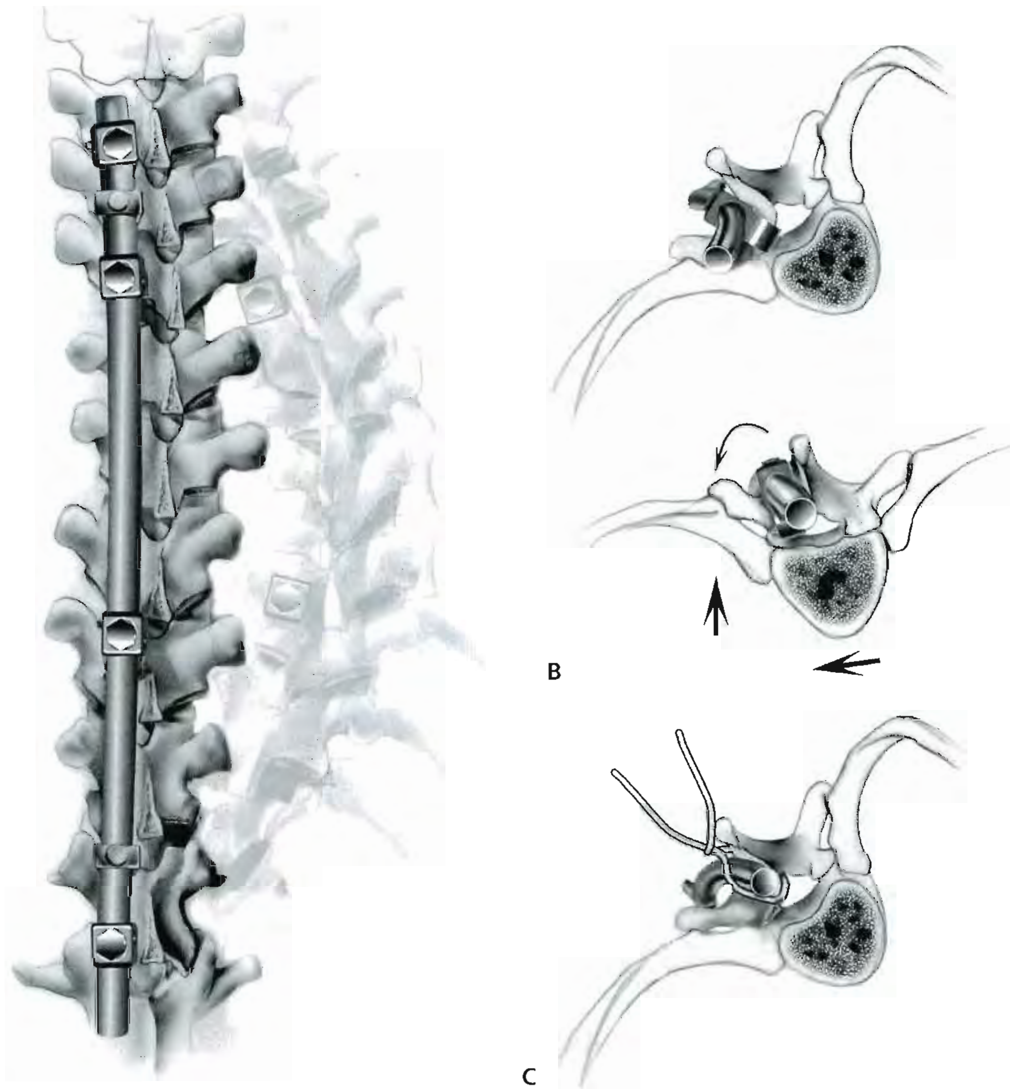


FIGURE 2-67. Next, the blunt probe or pedicle finder is used. This is advanced in the desired direction (correct angle) while twisting it back and forth. The probe should advance relatively easily once started and if in the pedicle. A probe with a flat tip is best because rotating the probe while advancing allows the feel of cancellous bone **(A)**. If significant resistance is met, reconsider either the starting point or, more likely, the angle the probe is following. If the probe breaks through the cortex of the pedicle, passage will suddenly become easy, and the feel of twisting the probe in the cancellous bone will be lost.

When the desired depth is reached or if there is a question about whether the cortex of the pedicle has been breached, the flexible feeler is used. This device has a thin flexible shaft that transmits the feel to the surgeon. It has a small ball tip and a small curve at the end. First, the feeler is inserted to the depth of the probing. If, at the depth of the hole, any sensation other than solid bone is encountered, the feeler has gone through the vertebral cortex. Next, the feeler is used to feel the medial, lateral, superior, and inferior walls of the pedicle. The rough feel of bone should be felt in all locations, indicating that the pedicle is intact **(B)**. If this sensation is not found in all four quadrants, an attempt may be made to redirect the probe.

After the surgeon is satisfied, either the screws or a small Kirschner wire or other marker may be inserted into the holes for radiographic confirmation of proper placement. The anteroposterior view is of little help in determining the medial and lateral placement in the transverse plane, whereas the lateral view clearly shows the screws in relation to the pedicles in the sagittal plane.

FIGURE 2-68. Instrumentation performed without pedicle screws. If pedicle screws were used, the principles would be the same, although there would probably be more points of attachment to the rod. The rod is contoured to conform to the normal sagittal contour of the segment to be fused. In many areas and in many cases, the rod can be rotated to match the contour of the spine. However, this is never the intent, and the rod should never be bent to allow easy insertion of the rod into the hooks. Rather, its contour should be the desired sagittal contour of the spine. As shown here, the rod does not easily fit into the hook at T11. It is necessary to translate the hook and vertebrae to the rod with the instruments provided with the particular fixation being used.



A B C

FIGURE 2-69. The rod on the concave side is now inserted into all of the hooks and screws. The hooks are not tightened on the rod, however, to allow rotation. The rod is grasped with a rod clamp and is rotated to bring it into its desired sagittal alignment. While doing this, careful attention is paid to all of the hooks to be sure they remain firmly seated **(A)**.

As the rod is rotated, its apex moves dorsally and laterally. The vertebrae are also brought laterally, correcting the scoliosis and dorsally correcting the hypokyphosis **(B)**. When the rod is in normal sagittal alignment, compression or distraction, as appropriate, can be done to seat the hooks firmly. There is usually little correction to be gained at this point, however.

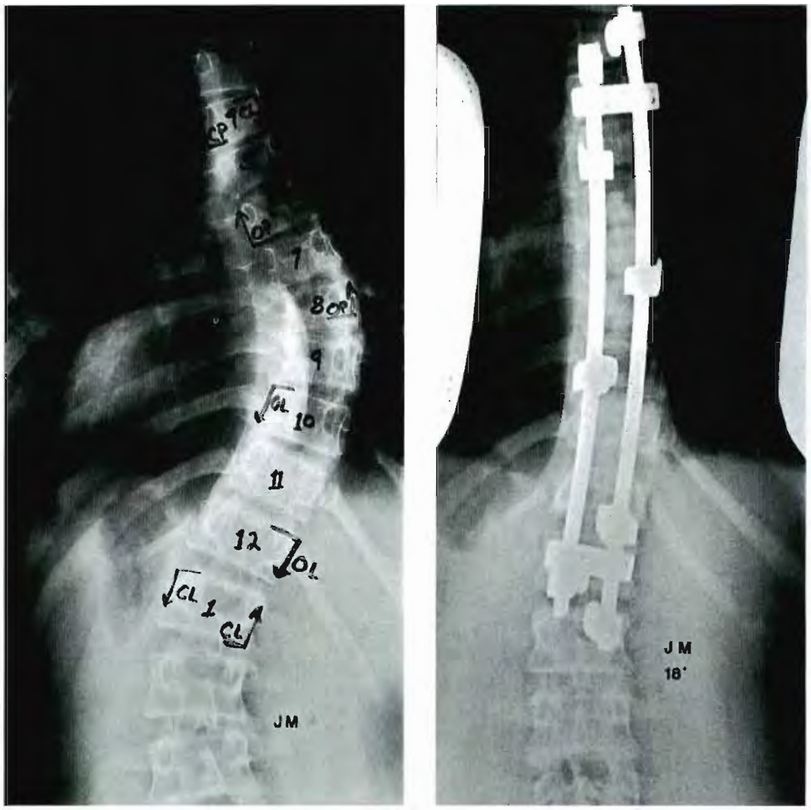
In the translation maneuver, using sublaminar wires as shown here **(C)**, the rod is inserted in the top and bottom hooks or screws and is aligned in the correct sagittal plane. The wires are then tightened, bringing the intermediate vertebrae of the curve laterally to correct the scoliosis and dorsally to correct the hypokyphosis. Before the rods are completely tightened, the second rod is inserted and the cross-links applied. This will give additional rigidity to the concave rod, and the wires can be further tightened.

A B

FIGURE 2-70. The convex rod is then inserted in a similar manner to the concave rod **(A)**. It is recommended that the central portion of this rod be contoured flat so that when it is rotated, the flat portion will tend to push down on the rotated vertebrae, producing further correction. We have observed that little if any additional correction is gained with this rod in the usual curve. It does, however, provide additional rigidity by adding compression and allowing a rigid frame to be constructed. The most cephalad hook is tightened first. The apical hook then is compressed against it and tightened. The most caudal hook is then compressed and tightened.

Often, there is an insufficient amount of the rod protruding beyond the inferior hook for a rod clamp and spreader to be used. In this case **(B)**, a rod holder cephalad to the hook and the hook compression device can be used. Finally, the hook on T12 is compressed against the hook on T1 and tightened, producing the claw configuration. Care should be taken to secure the most inferior hook, which has a tendency to dislodge. This can be done by deeply notching the lamina so that the hook is well seated, compressing it securely, and as illustrated in this case, using a claw configuration with an additional hook on T12.

The final stage is to secure the cross-links. These are necessary to provide torsional stiffness (13). The rods may be pushed apart with a spreader or drawn closer together with a compression clamp if they do not fit exactly. Regardless of the length of the rods, two cross-links provide sufficient rigidity, and if pedicle screws are used on both side, one cross-link may be all that is necessary.



A B

C

FIGURE 2-71. A single thoracic curve treated with all hooks. Note the substitution of a supralaminar hook on the convex side top vertebrae instead of the claw and the use of two pedicle hooks without the claw configuration on the concave side top. **A:** Preoperative radiograph with the instrumentation marked. **B, C:** Results 1 year after surgery.

FIGURE 2-72. Example of single thoracic curve treated with a claw at the top of the curve on both sides, pedicle screws at the bottom on both sides, and sublaminar wires to translate the intermediate vertebrae. **A:** The preoperative film with the instrumentation marked. **B, C:** Anteroposterior and lateral radiographs 2 years after arthrodesis show good correction of the curve and restoration of the normal sagittal contour of the spine. (*continued*)

C

FIGURE 2-72. ***(Continued)***

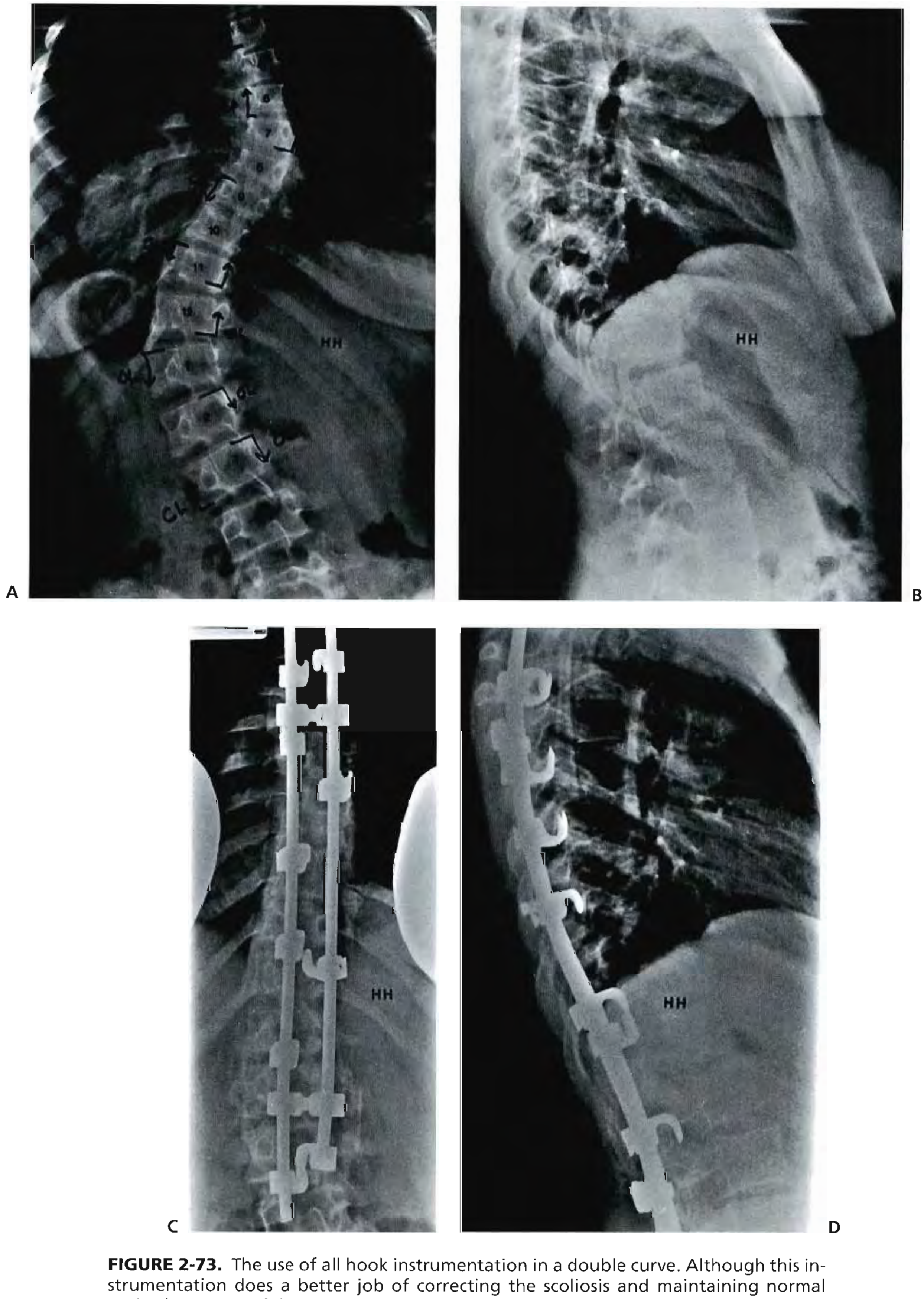


FIGURE 2-73. The use of all hook instrumentation in a double curve. Although this instrumentation does a better job of correcting the scoliosis and maintaining normal sagittal contours of the spine than other methods using the Harrington rod, it does not correct the lumbar scoliosis as well as the thoracic scoliosis in many cases. This is because the hooks do not have the rigid purchase on the lumbar lamina that the pedicle hooks give on the thoracic lamina.

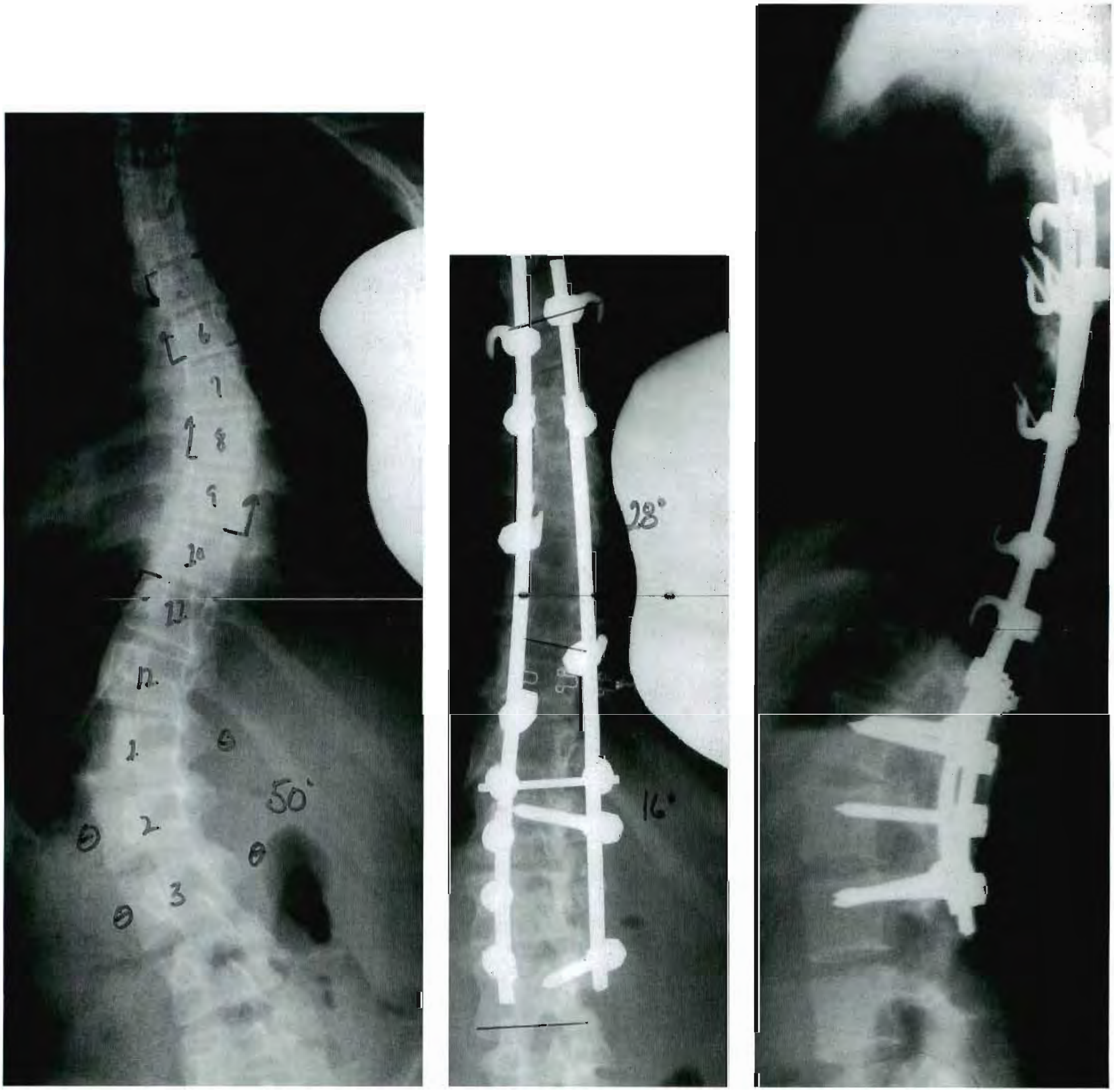
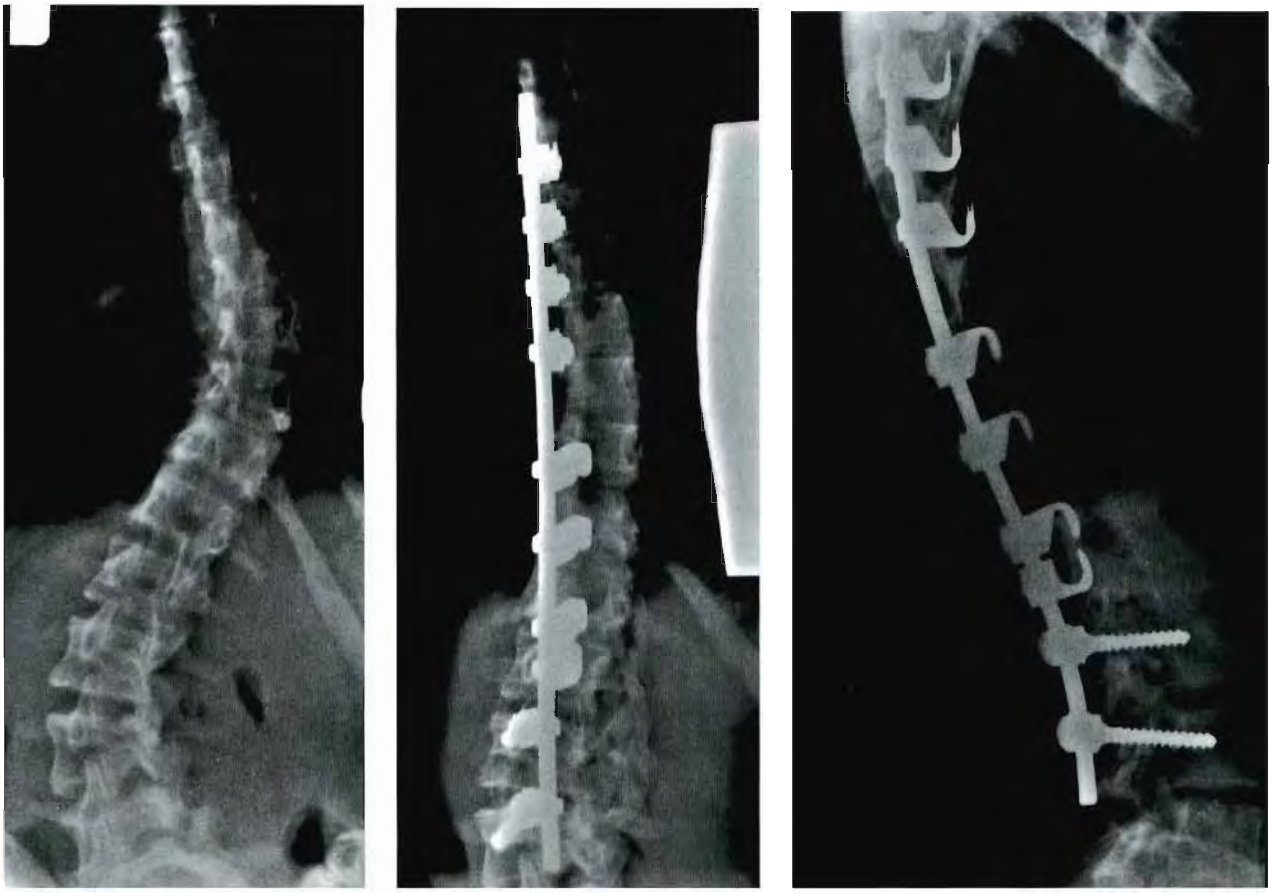


FIGURE 2-74. Radiographs of a double curve treated with hooks in the thoracic spine and pedicle screws in the lumbar spine. The correction of the curves was gained by rotating the rod on the right side of the spine after it was seated in all of the hooks and screws.



A B, C

FIGURE 2-75. A technique that has fallen out of favor because of rod blockage and pseudarthrosis is the single rod technique. This technique was based on the observation that the sacral rod does not provide additional correction. **A:** The preoperative radiograph of a double curve. **B, C:** The postoperative anteroposterior and lateral views using a single rod.

POSTOPERATIVE CARE

The rigidity of the fixation is such that no special considerations need to be given in the immediate postoperative period to the movement or positioning of the patient. Patients are mobilized according to the surgeon's wishes. It is feasible to have the patient stand on the first day after operative, ambulate on the second day, and be ready for discharge on the third or fourth day. Many choose to go slower. No postoperative immobilization is used. Patients are usually ready to attend school in 2 to 3 weeks after the surgery. Patients are restricted from all strenuous and sporting activities for 6 to 9 months. Patients are seen at 1, 3, and 6 months and at 9 to 12 months after surgery with radiographic assessment. After this period, follow-up is continued on a yearly basis.

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2.10 THORACOPLASTY

Spinal rotation and secondary rib prominence in the thoracic and thoracolumbar region and paraspinous muscle prominence in the lumbar region are often the main concerns of patients and parents. There is no direct correlation between rib prominence and curve magnitude. Over the years, little attention has been paid to the residual rib prominence in patients with scoliosis. Despite the advent of derotation systems and segmental fixation, residual rib prominence, sometimes associated with pain, is often the major complaint of patients after surgical correction for scoliosis.

Clinical indications for thoracoplasty (1–9) include a sharp angular rib deformity, a rib deformity of 3.5 cm or a rigid deformity, or a preoperative rib angle on radiograph and clinical examination of greater than 15 degrees. The retrieved ribs can be used for bone graft, obviating the need for an iliac crest bone harvest.

Surgically treated patients often desire to have a rib resection after surgery for large residual thoracic prominences and for prominences that cause pain or that are frequently traumatized when sitting. In adults, curvatures are generally rigid, and cosmetic results are best achieved when the surgical correction is accompanied by thoracoplasty.

A good idea of how the rib deformity will correct with surgical correction of the curve alone can be formed by having the patient (e.g., with a right thoracic curve) in the Adams forward bend position laterally flex to the right side. Reduction of the rib prominence indicates flexibility of the curvature as well as flexibility of the thoracic prominence; hence, this type of patient would probably not require a thoracoplasty.

Patient and parent expectations about the results of thoracoplasty must be realistic. Patients undergoing thoracoplasty have diminished pulmonary function postoperatively for an extended period of time. In addition, it is important to discuss the elements of the patient's deformity with the patient and the parents preoperatively because some of the deformity may be the result of prominence of the transverse processes as a result of marked rotation of the spine. In situations such as these, mere removal of the offending ribs does not entirely alleviate the deformity. In addition, in young patients, the ribs grow back, and they may grow back in a somewhat deformed shape.

Thoracoplasty can be accomplished before or after surgical correction of the curvature. Authorities recommending correction before the surgery argue that blood loss is less at this point in the operative procedure (2). During the correction of spinal deformity, however, many surgeons use manual pressure on the apical ribs to help bring the apex of the curvature into close proximity to the spinal instrumentation. Performing a thoracoplasty beforehand obviously precludes use of the ribs as an adjunct to correction of the spine (Figs. 2-76 to 2-84).

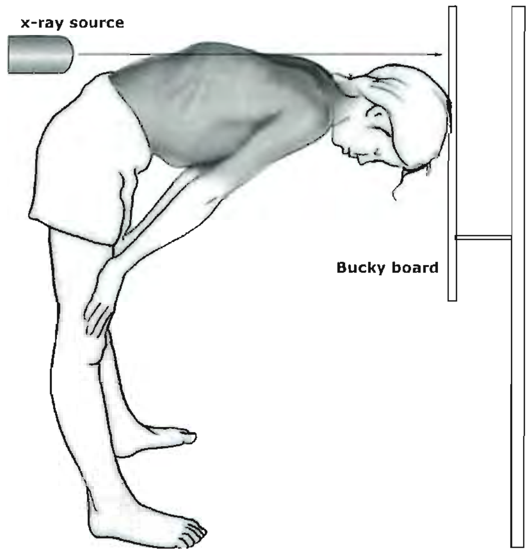


FIGURE 2-76. The rib deformity in scoliosis is best quantitated by a rib prominence radiograph. Additional studies, such as computed tomography scans, are rarely necessary.

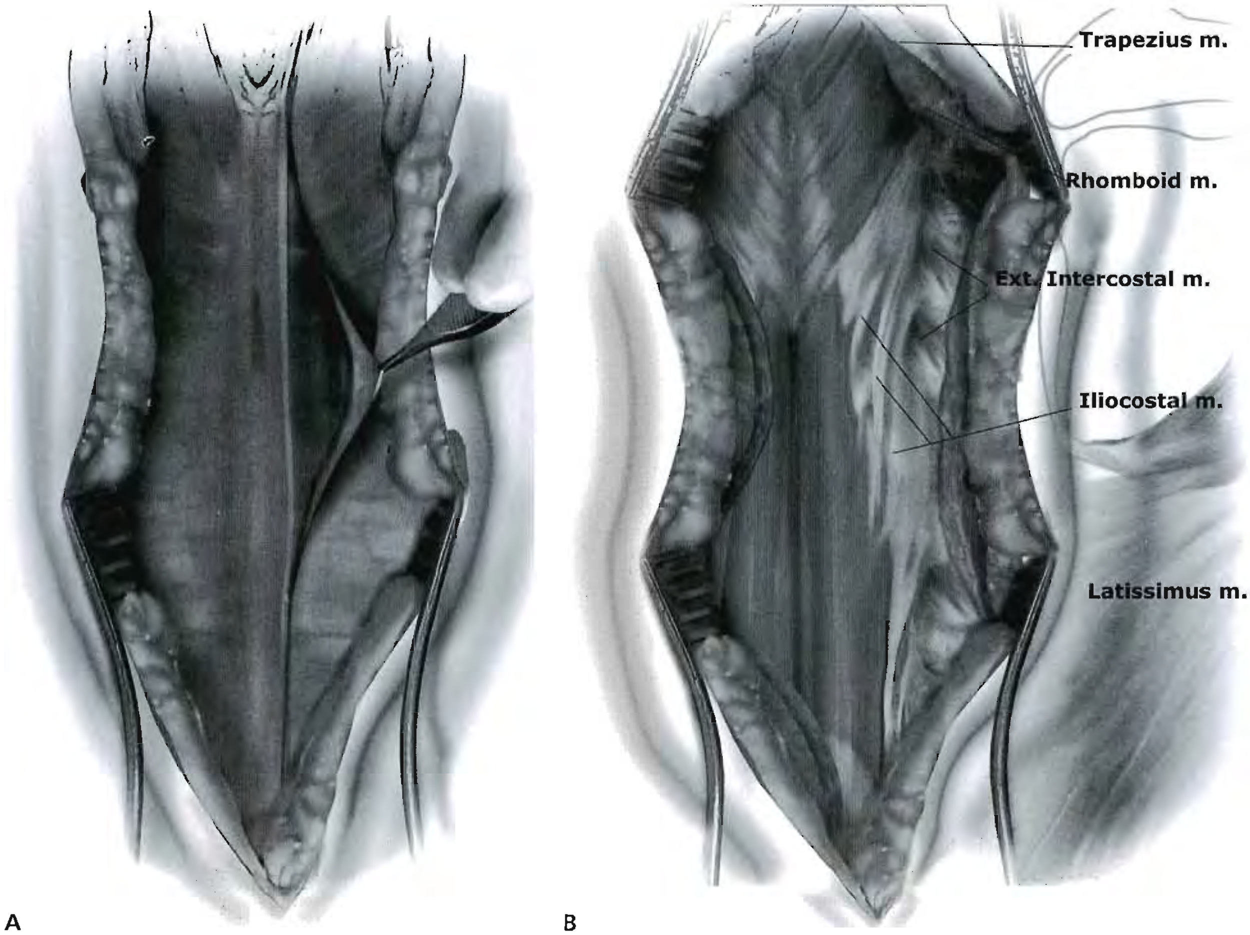


FIGURE 2-77. Thoracoplasty accompanying spinal instrumentation and fusion. The same approach can be used in patients previously treated by surgery, but the tissue planes may be less well defined. If a thoracoplasty is to accompany a spinal fusion and instrumentation, the incision must extend down to about the L2 or L3 region to be able to retract the appropriate fascial and muscular planes.

A thin layer of thoracolumbar fascia is incised in the region of L2 to L3 in a plane parallel and adjacent to the spinous processes. The fascia is elevated off of the paravertebral muscles working distally to proximally and from the midline laterally. All of the apical ribs of the curvature are visualized. We prefer to elevate the paraspinous muscles and the iliocostal muscles off of the ribs to be resected before incising the rib periosteum. All of the rib prominence should be resected, which often includes portions of five to eight ribs. The amount of rib to be resected is difficult to quantitate, and each patient must be assessed individually. The area of prominence can be marked out preoperatively with the patient in the Adams forward bend position. We generally start with the apical rib and then work proximally and distally, usually requiring a lesser amount of rib resection at each level.

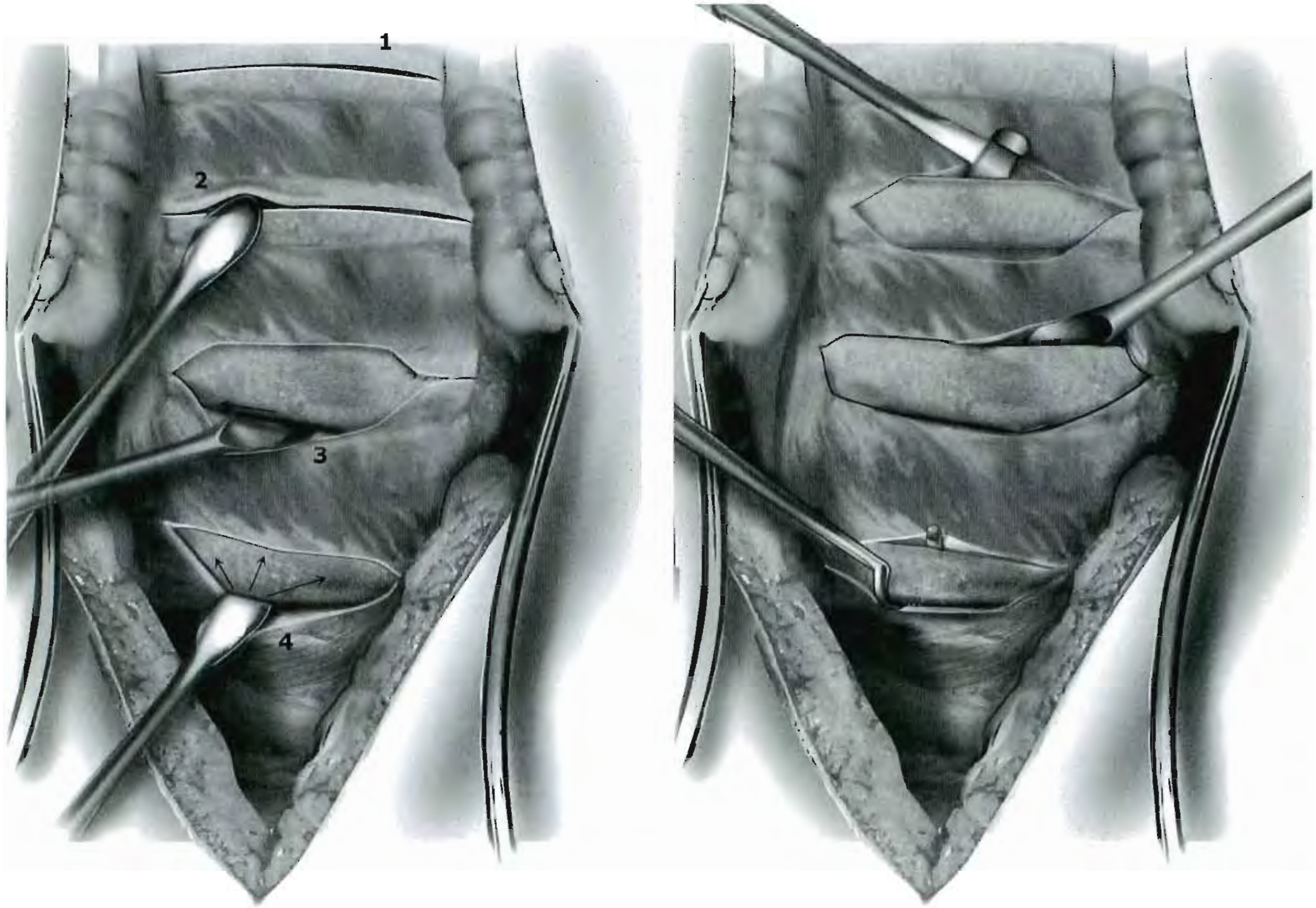


FIGURE 2-78. The periosteum over the ribs to be excised is incised longitudinally with coagulation cautery, staying in the center of the rib. An elevator can be used to elevate the periosteum on the rounded superior and sharp inferior aspect of each rib. Elevators such as the Alexander or Cobb elevator may be used for this purpose. After the edges of the rib are defined, the periosteum can be elevated over the superior margin and under the inferior margin using either a Cobb elevator, an Overholt #2, or the end of the Alexander elevator. Great care should be taken to prevent penetration of the pleura. The entire length of rib to be excised is exposed in this manner. Alternatively, after the edges have been defined and a small section of the rib is exposed circumferentially, a Doyan elevator can be used to expose the rib throughout the length of the intended resection.

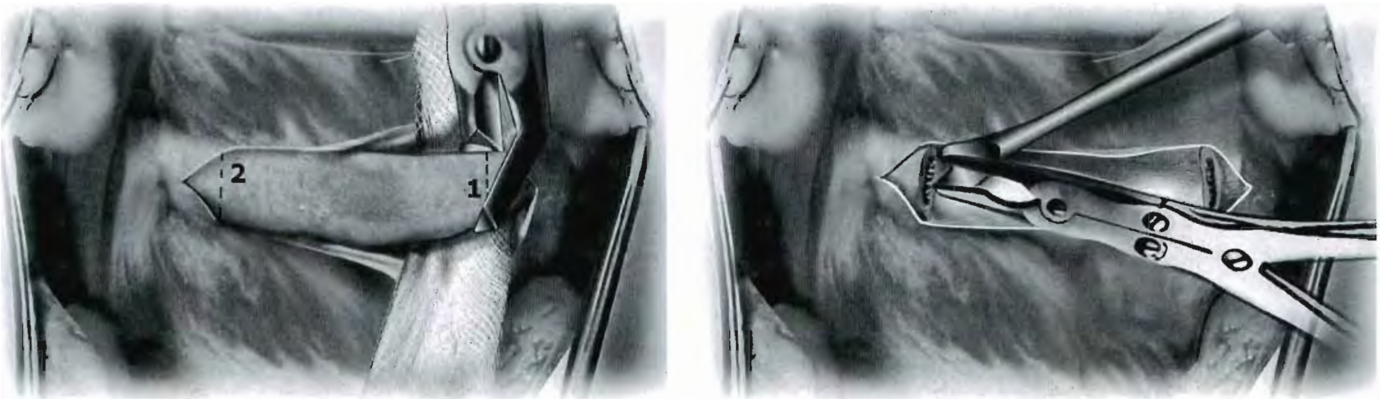


FIGURE 2-79. After the periosteum is dissected off the deep surface of the rib, a surgical sponge is inserted under the area to protect the pleura. The rib is then cut with a rib cutter at the lateral margin and grasped with a towel clip or Kocher hemostat, and all bleeders are coagulated. The amount of resection depends on the anatomy of the prominence, whether it is sharp and angular or a gradually rounded prominence. When resecting the rib laterally, it is important not to leave any sharp bony spikes, which may penetrate the pleura. The rib can be cut with a double-action rongeur or a rib cutter. Medially, the rib is generally cut adjacent to the tip of the transverse process. Great care must be exercised at this point, particularly in biting off any sharp edges of the residual rib adjacent to the transverse process because it is easy to penetrate the pleura.

After all the ribs are removed, all retractors are removed, the two skin edges are approximated, and the rib prominence is reassessed. If any residual deformity is present, additional resections may be necessary. It is also important at this point to assess whether any of the residual rib stumps adjacent to the transverse processes are causing prominence and need removal. In severe deformities with marked vertebral rotation, it is usually only the transverse process and the attached neck of the rib that remain prominent. These may now be resected, taking great care to avoid penetration of the pleura.

The entire wound is flooded with saline. The anesthesiologist uses repeated Valsalva maneuvers to look for air leaks; if found, these must be repaired. Hemostasis is obtained and preparation for wound closure begun. The ends of the ribs may be waxed, and Gelfoam may be used in the periosteal bed to assist with hemostasis. If no penetration of the pleura has occurred, the wound can then be closed with a medium Hemovac lying over the resected rib bed and brought out through the skin distally.

For cases in which an air leak has occurred, there is some debate about whether a chest tube should be inserted or whether the air leak itself should be repaired. If the pleura has been penetrated, the rib bed can be repaired by suturing intercostal muscle medially to laterally over the defect. Before final closure of the defect, the anesthesiologist expands the patient's lung, expressing air from the pleural cavity as the suture is secured. This prevents further pneumothorax as well as seepage of blood into the chest from the resection area or the scoliosis surgical field. We prefer to insert a chest tube if a pleural leak has occurred before closure. The fascial plane is then sutured with an absorbable suture and standard wound closure attained.

FIGURE 2-80. If the rib resection is done before surgical correction, only about 2 cm of rib needs be resected because the spine will translate toward the midline, ultimately leaving a larger gap than that at the time of rib resection. Some surgeons prefer to suture the medial edge of the remaining rib down to the remaining medial segment (6). If too much rib is taken, a concavity could be created in the area of the previous rib deformity, which may appear more unsightly to the patient than did the rib deformity. It is often difficult to predict how the residual rib will behave after a section has been removed. Some may continue to be rigid and prominent; others may "lay down" along the chest cavity.

If the resection is done after deformity correction, the entire rib deformity should be resected as visualized on the operating table. The resections often extend from the posterior axillary line to the transverse processes. If the transverse processes themselves are prominent, these may need to be resected as well.

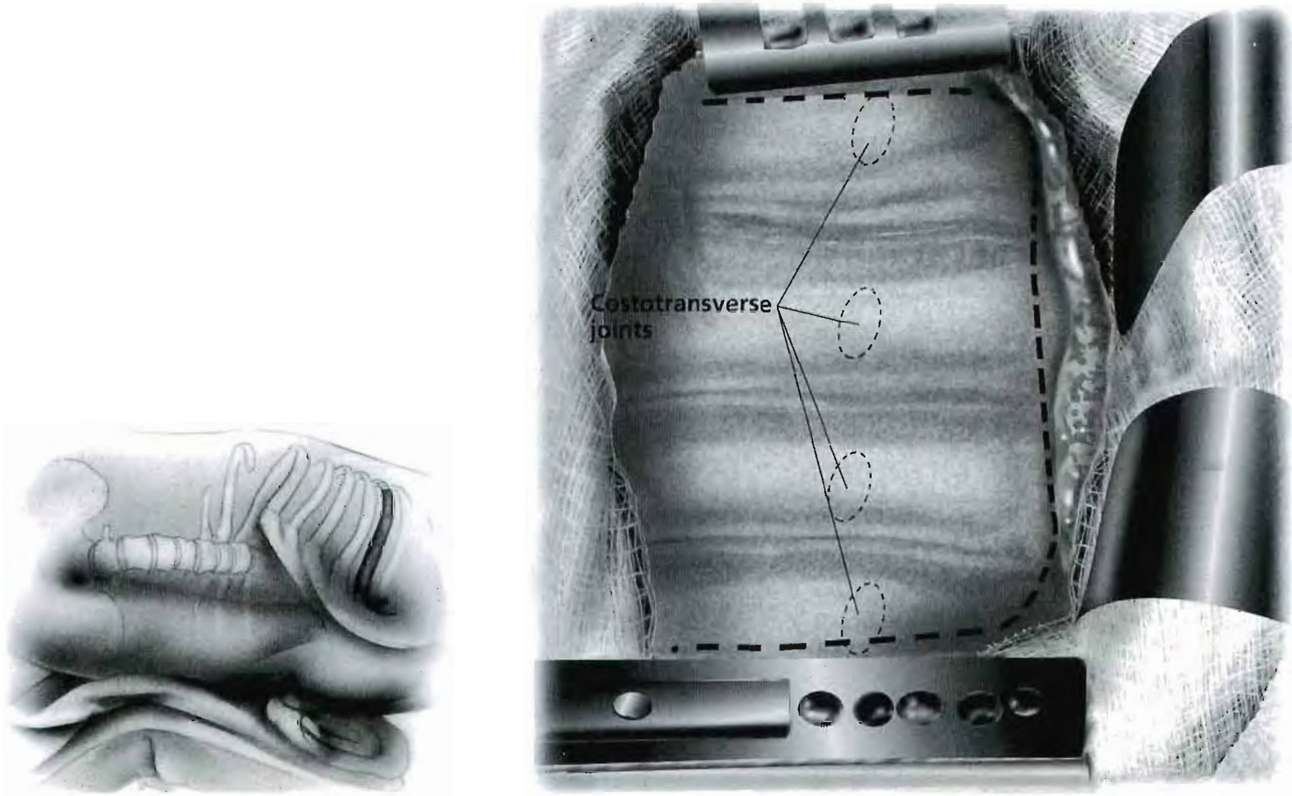


FIGURE 2-81. Thoracoplasty can also be accomplished during an anterior approach to the spine. The anterior approach may be used in conjunction with an anterior release and fusion for the correction of a severe or rigid curvature or in a young patient having an anterior fusion to prevent later bending of the fusion (crankshaft effect). In the anterior approach to the thoracic region, most surgeons resect the superior-most rib in their standard thoracotomy approach. The incision along the periosteum of the resected rib is then connected to the longitudinal incision in the parietal pleura, which is used for the anterior diskectomy or fusion technique.

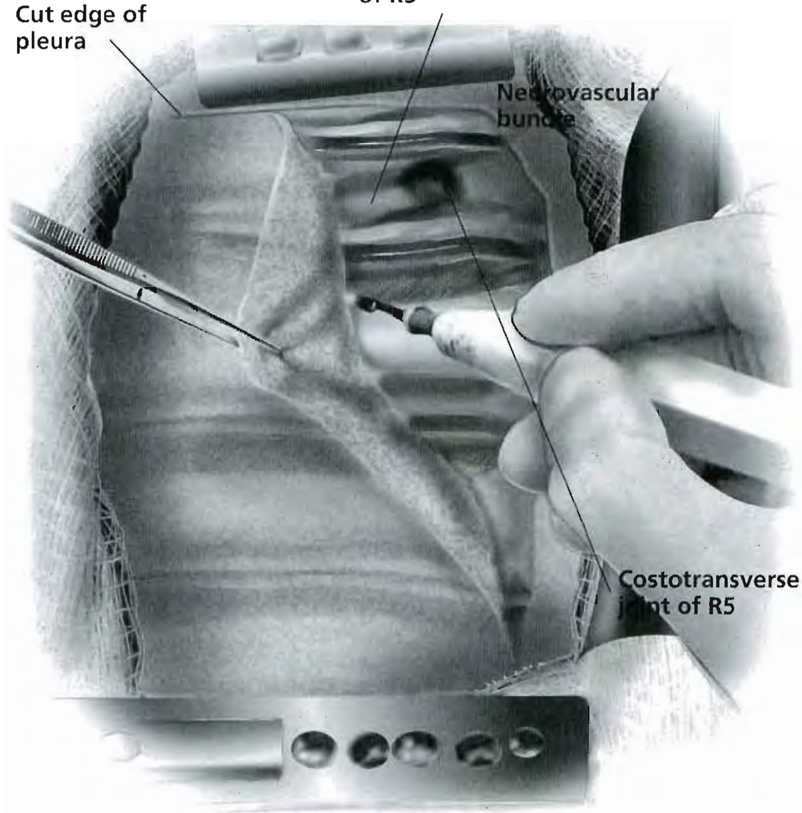
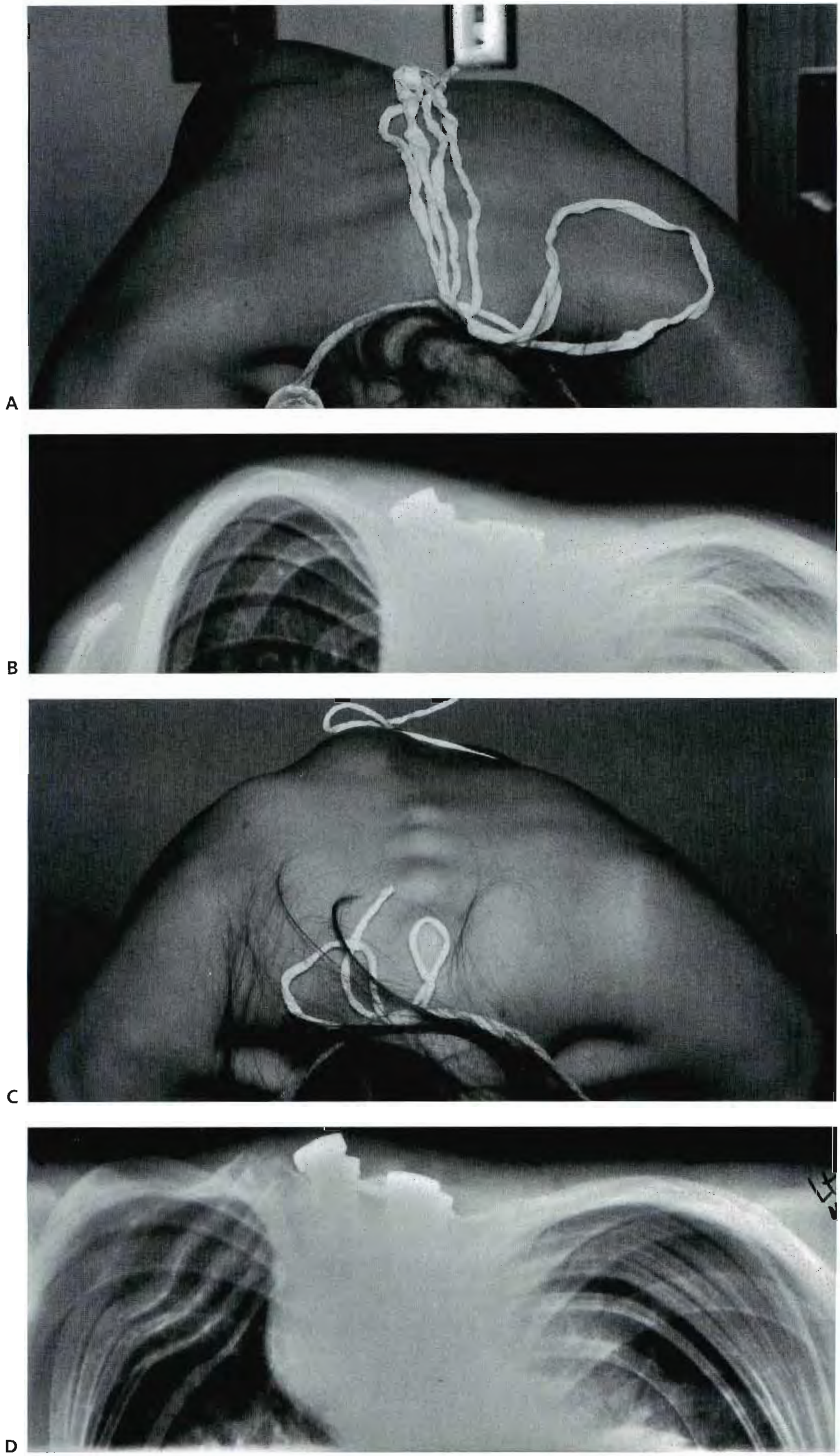


FIGURE 2-82. The pleural incision is carried distally and is connected to a periosteal incision over the most distal rib to be resected. After the segmental vessels have been ligated, this flap is then elevated off the intended resection area carefully with coagulation cautery.

FIGURE 2-83. Next, the ribs to be resected are subperiosteally exposed using a Cobb elevator and sectioned about 2 to 3 cm distal to the end of the transverse process. Each rib is then grasped with a towel clip or Kocher hemostat and separated sharply from the underlying costotransverse ligaments using a sharp elevator. The rib neck and head are then disarticulated from the attachments. In general, the apical five to eight ribs are removed, depending on the size of the rib prominence. After rib removal, diskectomy and fusion are carried out. Removal of the entire rib head and neck facilitates diskectomy. Morselized rib can then be used for bone grafting. The periosteal flap is then resutured to the spine, and the chest wall is closed in the standard fashion over chest tube. The chest tube is generally removed in 24 to 72 hours, depending on drainage. The postoperative course then generally follows that for posterior thoracoplasty patients.


A
B
C
D

◀ **FIGURE 2-84.** This 17-year-old girl underwent posterior spinal fusion and instrumentation for adolescent idiopathic scoliosis 2 years earlier. She was having problems with pain over the rib prominence and requested thoracoplasty. **A, B:** The rib prominence on the Adams forward bend test and on the preoperative rib views. **C, D:** Results 6 months after surgery. Note that the remaining medial prominence is the patient's hardware secondary to significant residual spine rotation. Also note the regrowth of the resected ribs. Despite this, the patient's symptoms were completely relieved, and she was satisfied with the outcome.

POSTOPERATIVE CARE: POSTERIOR THORACOPLASTY

Postoperatively, Hemovac drains can usually be removed in 24 to 48 hours, depending on drainage amounts and surgeon preferences. The postoperative regime of thoracoplasty patients varies widely from no special postoperative care to the use of a protective plaster shell. The advocates of the protective shell feel that this avoids postoperative flail chest and, more importantly, minimizes motion of the cut ribs on top of the pleura and prevents pleural effusion (2,8). Advocates of the shell use it postoperatively for about 3 months in adolescents and 6 months in adults. We prefer to use an elastic rib belt for comfort. Ribs regenerate over a 3- to 6-month period both in children and adults. Many patients develop a pleural effusion, which usually resolves spontaneously. For symptomatic pleural effusion, thoracocentesis is usually sufficient to address the problem.

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2.11 ANTERIOR INTERBODY ARTHRODESIS WITH INSTRUMENTATION (FLEXIBLE OR RIGID ROD) FOR SCOLIOSIS

The advantages of anterior arthrodesis and instrumentation for idiopathic lumbar and thoracolumbar scoliosis have been recognized for many years (1). Because of the removal of the disks and the rigid fixation of the screws compared with sublaminar hooks, the correction is better; in addition, the correction of rotation is better. This means that it is usually possible to fuse one less level, saving lumbar motion and perhaps improving the natural history of the joints below (2).

Although the Zielke instrumentation offered significant advantages over the Dwyer cable, it has now been superceded by rigid rod systems that offer further improvement in both the rigidity of the fixation and the ability to preserve lumbar lordosis.

Both methods are described, along with the thoracoabdominal approach to the lower thoracic and lumbar spine (Figs. 2-85 to 2-101).

FIGURE 2-85. In most curves, it is safe to select the level based on the disk space that remains wedged on the bending film. Vertebrae that do not come to neutral or bend in the opposite direction on a bending film should be included in the instrumentation. This rule assumes complete correction of the curve or slight overcorrection. In the thoracolumbar curve illustrated **(A)**, the disk space between L3 and L4 definitely opens on the bending film, whereas the disk space between L2 and L3 comes to neutral **(B)**. Because of the rapid progression of this curve and the remaining growth, it was believed safest to include the L3 vertebra in the fusion. A bend film in the opposite direction is advisable to ensure that there is not a fixed lumbosacral curve in the opposite direction. Flexibility of the counter curve must also be taken into consideration with this technique. If it does not correct sufficiently (20 degrees or less) on a bend film, the surgeon should be careful because the patient may be severely out of balance after the thoracolumbar curve is straightened.

FIGURE 2-86. A thoracoabdominal approach is used to gain access to the vertebral bodies and disks that will be included in the fusion area. The rib to be excised should correspond to the upper-most vertebrae to be instrumented. The typical thoracolumbar curve illustrated uses an incision over the 10th rib extending across the costal margin into the abdominal wall. The incision in the abdominal wall stays lateral to the rectus sheath and is extended as far as necessary depending on the vertebra to be fused.

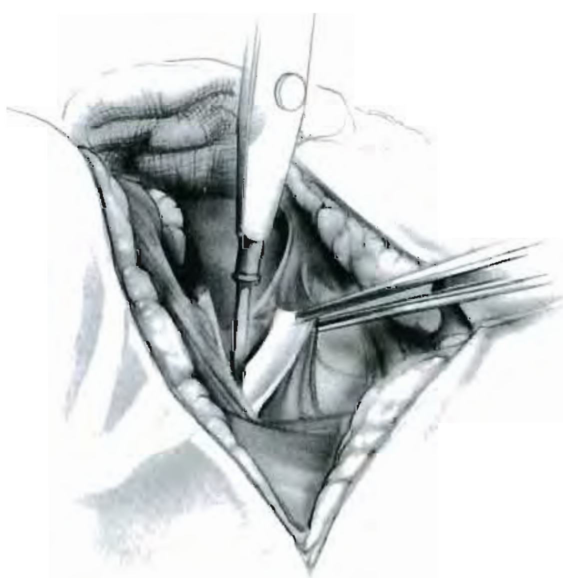


FIGURE 2-87. After the rib is removed and the pleural cavity opened, the costal cartilage is split. Teasing apart the muscle beneath demonstrates the peritoneum.

FIGURE 2-88. Because the peritoneum is adherent to both the underside of the diaphragm and the abdominal wall, it must be peeled off to avoid entering the peritoneal cavity and to gain access to the retroperitoneum. A small moistened sponge wrapped over the finger aids in this dissection.

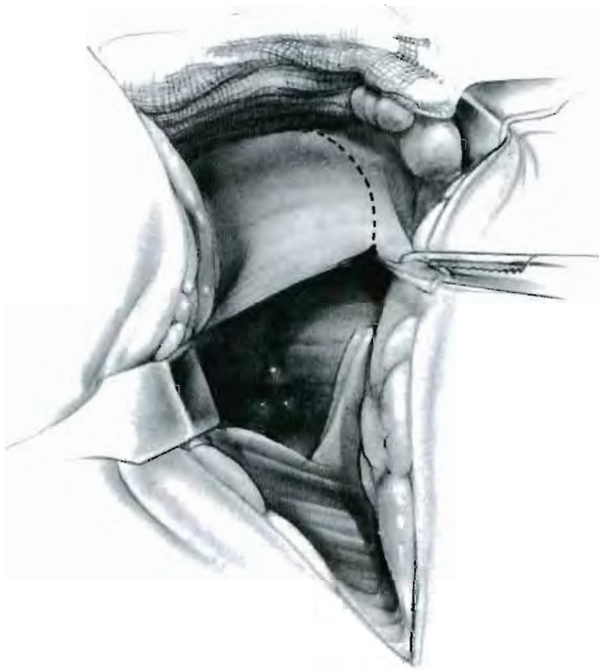


FIGURE 2-89. After the peritoneum is peeled from the underside of the diaphragm, the diaphragm is detached from its costal margin, leaving just enough on the chest wall to reattach it. Following this attachment in its posterior curving course leads to the spine. After removing the peritoneum from the underside of the abdominal wall, the incision is extended by cutting through the muscle layers lateral to the rectus sheath. The spine is exposed by sweeping the peritoneum and the retroperitoneal fat forward off the spine. The spleen, kidney, ureter, and aorta all can be palpated. The vena cava is best not seen. The surgeon must be careful not to damage these structures with retractors and other instruments.

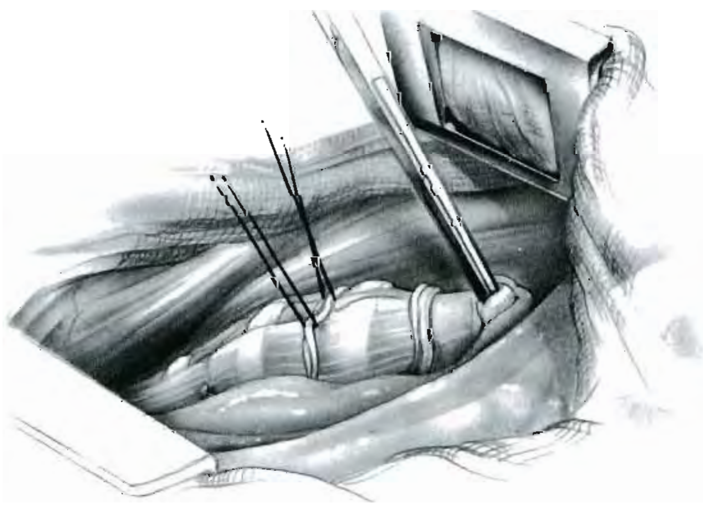


FIGURE 2-90. The parietal pleura covering the thoracic spine is opened. The disks and the segmental vessels crossing the vertebral bodies are seen easily. The lumbar spine is covered with a fibrofatty layer and the psoas muscle. This fibrofatty investing layer is best opened by sharp dissection in the midline. This exposes the bulging disks, which is the safe avascular area to begin the circumferential dissection of the spine. Between the disks and crossing the concave center of the vertebral bodies are the segmental vessels. These are dissected free of the loose fascia and the areolar tissue and ligated near the midline to avoid injury to the arterial collaterals, which help to preserve spinal cord blood supply.

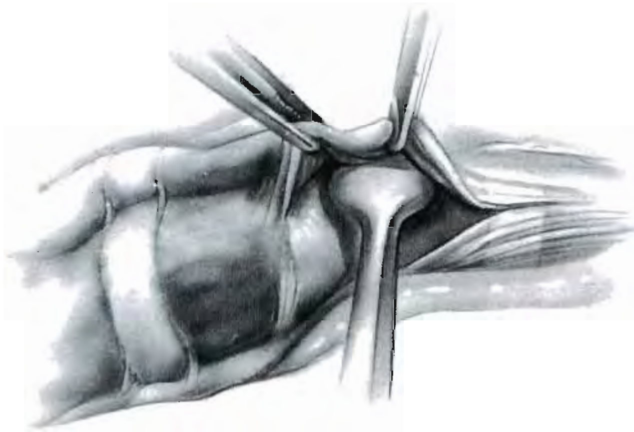


FIGURE 2-91. Exposure of the vertebrae and disks can be done either extraperiosteally, by pushing the loose areolar tissue off the periosteum, or by cutting the periosteum over the vertebrae and disks and elevating it as a continuous layer, as illustrated here. The subperiosteal approach provides excellent exposure of the disks and end plates and perhaps better healing at the expense of 20 minutes of operating time and some increased blood loss. The spine should be exposed to the base of the transverse processes on the convex side and as far past the midline as possible on the concave side. Regardless of the method used, it is advisable to dissect bluntly with a finger around each vertebral body to palpate the concave surface and the base of the transverse process either directly or through the psoas. This permits more accurate aiming of the screw that is placed through the vertebral body and, at the same time, allows the surgeon to palpate the screw tip. This latter benefit is important because it is necessary to be certain that the screw has penetrated the cortex on the concave side of the vertebral body (see Fig. 2-93).

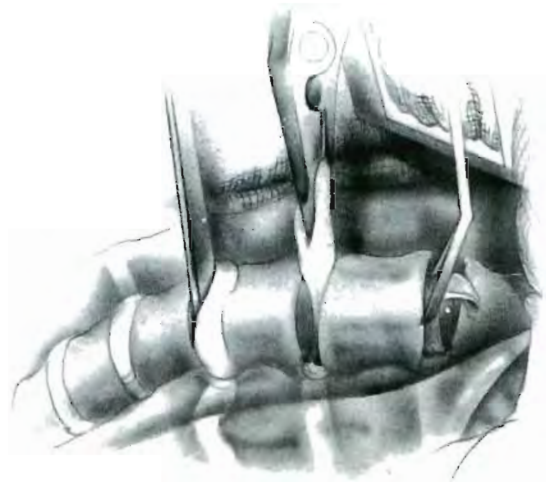


FIGURE 2-92. If the end plates remain open, a broad chisel can be inserted between the end plate and the bone of the vertebra. The chisel is advanced by gentle tapping with a mallet to avoid the plunges that can occur when pushing. Twisting and prying the chisel loosen the end plate and the disk for easy excision with a rongeur. The end plate may also be loosened with a Cobb elevator, taking great care to control its advancement. Any remaining vertebral end plate is removed with the Zielke ring curette. Arthrodesis can be enhanced further by using a 1/4-inch curved osteotome to remove the compact bone beneath the vertebral end plate, exposing its cancellous bone. Because this increases the bleeding, it is best postponed until the graft is inserted. The excision of the disk should be thorough. The entire annulus should be removed from the transverse process of the convex side to a point past the midline, leaving the annulus on the concave side as a hinge. It is easy to be misled about the amount of disk and annulus that has been removed. The annulus on the concave side and the posterior longitudinal ligament posteriorly should be exposed. Care must be taken to note the rotation of the vertebral bodies and thus the changing location of the spinal canal.

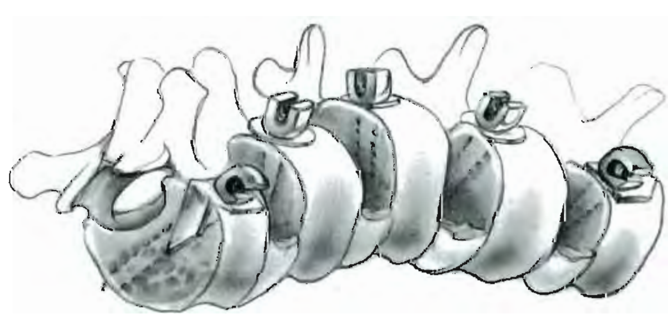


FIGURE 2-93. The placement of the screws to produce the derotation effect is believed to be important in the Zielke technique (3). The position of the screws corresponds to the rotation of the vertebra. In principle, each screw should parallel the posterior surface of the vertebral body. Because of the rotation of the vertebrae in the curve, the cephalad and caudal screws are more ventral, whereas the screws at the apex are more dorsal. Correction can be enhanced by placing the most caudal and cephalad screws about 1 cm more ventral than the screw at the apex. Fixation of the screws can be enhanced by angling them in a slightly posterior-to-anterior direction. When all of the screws are correctly placed, they form a line concave ventral. Later, the derotator will pull the apex of the rod (which conforms to this arch) forward, derotating the spine.

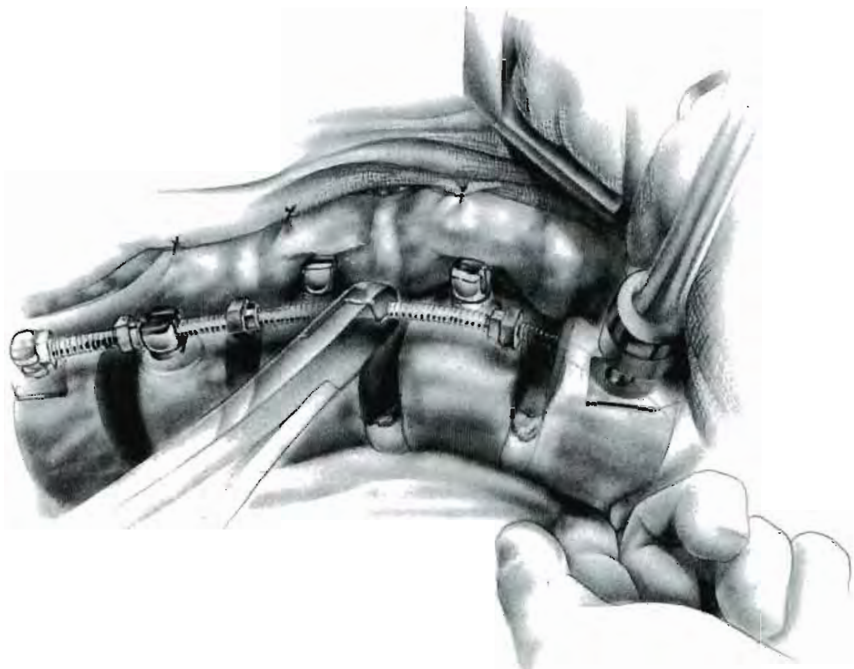


FIGURE 2-94. At the top and bottom vertebrae, a staple is placed in the desired location with its blade best directed between the bone and the vertebral end plate. On all other vertebrae, a washer is used. If used in the manner for which it was designed—concave surface facing up—it will fit the shape of the vertebral body better. In some instances, however, it blocks the tightening of the nut. This can be avoided by placing the washer convex side up.

The depth of the screw can be measured by a caliper placed around the vertebral body if the dissection is sufficient. If not, a depth gauge can be inserted into the disk space along the exposed surface of the vertebral body. At least 5 mm will have to be added to this to account for the thickness of the annulus and the height of the washer. The hole is started in the vertebral body with an awl. A finger is placed on the concave side of the vertebra, and the screw is directed toward the distal joint of the palpating finger. If the disk has been removed thoroughly, the proper direction of the screw is confirmed by direct visualization of the posterior longitudinal ligament. The screw must penetrate the cortex on the far side of the vertebra to gain sufficient grip. Palpation is the best way to determine this. If soft porotic bone is encountered or if the screw tends to pull out, methylmethacrylate is injected into the screw hole, the screw is reinserted, and the cement is allowed to set. It is recommended that the end screws are side opening and the other screws top opening. This uses the elasticity of the rod to lock it in place. It is often easier, especially in severe curves, to use all top-opening screws.

The rod is prepared by placing the nuts on it at the appropriate intervals. Double nuts may be used at each level or only at the top and bottom screws. Should the rod break, double nuts will prevent loss of correction at the other levels.

FIGURE 2-95. The rod is then inserted into the open slots of the screws, and the nuts are tightened enough to engage the head of the screw and hold the rod in the screw head. To do this, it is often necessary to place a rod clamp on the side of the screw head opposite the nut being tightened to force the projection of the nut into the screw head. Compression of the opposing vertebral bodies should be avoided at this point.

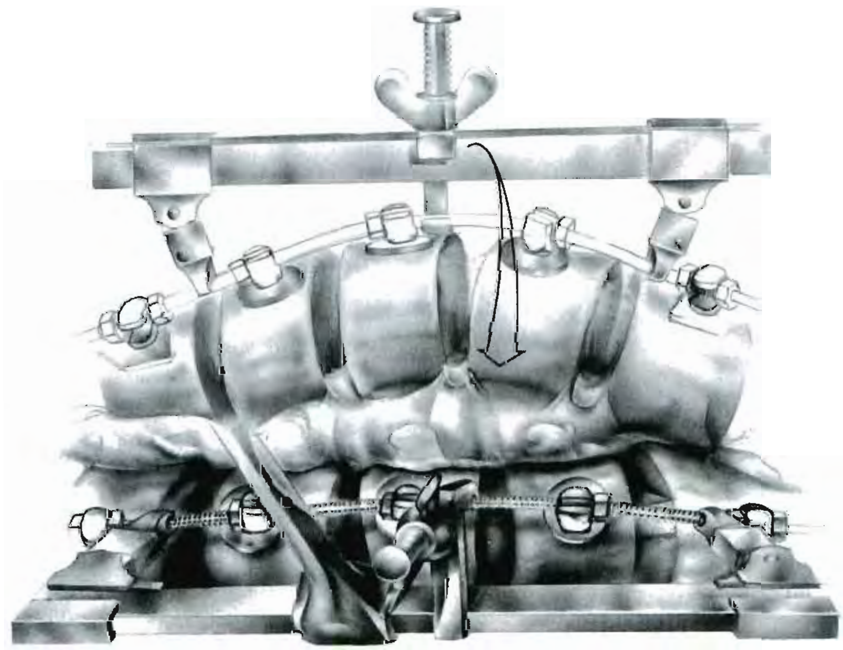


FIGURE 2-96. Derotation of the spine is accomplished by first placing the articulated derotation bar on the rod. The wing screw on the derotator bar is tightened to secure the bar on the rod. The lever is placed on the bar and slowly and gently pulled ventrally to derotate the apical vertebrae. Care must be taken with the derotation lever because an enormous amount of force can be applied. Actually, the derotation can usually be accomplished by hand, but the lever is moved out of the way to allow easier tightening of the nuts. As the apical vertebra is derotated, the disk spaces open ventrally and lordosis is created.

To maintain the lordosis as the nuts are tightened, it is necessary to insert wedges of bone between adjacent vertebral bodies anteriorly in the midline (Fig. 2-97). It is best to use tricortical iliac bone, either autogenous or from the bone bank. This is more stable than anything that is fashioned from rib. Excision of the annulus past the midline allows this graft to be placed anteriorly, creating lordosis and not blocking correction of the scoliosis.

FIGURE 2-97. After the bone graft is placed, the nuts are tightened beginning at the apex and moving cephalad and caudad. This corrects the remaining curve. If there is any question that the desired amount of correction has been obtained or fear that overcorrection has occurred, a radiograph can be obtained easily. As the tightening progresses, the apposition of the vertebral bodies and of the screws should be observed. It is possible to tighten the nuts to the point at which the top screw in the thoracic vertebra pulls out. After the desired correction is obtained, the threads of the rod are destroyed adjacent to each nut to prevent them from loosening. This can be done by twisting an old osteotome in the treads.

A

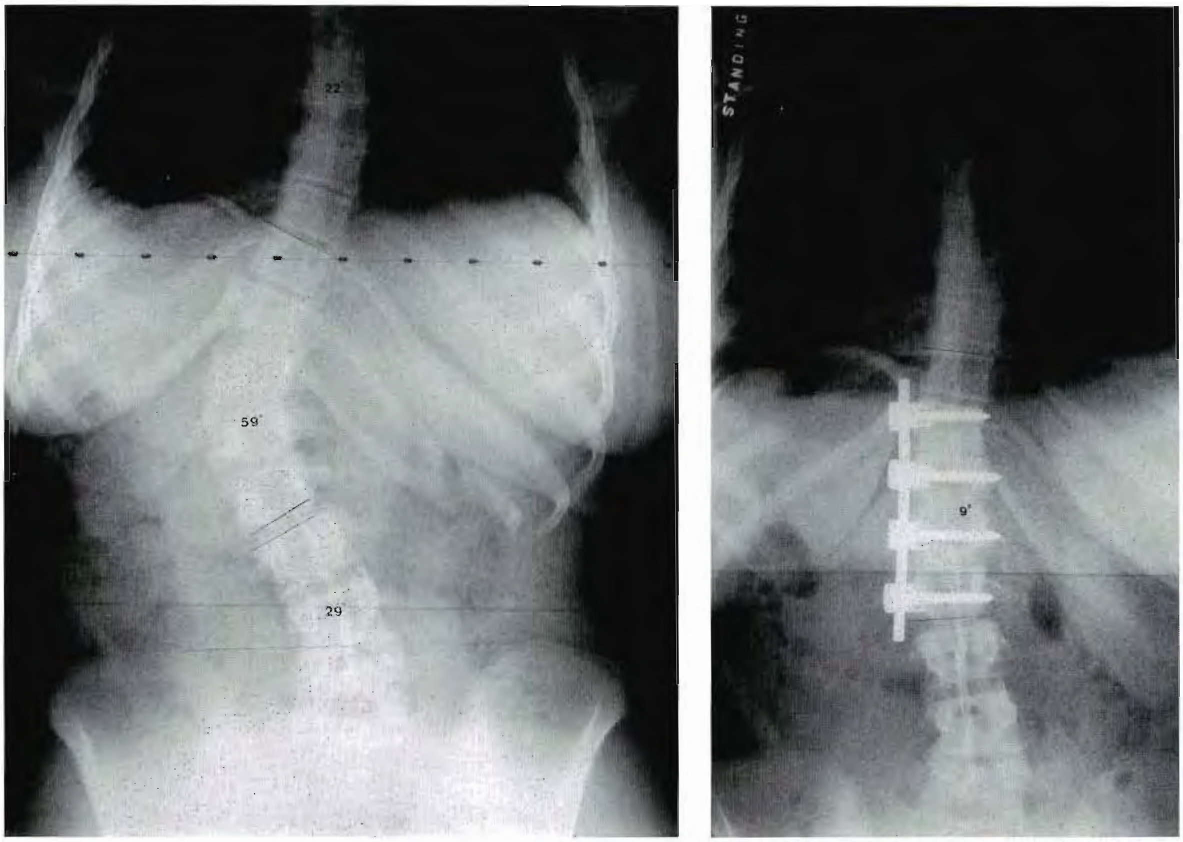
B

FIGURE 2-98. The postoperative radiographs **(A, B)** demonstrate the excellent correction of both the scoliosis and the rotation with Zielke instrumentation. The anterior cortical rib grafts did not maintain the anterior disk space height, and although significant kyphosis was avoided, the lordosis has been lost.

FIGURE 2-99. When a rigid rod system is used, it is not believed necessary to vary the placement of the screws, as in the Zielke technique (4). Rather, the screws are placed in a straight line. The rod is bent to produce the normal lordosis. This curve generally conforms to the scoliosis, making rod placement easy (5).

FIGURE 2-100. After the rod is secured into the screws, the rod is rotated. The rigid rod pulls the screws with it, producing excellent rotation and lordosis. The compression clamps are used at this point to compress each of the vertebrae together, correcting the scoliosis.

The parietal pleura is closed to cover the rod and the screws in the thoracic spine, and the psoas muscle is allowed to cover the lumbar portion of the rod. It is critically important that no metal be left exposed in a position where it will come in contact with a major vessel, because in such instances, eventual erosion of the vessel will occur. This is particularly a problem when instrumentation is carried to the lower levels of the lumbar spine. The diaphragm is repaired and the wound closed with a chest tube in place.



A

B

C

FIGURE 2-101. A: The preoperative curve. **B, C:** The postoperative anteroposterior and lateral views, respectively. On the lateral view, note the rod curving anteriorly and the better preservation of lordosis as compared with the Zielke fusion.

POSTOPERATIVE CARE

When drainage from the chest tube is about 50 mL or less per 8 hours, the tube is removed. As soon as the chest tube is removed, the patient begins ambulation. After Zielke instrumentation, a small Orthoplast jacket or similar device is made to immobilize the fusion area. Ambulation does not have to await fitting of the jacket. The jacket is worn until arthrodesis of the vertebra is observed on the radiographs. This usually takes between 3 and 6 months. Most surgeons use no postoperative immobilization after instrumentation with a rigid rod.

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2.12 HEMIVERTEBRA EXCISION

Hemivertebrae (caused by failure of vertebral formation) are one of the main causes of significant spinal deformities both in the coronal and sagittal planes. In some cases in which the hemivertebra occurs with another congenital anomaly, such as a unilateral unsegmented bar associated with a contralateral hemivertebra, the natural history of a poor prognosis is well known. In most cases, however, the natural history of the hemivertebra is less predictable.

Hemivertebra may occur in any region of the spine. The most problematic hemivertebrae are those in the cervicothoracic and the lumbosacral junctions. In these two regions, the adjacent spinal segments are unable to compensate for progressive curvatures caused by the hemivertebra.

Patients being considered for hemivertebra excision must be evaluated like any other patients with a congenital spine deformity. A careful neurologic examination and an examination for skin manifestations of spinal dysraphism (sacral dimple, sinus tracts, or hairy patches) should be performed. Renal ultrasound should be obtained to evaluate the kidneys because there is a high association (about 20%) of renal anomalies in patients with congenital anomalies of the spine.

The spine must be evaluated radiographically in both the coronal and sagittal planes to identify evidence of decompensation. Radiographic evaluation includes standing posteroanterior and lateral full-length scoliosis films, making certain to compensate for any limb length inequality. Side bending radiographs help determine the flexibility of adjacent secondary curvatures. Widening of the pedicles on plain radiographs may be indicative of a diastomatomyelia. Magnetic resonance imaging (MRI) should be used if the patient has clinical or radiographic evidence of spinal dysraphism. In general, MRI should be obtained in congenital spine deformities if surgical management of the condition will employ instrumentation or if hemivertebra excision is contemplated. Three-dimensional computed tomography scans are often helpful in delineating anatomy before surgical intervention.

Hemivertebra excision is ideally indicated in the patient who has a significant deformity with coronal imbalance, particularly hemivertebrae at the lumbosacral junction. These often cause severe decompensation and coronal plane deformities. Excision can also be used in the thoracic, thoracolumbar, or lumbar spine. Hemivertebra excision in the cervical spine is contraindicated.

The main indications for hemivertebrae excision are a curve greater than 40 degrees with coronal imbalance, a hemivertebra-generated curve with documented progression, or a lumbosacral vertebra associated with pelvic obliquity and lumbar scoliosis. Hemivertebra excision can be done at any age, but the ideal time is while the patient is young and still has flexible compensatory curves. Lumbosacral hemivertebra without major decompensating curves above the hemivertebra should not be treated using this technique (1–4).

The procedure is usually done as a staged procedure but on the same day. Depending on the location the hemivertebra, all the surgery can be performed in the lateral decubitus position, or the anterior hemivertebra excision can be performed in the lateral decubitus position and then the posterior portion of the procedure in the prone position (Figs. 2-102 to 2-108).

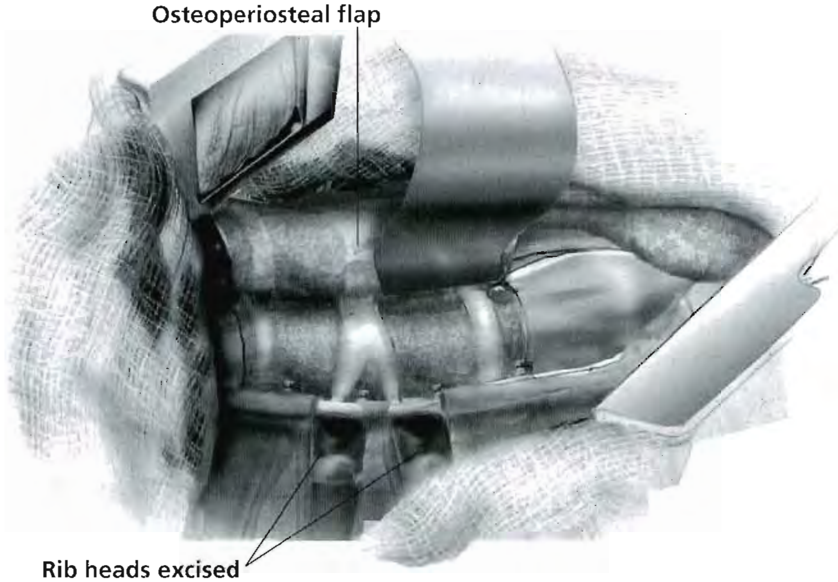

FIGURE 2-102. The patient is taken to the operating room and placed on a standard operating table in the lateral decubitus position with the hemivertebra side facing up. Standard lateral decubitus positioning is used with an axillary roll and padding under the peroneal nerve, between the legs, under the down arm, and between the arms. In general, we prefer to flex the operating table to allow maximal visualization and opening up of the disk spaces (see Fig 2-86). The patient's hemithorax and hemiabdomen are prepped out from just beyond the midline anteriorly to just beyond the midline posteriorly. Spinal cord monitoring should be done throughout the procedure and can be supplemented by a wake-up test.

If a thoracic hemivertebra is to be excised, a standard thoracotomy incision is made, removing the rib one or two levels above the hemivertebra. If the hemivertebra is at the thoracolumbar junction, a standard thoracoabdominal approach through the 11th or 10th rib may be used. This allows exposure and excision of a hemivertebra down to the L2 or L3 level. For lumbosacral junction hemivertebrae, a standard retroperitoneal approach is used. It is a good idea to identify the hemivertebra to be excised with radiographic markers, such as a Keith needle, before exposure to make sure you are at the correct level.

In exposing the hemivertebra, after segmental vessel ligation (see Fig 2-90), either an extrapereosteal or subperiosteal exposure can be used. We prefer to use a subperiosteal exposure to allow a flap with osteogenic potential to overlay the resection site. The spine must be subperiosteally exposed from the inferior aspect of the vertebral body above to the superior aspect of the vertebral body below. The osteoperiosteal flap must be elevated all the way around to the opposite side as shown. The flap allows protection of the great vessels on the concavity of the curvature.

In the thoracic spine, the rib head at the level of the hemivertebra should be removed to allow exposure of the transverse process and the disk space. The rib head at the next inferior vertebra in the thoracic spine may also need to be removed to allow for adequate exposure of the disk space. Bleeding can be controlled with bone wax.

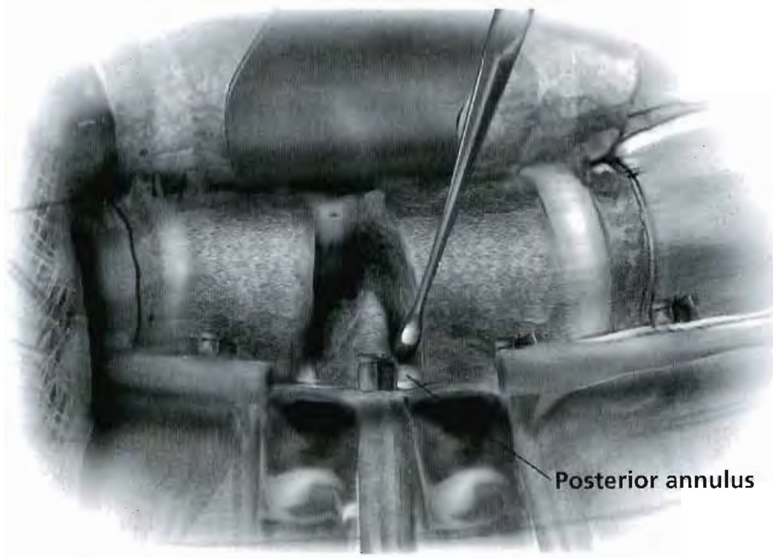

FIGURE 2-103. All disk material above and below the hemivertebra is excised using knife, curette, and rongeurs back to the posterior annulus (see Fig 2-92). We tend to use the rongeurs at the more superficial levels and then curettes as one approaches the posterior annulus.

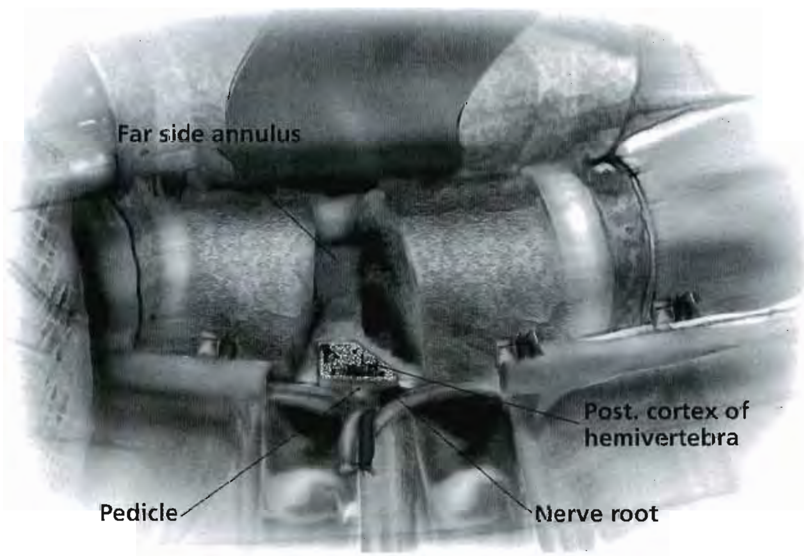

FIGURE 2-104. The inferior end plate of the vertebra above and the superior end plate of the vertebra below must also be excised. This can be done with curettes or Cobb elevators. It is important to leave a portion of the most lateral annulus intact to act as a stabilizing tether during the posterior hemivertebra removal and closure of the gap. It is important to excise all of the soft tissues opposite the hemivertebra. This may appear as disk material or fibrocartilage. Failure to excise all of this tissue except for the most lateral annulus will result in ineffective closure of the gap.

After the disk material has been removed, the hemivertebra excision is begun. This can be accomplished with a bur, rongeur, or curette. We prefer to use rongeurs and curettes. The bone removed is saved to be used as bone graft in filling some of the gap anteriorly and also posteriorly. We use rongeurs to remove the bulk of the hemivertebrae and then curettes, curetting from the concave to the convex side toward the surgeon. All the cancellous bone is removed back to the posterior cortex. In the thoracic spine, the transverse process is subperiosteally dissected anteriorly and rongeured off at its base.

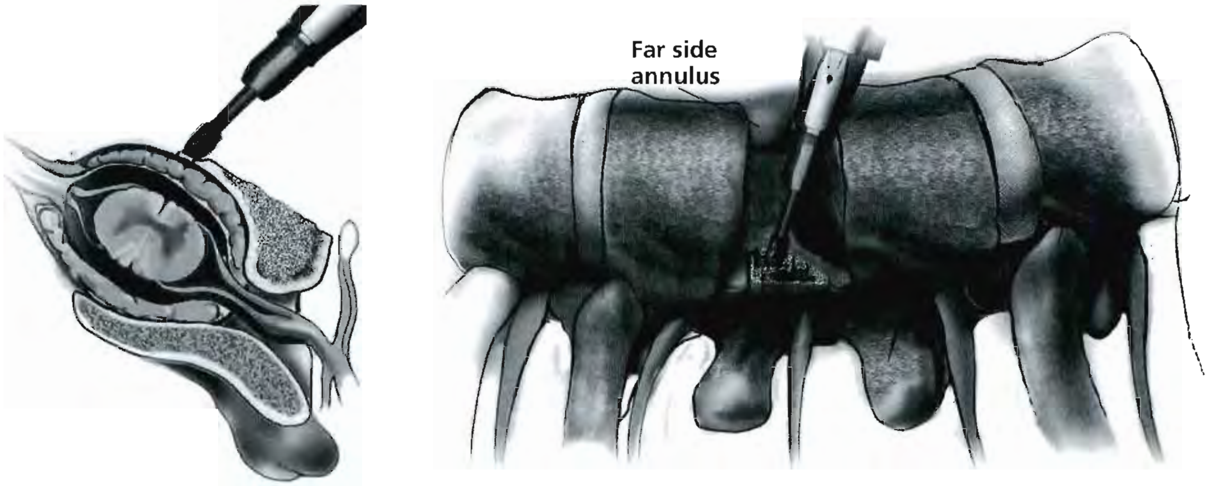

FIGURE 2-105. Final removal of the posterior vertebral cortex can be done in one of several ways. We prefer to use a diamond-tipped dental bur to enter the spinal canal in the midline. After a small hole is made, a small Harper-Kerrison rongeur may be used to remove the entire posterior cortex of the hemivertebra.

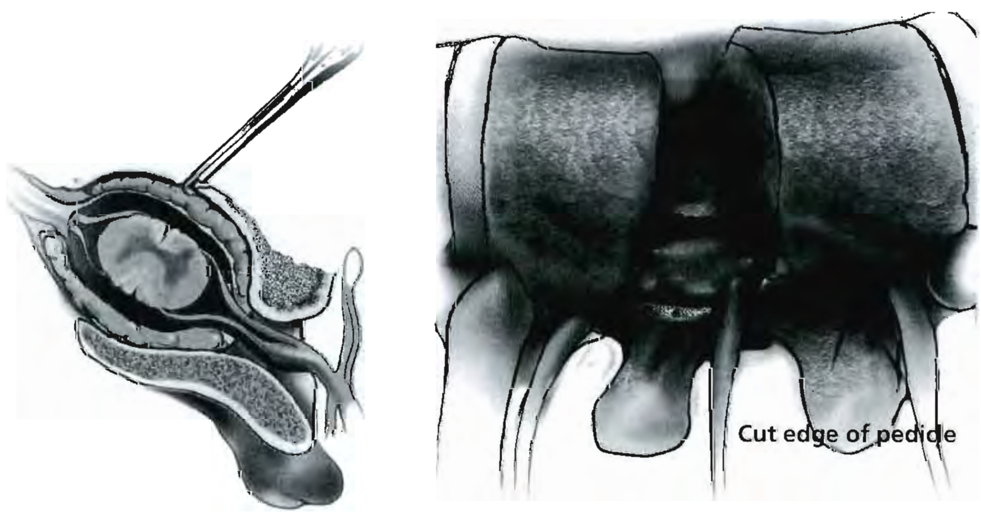

FIGURE 2-106. After the cortical bone is removed from the apex of the hemivertebra all the way back to the pedicle, the annular tissues superiorly and inferiorly can also be removed. The neural foramina both above and below the hemivertebra must be opened completely and the nerve roots visualized. Any bleeding that is encountered should be addressed with bipolar cautery or packing with thrombin-soaked Gelfoam.

The final structure removed anteriorly is the pedicle of the hemivertebra. The pedicle can be removed in several different ways. It can be gradually nibbled away with narrow-nosed rongeurs or, as we prefer, the central portion drilled until decancellated and the outer walls then removed with either rongeurs or curettage toward the pedicle center. The pedicle bone should be nibbled away as far posteriorly as possible.

The dura is covered with a Gelfoam or Oxycel pad or fat graft, and then bone chips from the excised hemivertebra are loosely placed into the space. The osteoperiosteal flap is then sutured back down loosely, and in the chest, the pleura is repaired. The wound is then closed in the standard fashion.

The second portion of the procedure can be done in the lateral decubitus position. However, we prefer to roll the patient prone and transfer the patient to a spine frame (e.g., Jackson table, Relton-Hall frame). In some small children, we prefer to use two laminectomy rolls (made of rolled bath blankets or foam), one under the chest and one under the iliac crests, leaving the abdomen free.

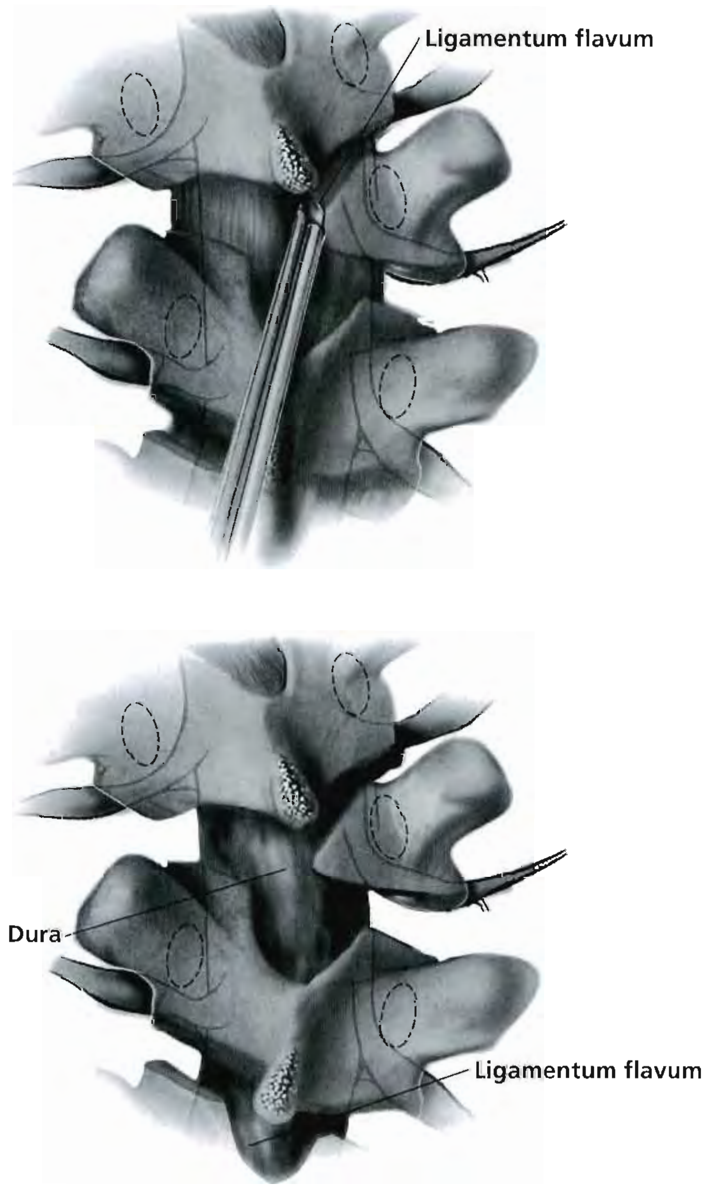

FIGURE 2-107. In the posterior approach, the spine is exposed from a standard midline exposure overlying the area of the hemivertebra. A radiograph is taken to determine the appropriate level for excision. The spine is then exposed subperiosteally. The ligamentum flavum above and below the hemilamina is carefully incised and removed with the Kerrison rongeur. Any bleeding is controlled by bipolar cautery or packing with thrombin-soaked Gelfoam. After the ligamentum flavum has been removed, the hemilamina is gradually removed from the midline to its lateral aspect. We generally do this with standard narrow-nosed rongeurs or Harper-Kerrison rongeurs. It is much easier to remove the posterior arch from the posterior approach when more of the pedicle has been removed from the anterior procedure.

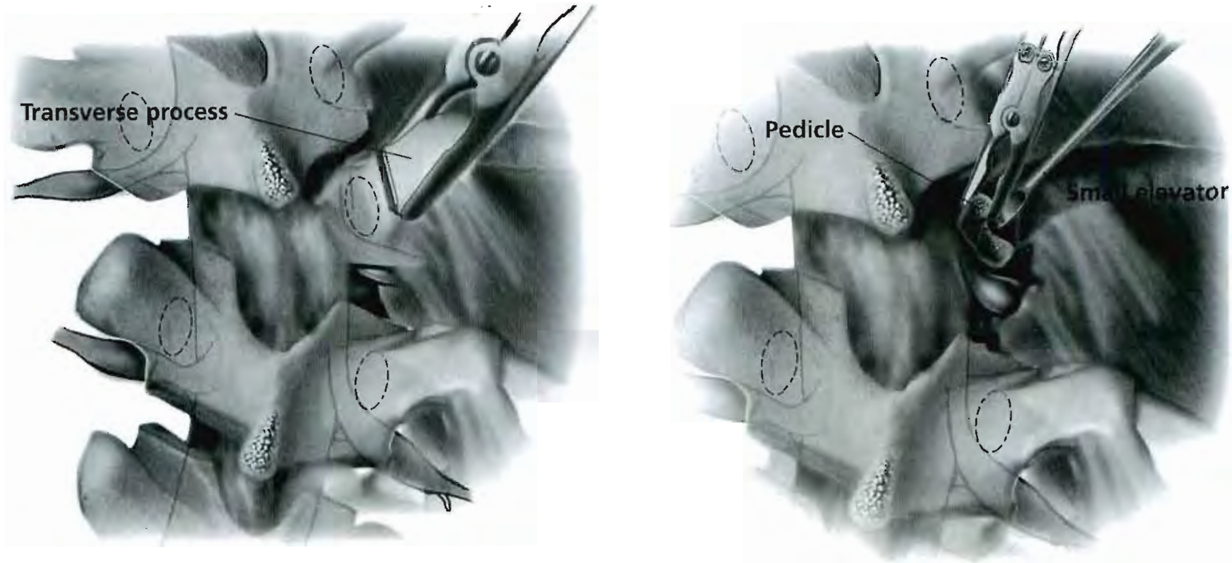

FIGURE 2-108. In the lumbar spine, the transverse process is transected at its base with a narrow-nose or Kerrison rongeur. In the thoracic spine if, the transverse process was left intact in the anterior approach, it must be removed at this point. After the lamina, facets, and transverse processes have been completely removed, the pedicle can be grasped with a rongeur or hemostat; with one prong inside the center of the pedicle and one on the cortical margin, the pedicle is slowly removed. If resistance is encountered, it is most important to use a small elevator to free the margin of the pedicle and remove it either in toto or piecemeal with narrow-nose rongeurs or curettes.

After all the bone is removed, the surgeon can easily visualize the dural sac with the nerve roots above and below the hemivertebra. The surgeon must take great care when watching the closure of the apical wedge osteotomy to make certain that the down-going pedicle does not impinge on the two nerve roots now going through the single neural foramen. If there is any concern about pedicle impingement, the superior pedicle must be thinned or even excised to prevent nerve root impingement. The laminae above and below can then be decorticated and the portions of the rib removed from the anterior portion of the procedure; the morselized hemivertebrae can be used for bone graft. When the hemivertebra to be excised is at the lumbosacral junction, a separate incision may be necessary to expose the iliac crest and obtain cortical and cancellous bone.

In very young patients, internal fixation is generally not possible, and the defect is closed and maintained in that position by casting. In the toddlers and older children, small compression devices may be applied using the rod and hook configuration. Another alternative in older patients is the use of pedicle screws in the pedicle above and below the hemivertebra with a small rod connecting the two screw heads. If no internal fixation is used, after wound closure, the patient must be turned carefully onto a pediatric spica table and a body spica cast applied that includes both legs down to the ankles. The cast should extend proximally up to the clavicle line. The patient's torso should be bent into the convexity of the curvature to maintain correction. Radiographs should be obtained in the operating room to ensure that the wedge is closed and that adequate correction has been obtained. It is also important to make certain that pressure is applied to the apex of the deformity posteriorly while the plaster is drying to prevent the spine from drifting into kyphosis. If adequate correction has not been obtained, the cast can be wedged while the patient is still under anesthesia. If internal fixation is used, the surgeon will decide whether casting is necessary. If the surgeon feels that the internal fixation was very stable at surgery, the patient may be placed either in a cast or a TLSO after surgery, with a single leg extension, depending on the surgeon's preference. Our opinion is that external immobilization is important regardless of the stability of the internal fixation.

POSTOPERATIVE CARE

Most patients require 5 to 7 days of hospitalization. If the excision was in the thoracic region, the chest tube is usually removed between 36 and 48 hours after surgery. The cast usually remains intact for 3 to 4 months. The patient is maintained in a semireclining position. After about 4 months, the cast is removed, and radiographs are taken to assess healing. The patient is then placed in a thoracolumbar standing orthosis (TLSO) brace, with or without a leg extension, for an additional 2 to 4 months. Most patients heal within 6 to 8 months after surgery.

When the surgeon is comfortable with the security of the internal fixation and allows ambulation in a cast or TLSO with leg extension, the patient is permitted only sedentary activities for 2 to 4 months after surgery. At that time, the patient continues with immobilization for a total of 6 to 8 months, with activities remaining relatively sedentary.

Complications include incomplete correction secondary to inadequate excision of bony material. Pseudarthrosis may occur; however, this is more likely if internal fixation is not used. As mentioned previously, junctional kyphosis at the area of the hemivertebra excision may occur, particularly in patients who are treated without internal fixation. Some authorities believe that this is preventable by extending the fusion on the convex side two segments above and two segments below the hemivertebra, creating a posterior tether. Neurologic problems may also occur, supporting the need for thorough preoperative evaluation.

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2.13 POSTERIOR HARRINGTON COMPRESSION INSTRUMENTATION FOR KYPHOSIS

The use of the heavy ¼-inch Harrington compression rod (the small 3/16-inch rods are not strong enough and should not be used) and the #1256 hooks was the standard method of posterior instrumentation for kyphosis until the development of the Cotrel-Dubousset instrumentation. The Harrington system still has many advantages. The main advantage of the Harrington system, which becomes a significant issue in severe kyphotic deformity, is that it is easier to insert; in addition, the correction can be gained gradually at multiple levels. Although the hooks themselves are more difficult to insert than the Cotrel-Dubousset hooks because they must be on the rod, it is not as difficult as trying to get the original version of Cotrel-Dubousset rod into the closed hooks. The top-loading systems (such as the Moss-Miami) significantly facilitate rod insertion. Probably the only true disadvantage of the Harrington compression system is that a cast or orthotic support is required until arthrodesis is achieved.

The Harrington system remains a useful technique in patients with severe kyphosis to aid in the insertion of a rigid rod. The Harrington compression system is inserted on one side of the spine. The hooks for the rigid rod are placed on the opposite side, and the system is then tightened, gaining partial correction and thus making insertion of the rigid rod easier. It is then removed, and the second rigid rod is used in its place.

The selection of the levels to be fused and the exposure of the spine is the same as for the Cotrel-Dubousset instrumentation. Again, it is important to extend the fusion into the normal lordotic segment of the spine below the kyphosis, usually at L2 or L3.

There should be at least three, and preferably four, hooks on each side of the spine both above and below the kyphotic area. In the thoracic area, the purchase sites can be a combination of lamina and transverse processes. The most cephalad purchase site must be under the lamina. This is necessary to anchor the rod and prevent the hooks from sliding off of the transverse processes. In adolescent boys with strong bones and flexibility restored to the deformity by anterior diskectomy, the most cephalad hook on each side may be under the lamina, whereas the next three can be on the transverse processes. If the bone is porotic, the transverse processes are small, or the curve has remained stiff after the anterior release, more or all of the hooks should be under the lamina (Figs. 2-109 to 2-113).

FIGURE 2-109. To prepare hook sites in the thoracic spine for compression, it is first necessary to remove the overhanging portion of the spinous process and gain access to the spinal canal by removing a portion of the ligamentum flavum. A Kerrison rongeur then is used to remove portions of both the superior and inferior facet, as illustrated at the top of the incision. Generous removal of the spinous processes and facet joints in the thoracic spine is essential to prevent impingement and allow for maximal correction. The inferior hook site and the facetectomy and laminotomy are the same as when the procedure is done with the Cotrel-Dubousset instrumentation.

FIGURE 2-110. Although it is possible and often easier to seat the most cephalad hook and then pass the rod through it, this cannot be done with the remainder of the hooks. The 1/4-inch rod is too inflexible, and the threads will be destroyed during attempts to pull it through the hooks. Therefore, the hooks and the nuts that are used to tighten them are all placed on the rod before its insertion.

Because the hooks are on the rod, it is not possible to tilt the hook and slide it under the lamina. Therefore, to make seating of the hooks possible, the laminotomy that is prepared will have to be larger than in most other circumstances. It should be large enough to "drop" the hook into the spinal canal and then slide it forward under the lamina.

FIGURE 2-111. Compression of this threaded rod is started in the middle on either side of the kyphosis and works toward the ends. Compression is accomplished by spreading the Harrington spreader between a hook holder on the hook and a rod clamp secured to the rod, then advancing the nut by spinning it with a small periosteal elevator. It is not necessary to gain the correction by laboriously turning the nuts with a wrench.

FIGURE 2-112. After the first rod is placed, the surgeon is tempted to tighten it to gain some correction that will make insertion of the second rod easier. This creates some compression of the opposite side, however, closing the holes that had been prepared for the hooks and making their insertion more difficult.

The hooks are tightened starting at the apex and moving from one side of the spine to the other to avoid creation of scoliosis. At the beginning, they can be tightened by the technique of spreading between a hook holder and a rod clamp. After this, the hooks are tightened with a wrench. As the nuts are tightened, the interface between the hook and the bone should be observed to prevent overtightening the hooks and fracturing the bone. If the surgeon is having difficulty judging the amount of correction, a cross-table lateral radiograph can be obtained. When tightening is completed, the threads behind each of the nuts are destroyed to keep them from loosening. This can be done with an old osteotome, twisting it in the threads.

Decortication of all bone that remains exposed is accomplished, and the graft is added before the wound is closed.

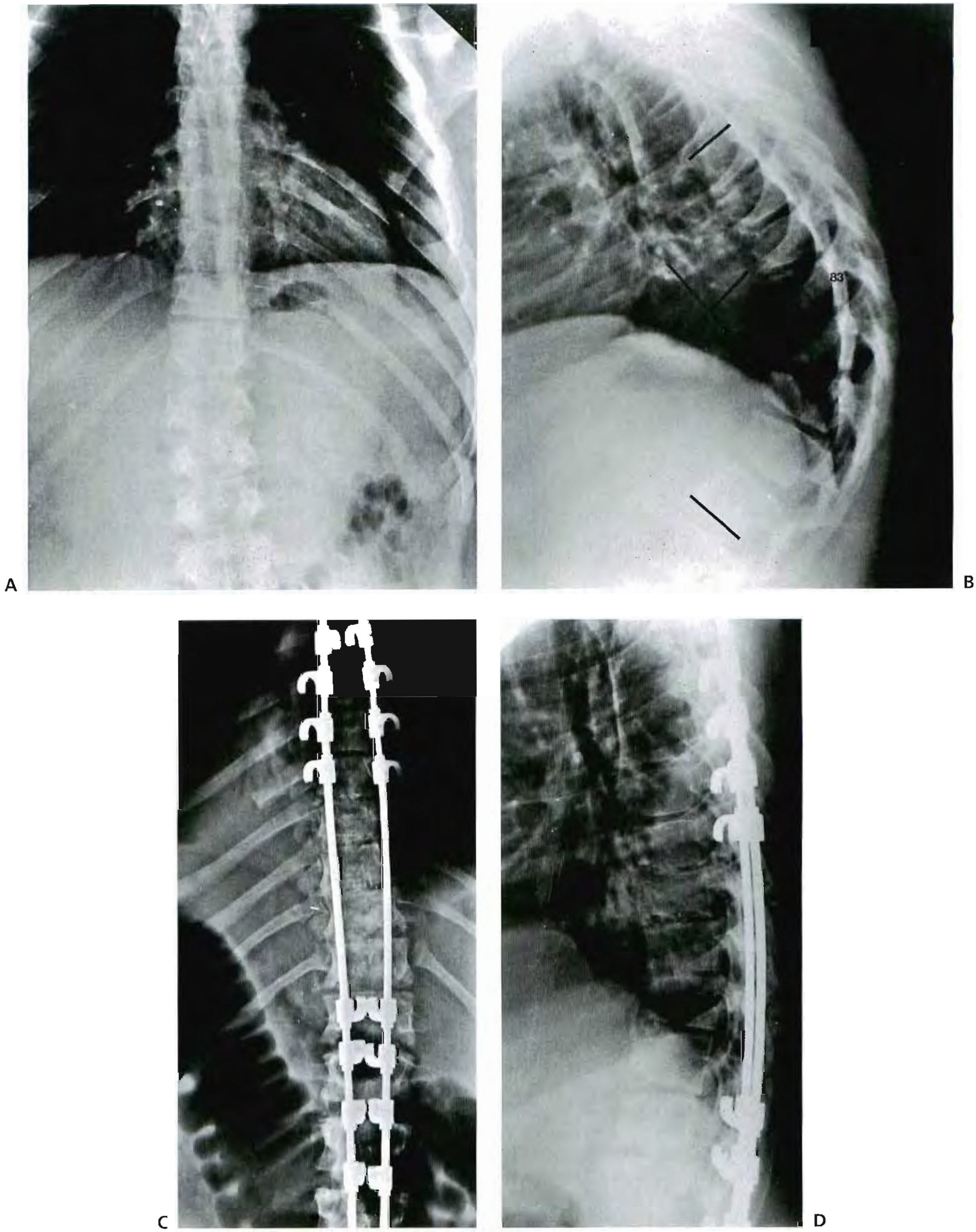


FIGURE 2-113. Radiographs of a 17-year-old boy with a history of deformity for the past 6 to 7 years **(A, B)**, which his parents attributed to "poor posture." During the past 2 to 3 years, he has experienced increasing aching in the region of the apex of the kyphosis. In addition, he was extremely displeased with his appearance. **C, D:** The correction achieved after anterior transthoracic diskectomy and fusion, along with posterior fusion and instrumentation with Harrington compression rods.

POSTOPERATIVE CARE

The fixation is strong enough so that no special concern is given to the initial management of the patient. The patient can be positioned as desired for comfort, and ambulation is usually started on the third or fourth postoperative day without any external support. At the time of discharge, the patient is fitted with a cast or orthosis that is worn for 4 to 6 months.

2.14 POSTERIOR COTREL-DUBOUSSET INSTRUMENTATION FOR KYPHOSIS

The rigid rod system (here the CD system is used as an example) has several attractive features for the treatment of kyphosis. It is very rigid and requires no postoperative immobilization. In patients who also have significant scoliosis, it has the ability to correct both the kyphosis and the scoliosis. The hooks can be placed independent of the rod (unlike the classic Harrington compression rod); it is not a problem to insert the hooks on the other side of the spine after the first hooks have been placed and tightened.

There are also disadvantages. The rods must be contoured to the desired correction, which means that most of the correction is obtained at once. This makes it difficult to get the rod into the inferior hooks in closed-hook systems after they have been placed in the superior hooks. The use of pedicle screws at the bottom of the instrumentation obviates this to a large extent.

The area of the spine that is to be fused is exposed, and the hook sites are prepared. There are two methods of hook purchase that can be used in the instrumentation of kyphosis. They differ in the method used to place the hooks on the thoracic vertebrae (Figs. 2-114 to 2-117).

FIGURE 2-114. The method of hook purchase illustrated here uses the claw configuration on the thoracic vertebrae. On the cephalad side of the kyphosis, there should be at least three purchase sites on each side of the spine. These purchase sites may be of several combinations of claws, supralaminar hooks, and transverse process hooks, all depending on the bone strength, the rigidity of the curve, and the surgeon's choice. Some surgeons prefer to use supralaminar hooks as purchase sites, as opposed to the transverse processes, and some also prefer to place the pedicle hook component of the claw, one level distal. In this case, two claw configurations were used. The third hook was a simple transverse process hook.

An alternative method on the cephalad portion of the kyphos is to use lamina hooks inserted into every other lamina. These can be staggered on each side of the spine. For example, a lamina hook may be inserted on the lamina of T3, T5, and T7 on one side of the spine and on the lamina of T4, T6, and T8 on the other side of the spine. These hooks are inserted on the cephalad aspect of the lamina to provide compression.

Three hook sites should be prepared on each side of the spine inferior to the kyphosis. It is important when selecting levels to extend the instrumentation into the normal lordosis. These hook sites are prepared easily by removing the inferior edge of the lamina and then the ligament flavum to allow the lamina hook to be seated within the spinal canal. The hook sites should be prepared on both sides of the spine before any hooks or rods are placed. If this is not done, the closing of the interlaminar spaces as a result of placing the first rod makes it more difficult to prepare the sites on the opposite side. The use of pedicle screws at the lower end of the kyphosis makes insertion of the rod easier, although they may not make the correction any better.

After this is completed, a radical facetectomy, with removal of a significant portion of the inferior portion of the lamina, is performed in the area of the kyphosis to permit correction. This can be accomplished by entering the spinal canal in the midline and using a Kerrison rongeur to remove the bone. The bone that is removed includes the inferior portion of the lamina and the superior facet as well as a portion of the inferior facet.

A B

FIGURE 2-115. Now comes the most difficult part of this technique: placing the rods and hooks. This is difficult because the rods must first be contoured to the desired final degree of correction; therefore, when they are inserted, most of the correction is gained at one time. If all of the hooks and the rods are placed cephalad to the kyphosis, it is not easy to push them down into the caudal hooks. In a patient with severe kyphosis, the surgeon has the distinct impression that something will break with continued pushing. Several tricks have been suggested to deal with this problem, such as having an assistant push on the apex of the kyphos, trying to lift the pelvis, or placing one rod in the cephalad hooks and one rod in the caudal hooks and pushing both down toward their corresponding empty hooks at the same time as in a double-lever system. These tricks may work in flexible curves.

Another method is to apply a small Harrington compression rod to one side, tighten it to gain correction, and then place the rigid rod system on the opposite side. The Harrington compression rod then is removed and replaced with the second rod **(A)**.

In the thoracic region, the Harrington compression rod **(B)** can be placed on the transverse processes. These are usually strong enough for this temporary correction, and the hooks can be inserted rapidly.

Below the kyphosis, the Harrington hooks can be placed in the holes that have been prepared for the hooks of the rigid rod system.

With the newer top-opening systems, the rod can be secured in the hooks proximal to the kyphosis apex and then cantilevered into the hooks below. Compressive forces are then applied to continue the kyphosis correction.

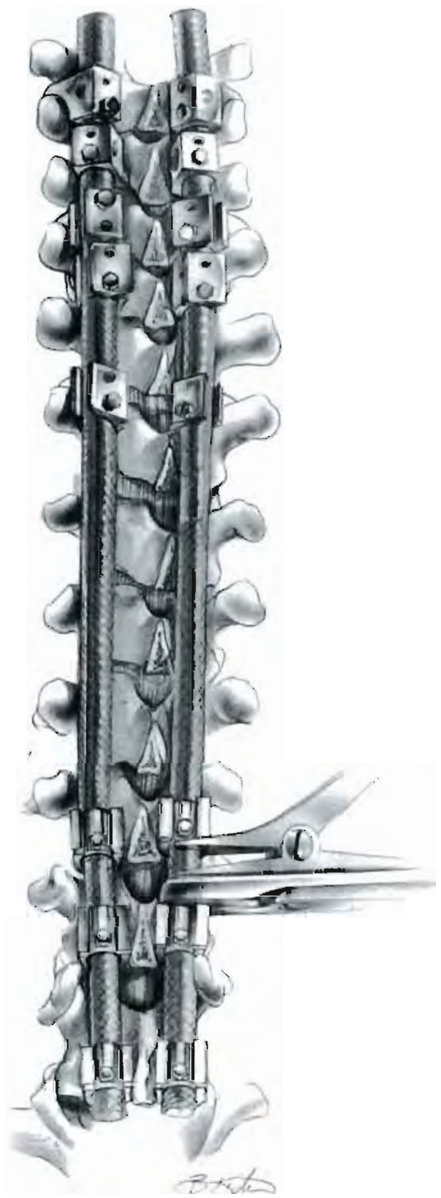


FIGURE 2-116. After both rods are placed, most of the correction will have been obtained if the rods were contoured correctly. Some additional correction may be obtained by tightening the hooks in compression, as was done with the Harrington compression rod, spreading between the hook and a rod holder clamped onto the rod. This has the additional advantage of tightening the hook against the bone and should be performed for each hook. To complete the operation, all possible decortication is accomplished, and a large amount of bone graft is added.

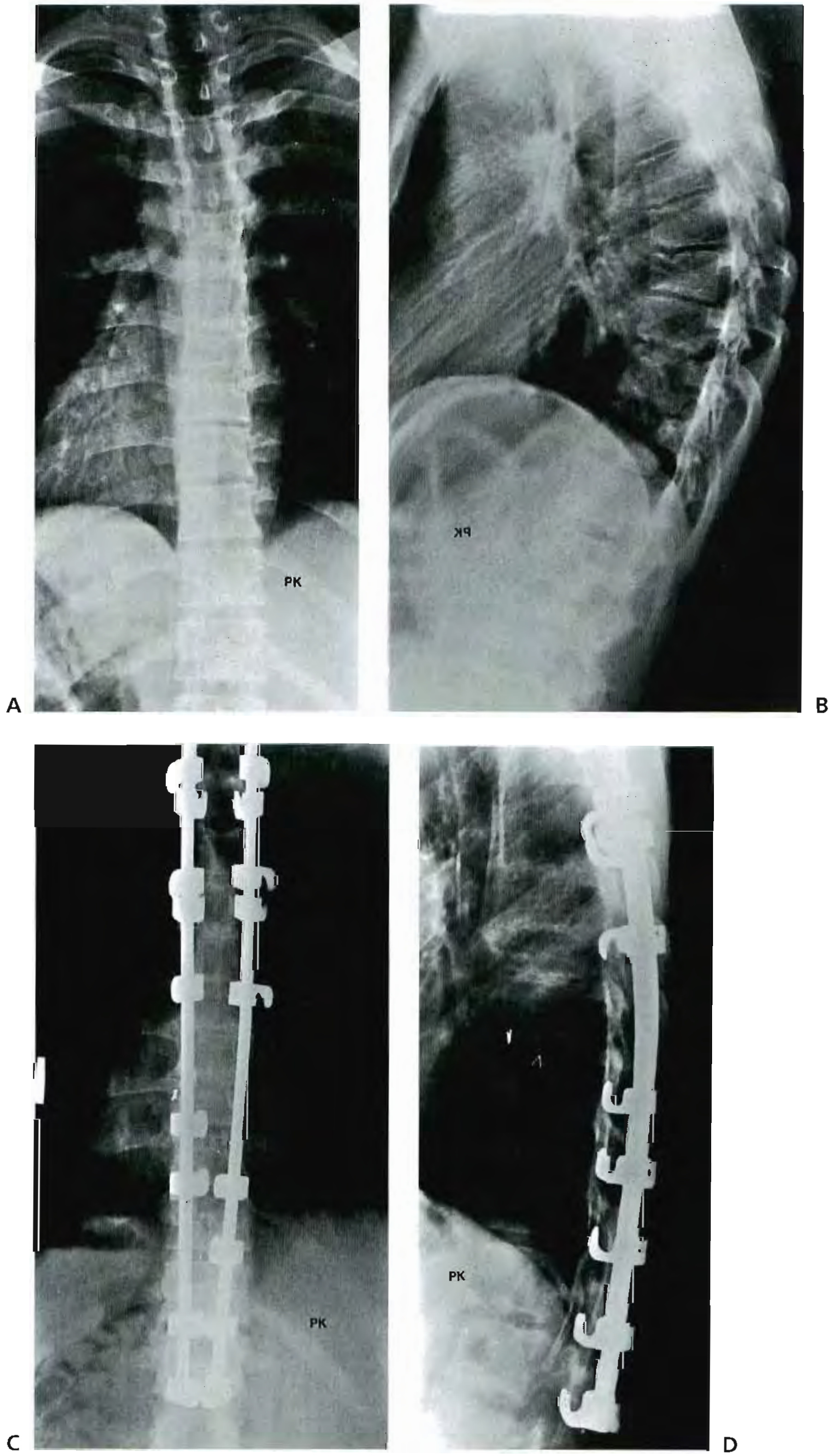


FIGURE 2-117. A, B: The anteroposterior and lateral radiographs of a 17-year-old boy with severe and persisting pain secondary to Scheuermann's kyphosis. **C, D:** The posterior radiographs with the Cotrel-Dubousset instrumentation in place. The upper hooks skipped a level to permit easier insertion, and the lower hooks were staggered to facilitate better decortication.

POSTOPERATIVE CARE

The advantage of the Cotrel-Dubousset instrumentation is that no external immobilization is needed. Therefore, immediate postoperative care is the same as for other spinal operations. The patient is mobilized as quickly as possible and followed in the same manner as a patient with scoliosis treated with the Cotrel-Dubousset instrumentation.

2.15 POSTEROLATERAL ARTHRODESIS FOR SPONDYLOLISTHESIS

Most children who require surgical treatment for spondylolisthesis are treated with an in situ arthrodesis without instrumentation. Because the posterior elements of the affected or slipping vertebrae are detached from the anterior body, the fusion is between the transverse processes lateral to the facets. Unless it is necessary to decompress the nerve roots by removal of the posterior elements and foraminotomy, there is no need to expose these elements completely.

Wiltse and colleagues (1) describe a paraspinal sacrospinalis muscle-splitting approach to the lower vertebrae of the lumbar spine. The advantages that the report cited were a more direct approach to the area involved and less bleeding than with other approaches. There appears to be much less discomfort postoperatively with this approach than with a midline approach (Figs. 2-118 to 2-122).

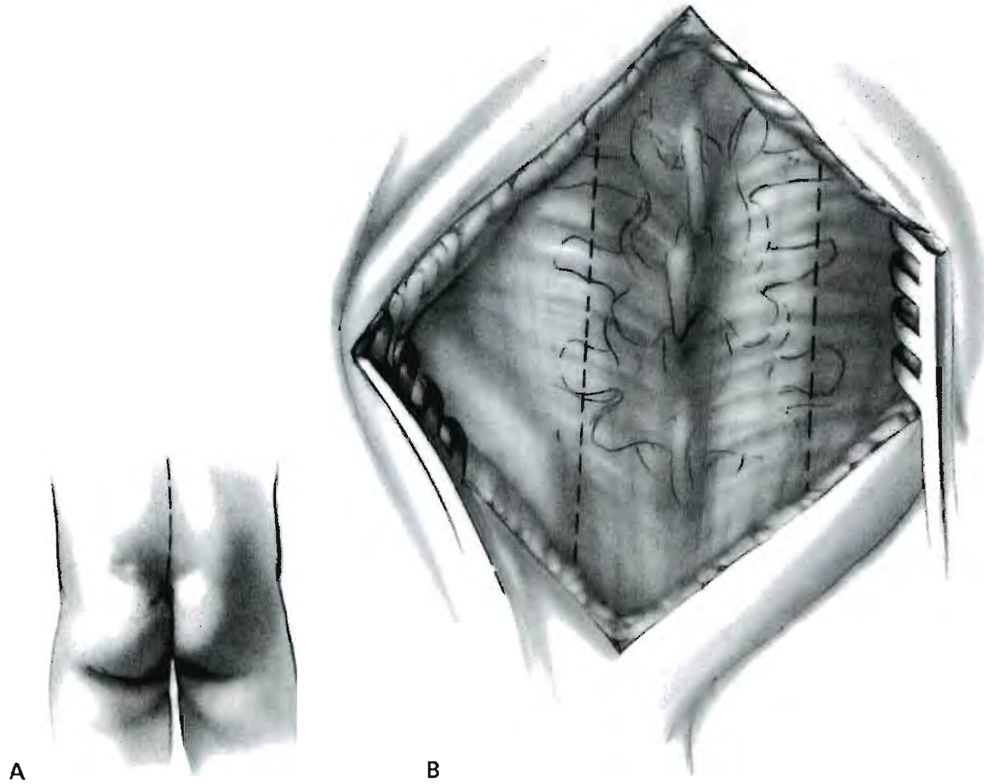


FIGURE 2-118. The patient is placed prone on foam bolsters so that the abdomen remains free. If it is available, a table that reduces the lumbar lordosis might be helpful. We prefer a midline skin incision as opposed to the two lateral incisions described by Wilste and colleagues (1). This incision should extend to the spinous process one level above the most cephalad vertebrae to be fused. As the incision approaches the natal cleft **(A)**, it curves toward the side from which the bone graft is to be taken. (Alternatively, the incision can be made straight but extended slightly distally to be able to access the iliac crest for bone graft harvest.)

The skin is elevated in the interval between the deep investing fascia of the paraspinal muscles and the more superficial layer of fascia. The interval between this layer is easily identified in the midline. It is necessary to carry this dissection **(B)** laterally in each direction for about 4 to 5 cm.

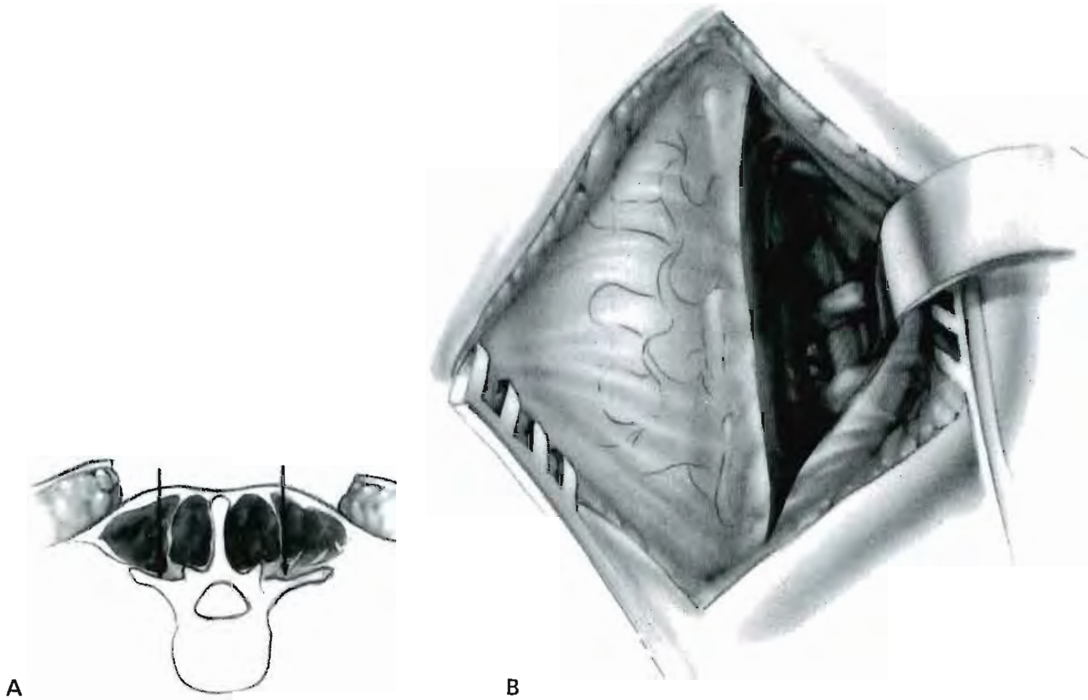
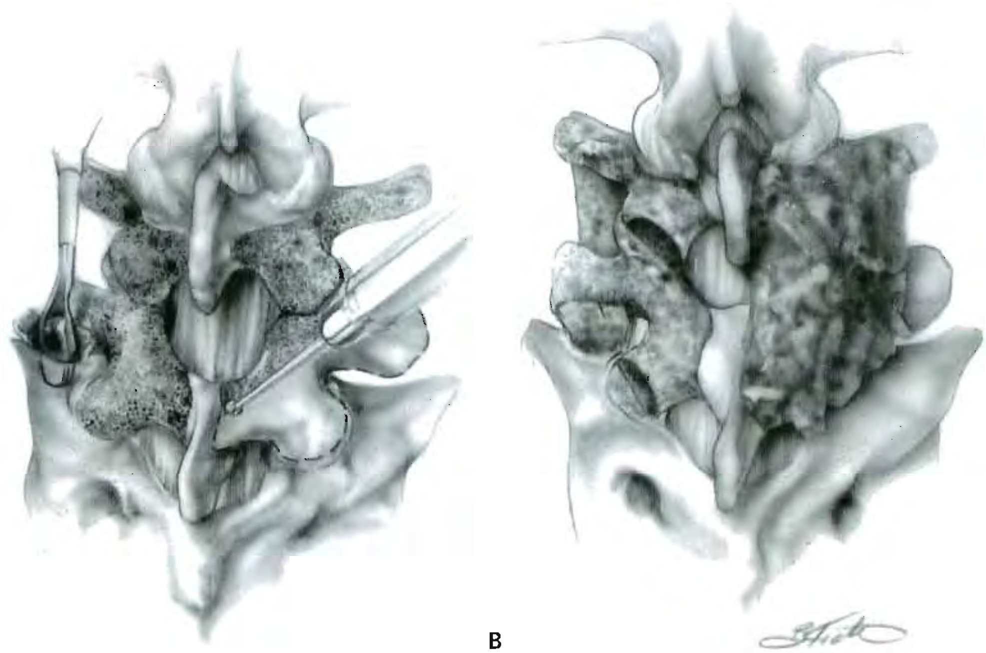


FIGURE 2-119. The sacrospinalis muscles **(A)** are now split about 3 to 4 cm from the midline over the transverse processes. The fascia is divided sharply **(B)** with a knife or electrocautery; then, with a combination of blunt dissection and electrocautery, the muscle is split until the tips of the spinous processes are identified.

FIGURE 2-120. The subperiosteal dissection now proceeds toward the midline, staying on the transverse processes. As the lateral surface of the inferior facet is cleaned, the dissection proceeds to the facet capsule. In the L4 to sacral fusion, the capsule of the L4 to L5 facet is removed, as is the capsule of the L5 to S1 facet; however, the superior facet of L4 articulates with L3, which is not included in the fusion. Therefore, the dissection of the L4 transverse process should stop before removing the capsule of the L3 to L4 facet, which is encountered at the medial extent of the L4 transverse process. The dissection then may proceed onto the lamina, if desired, in an effort to broaden the fusion mass and incorporate the loose posterior elements in the fusion.

The transverse process of the L5 vertebra is the key to identifying the correct levels. In some patients, especially those with more severe slips, it may be difficult to identify because it lies directly anterior to the ala of the sacrum and may be small. Because of this, it is easy to mistake the L4 transverse process for the L5 process unless care is also taken to identify the lumbosacral facet and follow it down to the transverse process of L5. At the same time that the transverse process of L5 is exposed, the ala of the sacrum is exposed. Here, the periosteum is thick and adherent, and special effort is required to ensure that it is well exposed.

After the exposure is completed on both sides, a tight packing is placed. This stops most of the venous bleeding and helps stretch and retract the tissues, making the next part easier. This is a good time to take the bone graft from the iliac crest.



A B

FIGURE 2-121. The next step is the decortication. We prefer to use a 5-mm bur because it provides excellent control and the ability to completely decorticate all of the transverse processes, the lateral side of the L4 superior facet, the lamina, and the facet joints. After this decortication is completed **(A)**, a Capener gouge is used to create a hole in the ala of the sacrum.

Next, as described by Hensinger and colleagues (2), a piece of cortical bone **(B)** is placed in this hole and under the L5 transverse process. This can be difficult in severe slips because the transverse process of L5 lies adjacent to the ala and anterior to the hole in the ala. In these cases, a piece of cortical bone placed anterior to the transverse processes of L4 and into the hole in the ala will accomplish the same thing. In mild slips (usually not the ones requiring fusion), the piece of cortical bone can extend from the ala to beneath both L5 and L4. This has the effect of preventing the muscles from displacing the cancellous bone graft, which is added next.

After the bone graft is placed, the muscle layers are allowed to fall together. Care should be taken to be certain that the bone graft is not dislodged by the muscles. If desired, the fascia can be closed to provide better hemostasis. Drains can be used beneath the flaps if it is believed necessary, and the midline incision is then closed.

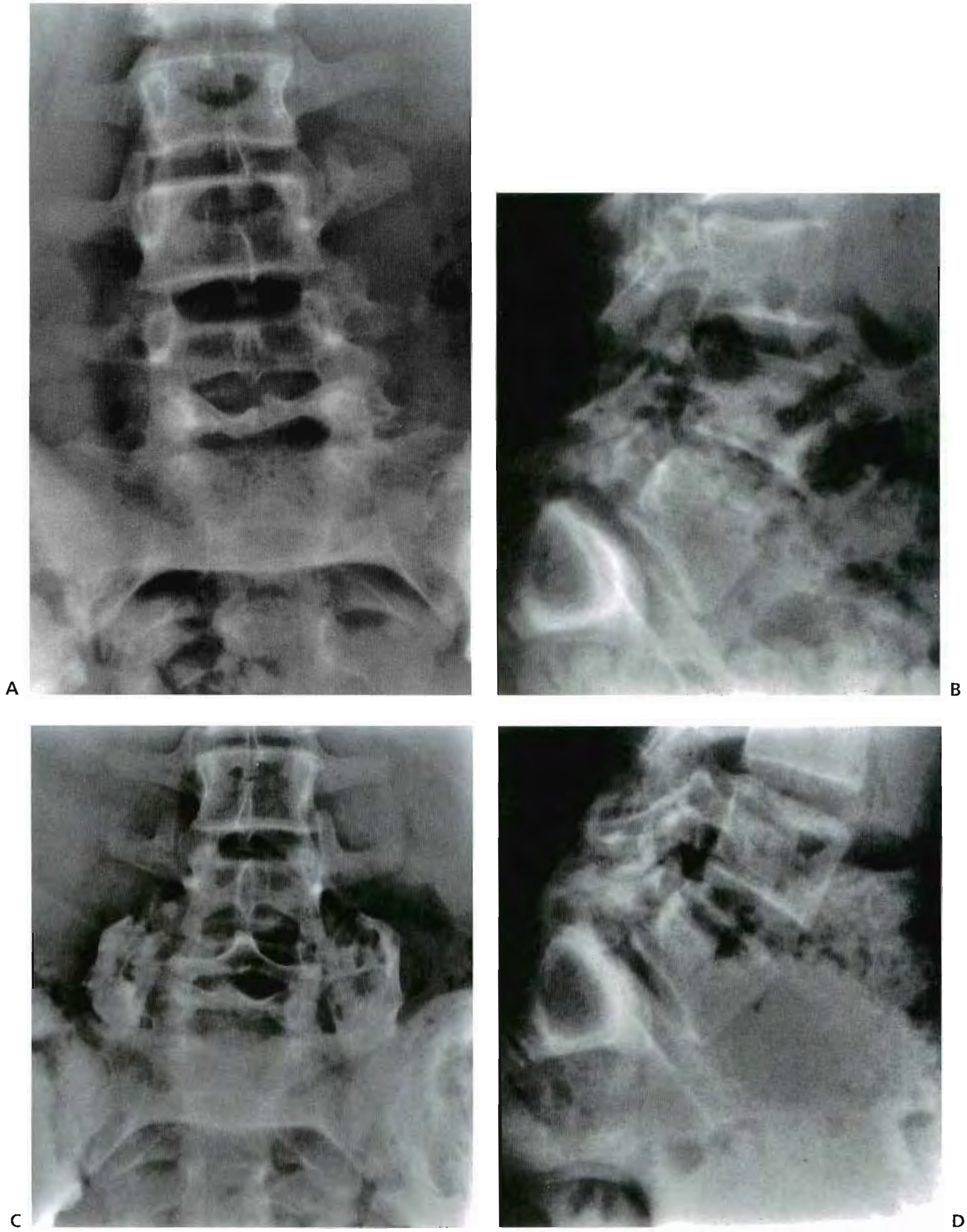


FIGURE 2-122. The anteroposterior and lateral radiographs **(A, B)** of a 13-year-old boy with a several-year history of increasingly severe back pain, made worse with activity and unresponsive to conservative measures during the past year. He underwent a posterolateral arthrodesis. Radiographs 6 months after surgery **(C, D)** demonstrate a consolidating arthrodesis.

POSTOPERATIVE CARE

The use of a brace, a cast, or bed rest depends on the surgeon's preference and the degree of slip and slip angle. For cases in which reduction is not accomplished, we prefer to use a prefabricated plastic lumbosacral orthosis for 4 months to limit lumbar motion. Patients are ambulatory the day after surgery and before their brace is ready. They usually can be discharged from the hospital on the third post-operative day. Normal activities are resumed when there is radiographic evidence of a solid arthrodesis.

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2.16 ONE-STAGE DECOMPRESSION AND POSTEROLATERAL AND ANTERIOR INTERBODY FUSION FOR HIGH-GRADE SPONDYLOLISTHESIS

The gold standard for treatment of severe symptomatic high-grade spondylolisthesis has been in situ fusion (1–3). The approach may be done by posterior interlaminar method or by the more popular bilateral intertransverse process, lateral gutter technique (4). Both methods have been reported to be effective with low rates of complications (2,5–8).

In situ fusion has been criticized as having a higher associated incidence of pseudarthrosis, not preventing bending of the fusion mass, and failing to correct deformity (9). The use of anterior iliac crest or fibular strut grafts has been recommended to avoid pseudarthrosis (10,11). The anterior approach to the lumbosacral junction, however, is not without risk, with reports of injury to the great vessels, sympathetic plexus, retrograde ejaculation, and sterility (10–14). More recently, combined approaches to high-grade unstable slips or staged procedures have been recommended (15–17). In addition, vertebral body resection, spinal osteotomy, and various techniques of reduction, or combinations of all of the above, have been recommended but are extremely difficult procedures with considerable rates of complications (9,18–20).

In 1982, Bohlman and Cook (21) described a one-stage decompression and posterolateral and interbody fusion technique through a posterior approach. Smith and Bohlman (22) later reported long-term follow-up of 11 patients in whom this technique was used to provide for spinal decompression and arthrodesis without correction of deformity. The procedure is generally recommended for mature patients. The goals of operative management are neural decompression and stabilization of the lumbosacral kyphosis. Indications for the procedure are high-grade spondylolisthesis (grade III, IV spondylolisthesis or spondyloptosis) with severe pain in the back or lower limb and objective sensory or motor impairment. The operation is also indicated in patients who have had previous failed surgical procedures. Preoperative evaluation should include a magnetic resonance imaging scan to demonstrate the severity of compression by the posterior aspect of the sacrum to determine the extent (if any) of sacral removal necessary. Computed tomography scans may be helpful in delineating the anatomy of the deformity (Figs. 2-123 to 2-128).

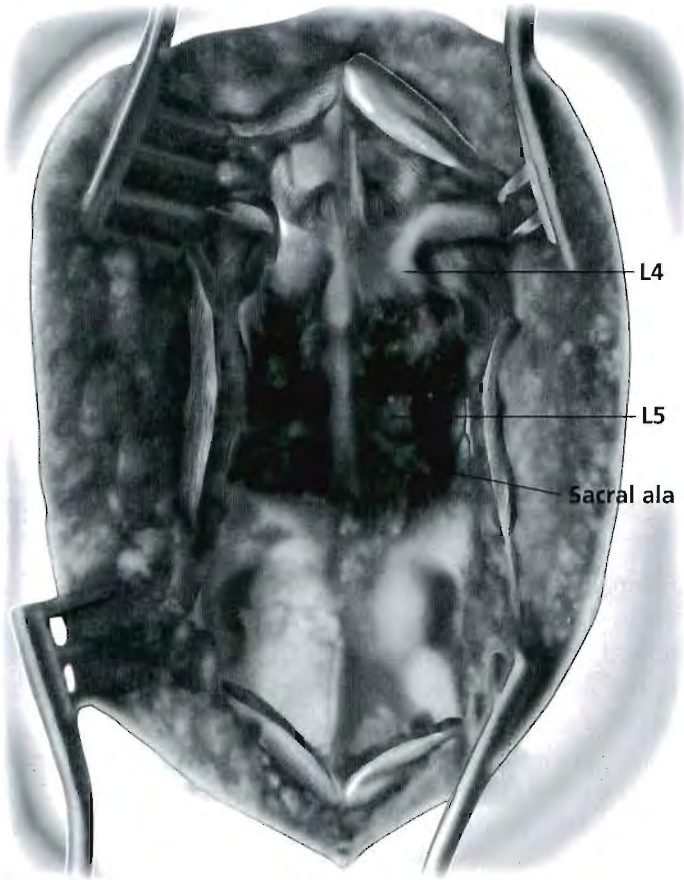


FIGURE 2-123. The patient is placed prone on a standard operating room spinal table (e.g., spinal frame on a standard operating room table, or special spinal table such as the Jackson table). Great care should be exercised in turning the patient to the prone position because in unstable high-grade slips, particularly in type I spondylolisthesis, the cauda equina is at risk for injury (23). One limb should be prepared in a sterile fashion for later fibular bone graft harvest.

A standard midline approach from L3 to S2 or S3 is made. The spine is carefully exposed subperiosteally from the tip of the transverse process of the fourth lumbar vertebra to the ala of the sacrum and down to S2 or S3. Great care must be taken when dissecting the loose posterior element because cauda equina injury may occur.

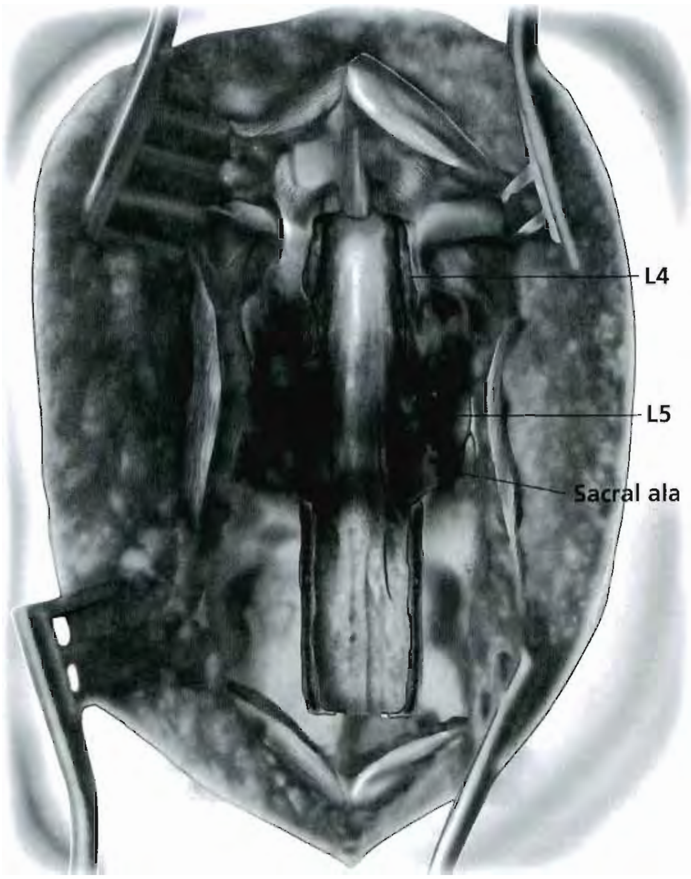


FIGURE 2-124. The loose posterior element of L5 is completely removed, taking great care not to injure underlying tissues. This is particularly important in patients who have had previous surgery. An additional laminectomy of the fourth lumbar to first sacral segments is also performed. Extension of the laminectomy distally to S2 may later be necessary to allow for dural sac and sacral nerve root retraction later in the procedure. The fifth lumbar nerve roots are decompressed by foraminotomy with excision of the inferior pedicle, disk, or both, as needed. Occasionally, the pedicle can be drilled and hollowed out and the walls collapsed inward to allow for the L5 nerve root to be untethered. The L5 nerve roots are often scarred or compressed by the sacral dome. In these high-grade kyphotic deformities, the roots are coursing almost directly anteriorly. At this juncture, the exposed area should include the dural sac and all nerve roots from L4 to S2.

FIGURE 2-125. When preoperative magnetic resonance imaging demonstrates a high-grade block because of posterior sacral obstruction, an osteotomy of the sacral prominence is accomplished to decompress the sacral dural sac. It may occasionally be necessary to remove a portion of the S2 or S3 lamina to allow for adequate dural and nerve root retraction. This is also needed for safe placement of the cannulated drill for the interbody graft placement. The osteotomy of the sacral prominence is done with an osteotome, first from one side and then from the other, working underneath the dura. Great care must be taken when retracting the dural sac and nerve roots. Any dural lacerations should be repaired with fine 6-0 suture at the time incurred, and/or with facial grafting as necessary. Bone wax can be used to control sacral medullary bleeding after the osteototomy. When adequate bone has been removed, the dural sac will fall forward and thus accomplish sacral root decompression.

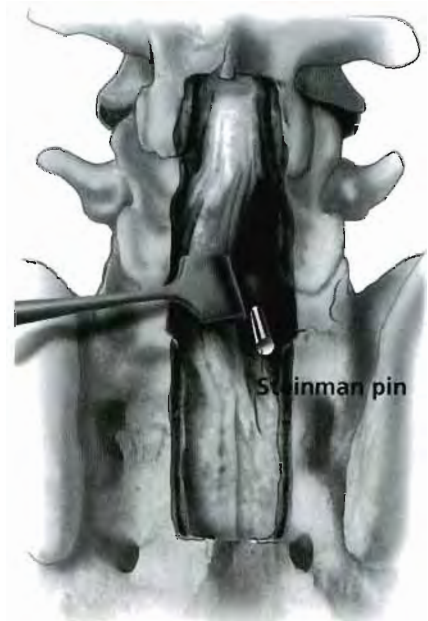


FIGURE 2-126. The dural sac is then retracted to expose the posterior aspect of S1. A 0.32-cm guide pin is inserted in the midline of the sacrum directed cranially into the dislocated and displaced body of the fifth lumbar vertebra. Fluoroscopic control is mandatory. A ½-inch or 10-mm cannulated drill is introduced over the guide pin, taking great care not to perforate the anterior cortex of the fifth lumbar vertebral body. The drilling can be done with a hand drill or power drill as preferred by the surgeon. Cortical perforation of L5 could lead to serious complications, with vessel or organ injury.

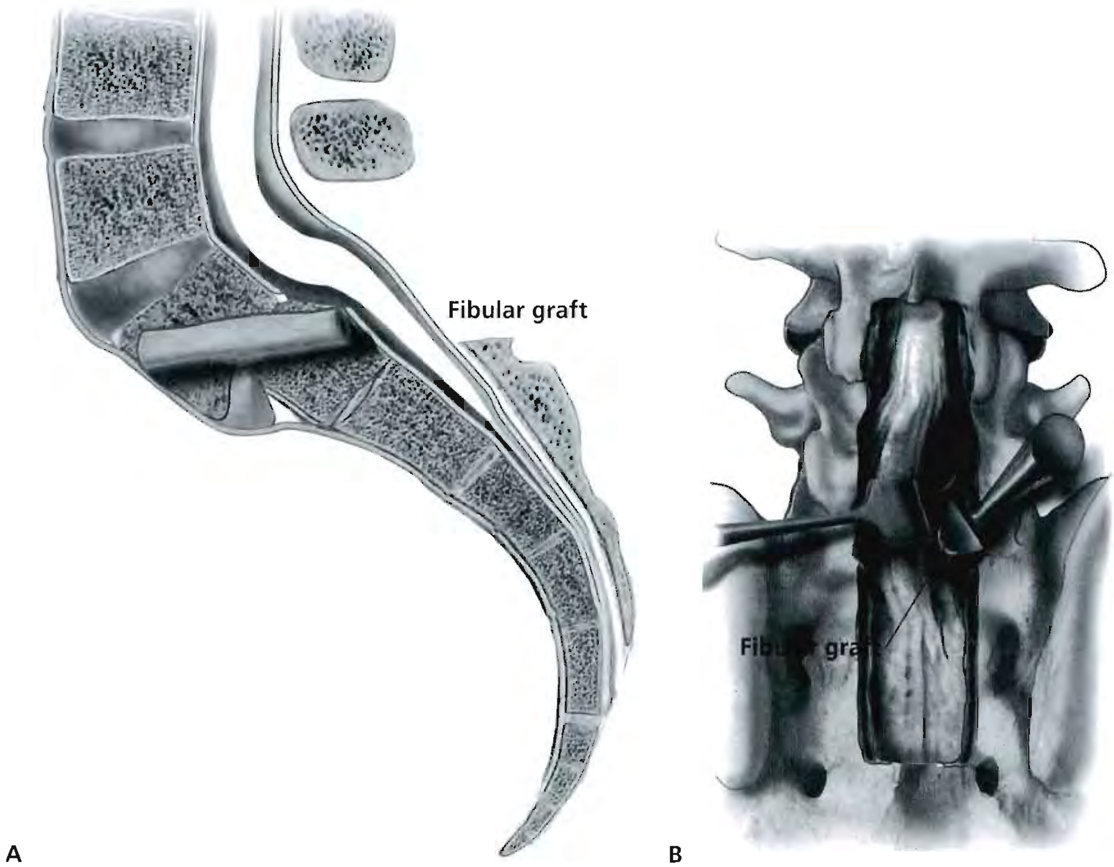


FIGURE 2-127. A middiaphyseal fibular graft is harvested and trimmed to fit (length; diameter is usually compatible with the 10-mm drill) into the drill hole when inserted. It is important to make certain the fibular graft does not protrude into the spinal canal after insertion. The fibular graft is impacted up to the cortical edge of the cephalad surface of the L5 vertebral body. After this is completed, a posterolateral fusion of L4 to S1 is completed in the standard fashion, with large amounts of allograft bone harvested from the iliac crest (see Fig. 2-121–157). The wound is closed over a suction drain. Prophylactic antibiotics are used preoperatively and perioperatively.

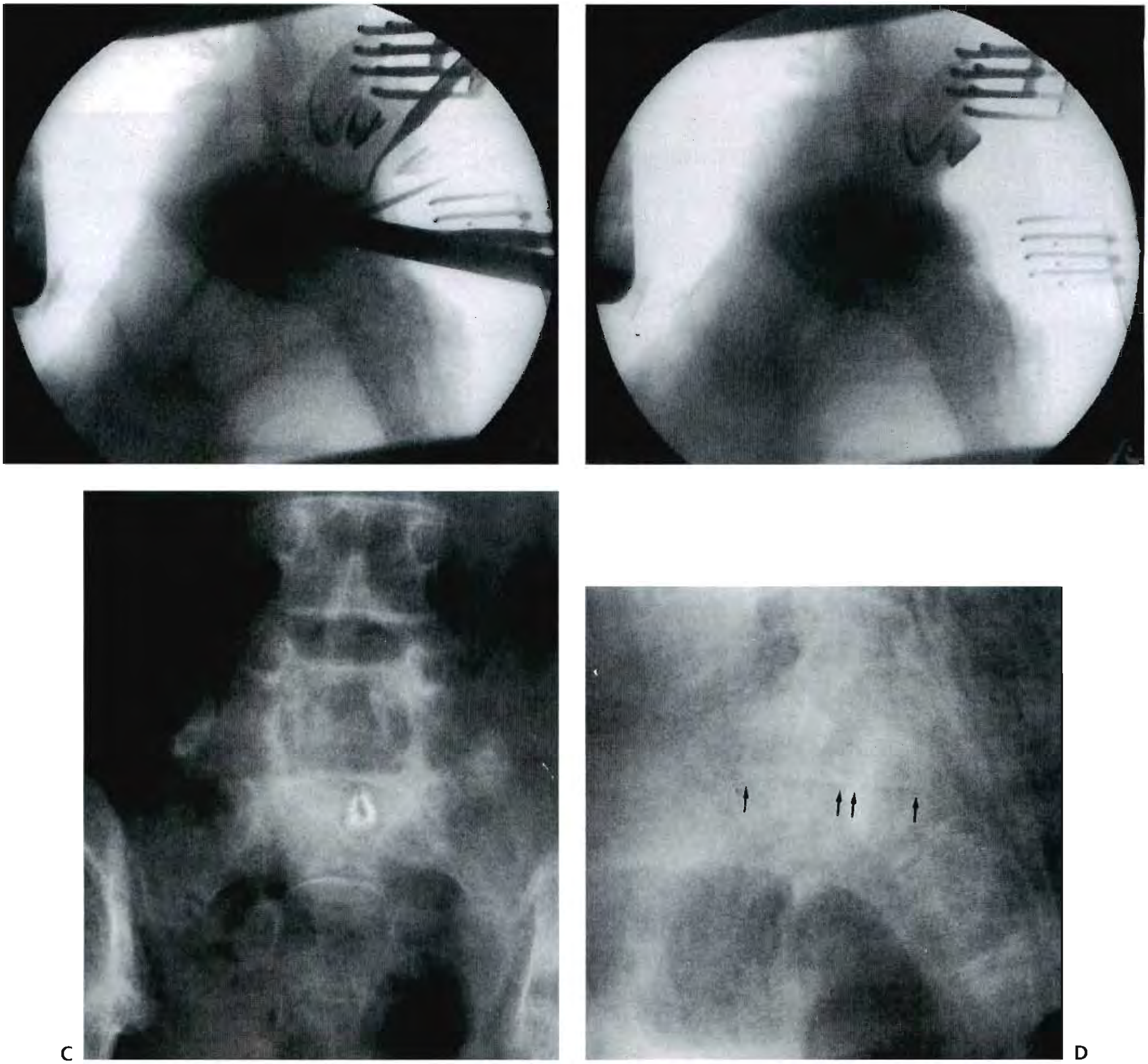
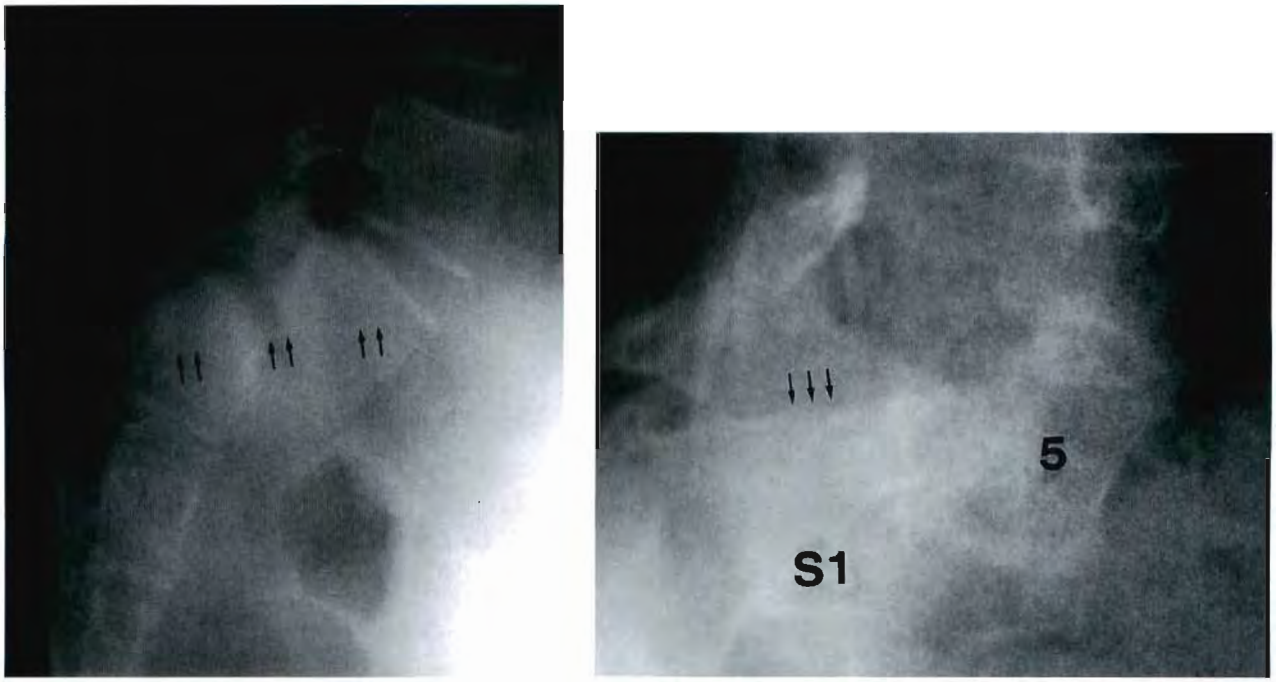


FIGURE 2-128. This 13-year-old girl with a high-grade type I (dysplastic) spondylolisthesis had experienced progression and failure of symptom relief from a previous L4 to sacrum in situ fusion. She had evidence of a severe L5 radiculopathy, including numbness in the L5 nerve distribution, and a weak EHL. Straight-leg lift was possible to only 2 inches off the examination table. Gait was waddling with a short stride length. Bowel and bladder control was normal. **A:** The 10-mm cannulated drill in place. **B:** The fibular bone graft in place in the operating room. **C, D:** The anteroposterior and lateral views of the lumbosacral junction in the plaster pantaloon 1 week after surgery. The patient was managed after surgery in a pantaloon spica for 6 months. (*continued*)



E F

FIGURE 2-128. (*Continued*) **E, F:** The lateral and oblique views 6 months after surgery, demonstrating good graft incorporation. The radiculopathy resolved completely, and the patient could perform the straight-leg raise to 90 degrees.

POSTOPERATIVE CARE

Postoperative treatment consists of bed rest until comfortable and then ambulation. Smith and Bohlman (22) believe that this technique is inherently stable and requires no supplementary internal fixation or external support. In immature patients, consideration to using a pantaloon spica cast should be given because these patients have greater potential for increased slippage in the first several months after surgery.

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2.17 POSTERIOR ARTHRODESIS C1 TO C2: GALLIE TECHNIQUE

The most common arthrodesis of the cervical spine is between the axis and the atlas because of the numerous congenital and developmental problems that affect this region. Although several techniques have been advocated to achieve arthrodesis of these vertebrae, the technique attributed to Gallie (1) is the most reliable and easiest to apply in children. In this technique, the wire not only helps to pull C1 back into position and hold it there but also holds the bone graft firmly in place (2,3). Occasionally, the posterior arch of C1 is not formed completely, making this technique impossible. Other techniques are possible (5).

In cases in which there is a great deal of instability with chance for neurologic injury, we prefer to place the patient in a halo vest or cast first. This can be done with local or general anesthesia as the circumstance demands. Reduction is achieved and confirmed by radiographs. If awake, the patient is now anesthetized and turned prone for the posterior fusion. No head rest is necessary, and there is little danger of neurologic injury while intubating and moving the patient (Figs. 2-129 to 2-136).

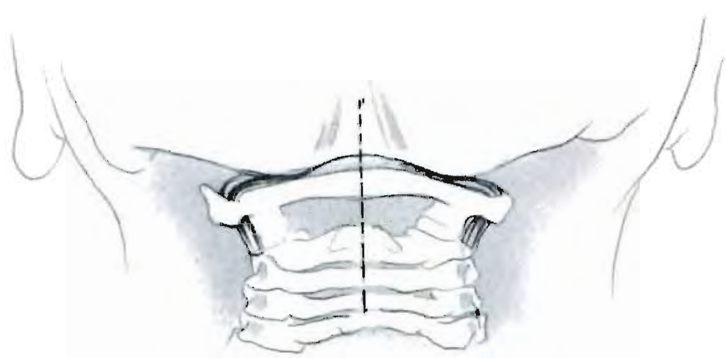

FIGURE 2-129. The occipital region of the skull is shaved, and the posterocervical area and the posterior iliac crest are prepared and draped. The incision extends in the midline from the base of the skull to the spinous process of C4. Dissection is carried down to the tips of the spinous processes. At this point, a metal hub needle is placed in the spinous process of C2, and a lateral radiograph is taken. This is done to identify positively the correct vertebrae to be exposed. In the young child, exposure of the base of the skull or any additional vertebrae may result in "creeping fusion."

FIGURE 2-130. When correctly identified, the posterior arch of C1 and the lamina of C2 are exposed subperiosteally by a combination of sharp and blunt dissection. It is important to remember that the vertebral arteries are unprotected by the bony foramen at the C1 level just lateral to the facets. In small children, this is about 1 cm from the midline; in larger children, it is about 1.5 cm from the midline.

To prepare the arch of C1 for passage of the wire beneath it, the periosteum must be separated from its anterior surface. This can be accomplished with a small, angulated, neural elevator. The spinal canal does not need to be opened. After this, a dental bur can be used to decorticate the exposed lamina of C1 and C2. This does not have to be as deep of a decortication as is performed in scoliosis cases.

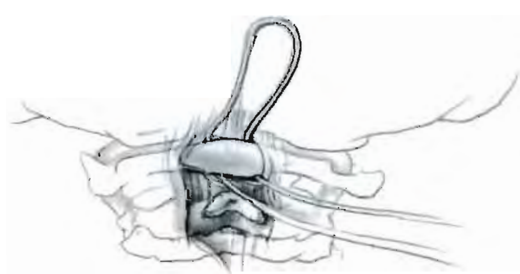

FIGURE 2-131. A loop of wire is passed under the arch of C1 from inferior to superior. The wire is bent back on itself, forming a smooth loop. Care should be taken not to introduce any sharp bends in the wire. The size of the wire depends on both the size of the child and the preference of the surgeon. Any size from 18 to 22 gauge can be used. Good-quality, fully annealed flexible wire allows a relatively larger size to be used because it pulls through easily without kinking.

FIGURE 2-132. The corticocancellous graft, which has previously been obtained and fashioned to fit over the lamina of C1 and C2, is now put in place. Small pieces of cancellous bone can be added beneath the corticocancellous graft. The loop of wire is pulled from under the arch of C1 over the graft and is placed around the spinous process of C2. A small notch cut in the base of the C2 spinous process helps to keep this in place.

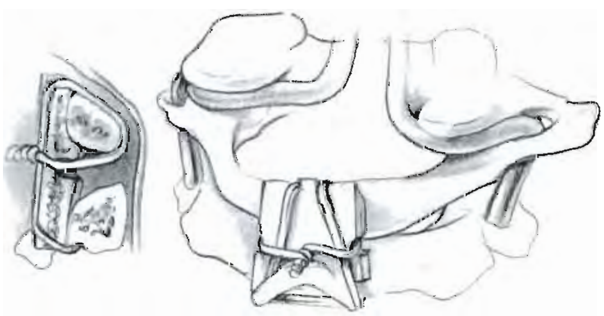

FIGURE 2-133. The two ends of the wire that come out from under the arch of C1 inferiorly are pulled tight and brought around the sides and over the top of the graft. It is at this point, when the surgeon is pulling the wire tight, that the importance of a flexible wire that is not too large is realized. In working with the wire, it is best to keep it taut. This minimizes the possibility of the wire impinging on the spinal cord and makes tightening easier. After the wire is pulled tight, it can be secured with a wire twister.

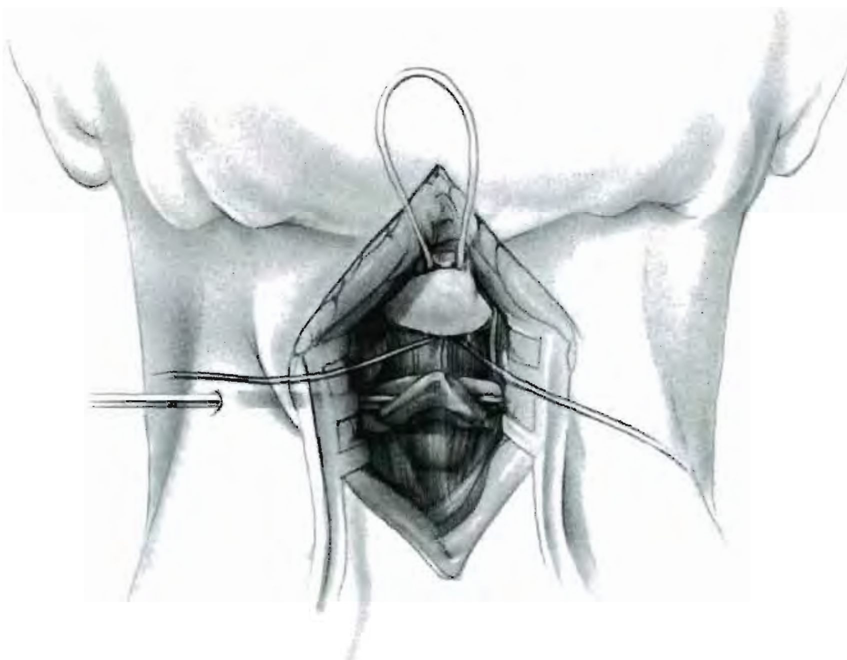

FIGURE 2-134. In children, the spinous process of C2 is often small and does not provide much strength for fixation of the wire. A technique for circumventing this problem has been suggested (4). In this technique, a threaded K wire of appropriate size is passed through a small stab wound in the side of the neck and through the paravertebral muscles and is drilled through the spinous process of C2. It is cut so that about 1 cm is protruding on each side.

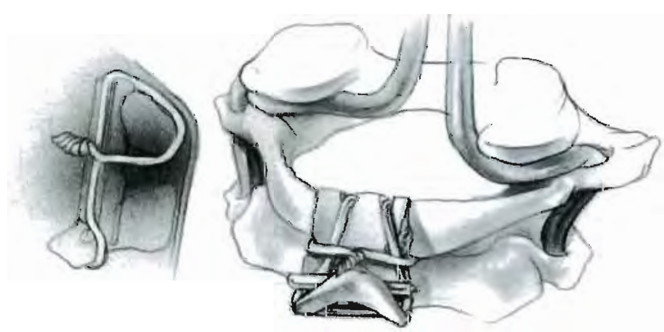

FIGURE 2-135. The corticocancellous graft is then put in place. It should fit under the K wire. The loop of wire that comes from under the arch of C1 is then drawn over the graft and looped around the spinous process of C2. The wire loop will be under the transverse Kirschner wire, however, which keeps it from slipping off the spinous process.

A

B

C

FIGURE 2-136. An 8-year-old child with a history of occipital headaches was observed by her orthodontist to have an absent odontoid. The extension lateral view of the cervical spine **(A)** demonstrates the os odontoideum. The flexion lateral radiograph **(B)** demonstrates the instability. One year after a posterior arthrodesis of C1 and C2 **(C)** with fixation by the Gallie technique, the spine is stable. Note the creeping fusion between the spinous processes of C2 and C3 where the interspinous ligament was cut.

POSTOPERATIVE CARE

There should be radiographic evidence of solid arthrodesis in 10 to 12 weeks. The postoperative care concerns what type of immobilization should be used until that time. Our preference has been to leave the halo on for about 6 to 8 weeks in young and unreliable children, followed by some type of collar for an additional 4 weeks. In reliable adolescents, in whom the bone is stronger, a Philadelphia collar or similar device is usually adequate.

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2.18 OCCIPITOCERVICAL FACET FUSION AFTER LAMINECTOMY WITH OR WITHOUT INTERNAL FIXATION

Occipitoatloid instability requiring occipitocervical fusion is often complicated by the fact that decompression of the base of the skull and the upper two cervical vertebrae is either required or the cause of the instability. These circumstances compromise the ability to achieve fusion because of the lack of bone surface to form a bed for the grafts, the large gap that must be bridged, and the instability (1). In addition, it has been demonstrated that the conventional cervical orthoses do not provide much immobilization for the upper cervical spine (2).

To circumvent these problems and provide stability to the fusion area, surgeons have developed methods of internal fixation (3,4). Many of these methods have developed from modifications of the Luque rod system (5). In 1986, Ransford and colleagues (1) published a report of a series of three patients and described the technique. In the same year, Bridwell reported a case treated in the same manner (6). Two years later, Itho and colleagues (7) reported a series of 13 patients treated with a prebent 4-mm rod. Since these reports, the technique has become more widespread (Figs. 2-137 to 2-145).

FIGURE 2-137. The patient is positioned in the prone position. If the halo has not been applied to the skull, it is done before the patient is turned prone. The halo may be attached to the operating table by use of a specially designed attachment or may be attached to traction, depending on the needs of the case.

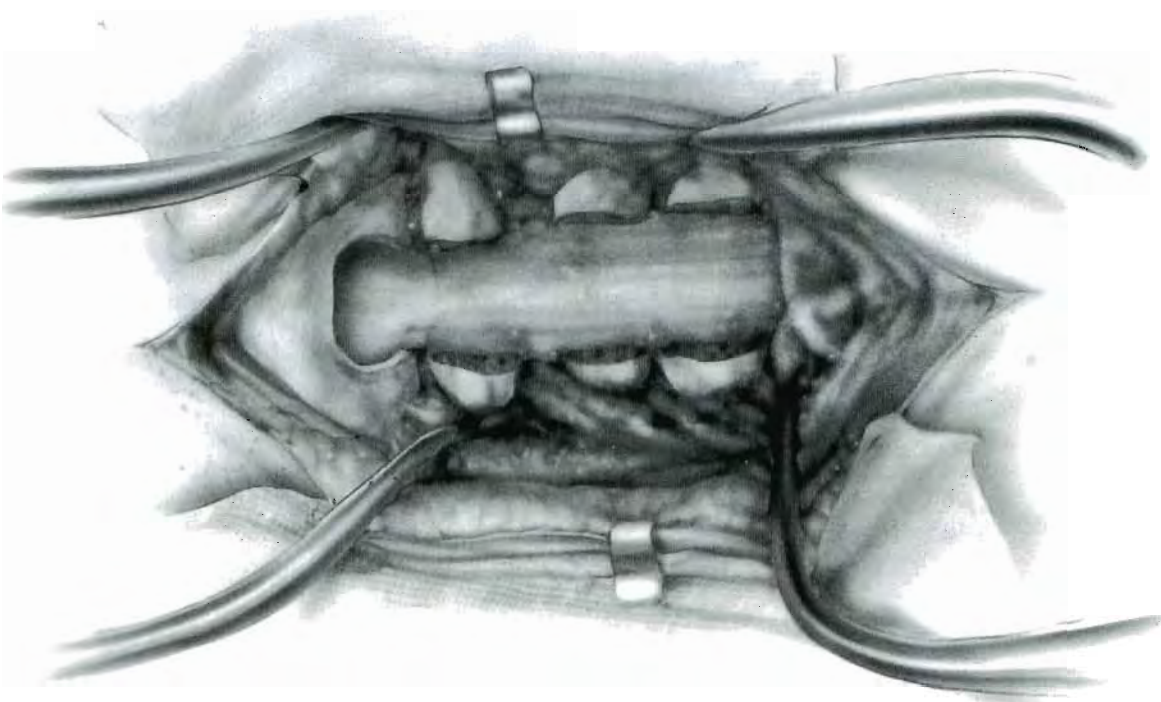

FIGURE 2-138. After the usual skin preparation and draping, a midline incision is used to expose the base of the skull and the cervical vertebrae to be fused. It is important to carry the subperiosteal dissection far enough laterally to have sufficient bone remaining after the laminectomy but not so far as to get into the venous plexus lateral to the facet joints or especially the vertebral artery at the C1 level. In the average-sized adult, the dissection should not proceed further than 1.5 cm lateral to the midline to avoid the vertebral artery as it crosses the arch of C1. In the child, 1 cm is safe. The laminectomy and suboccipital decompressions are performed as indicated.

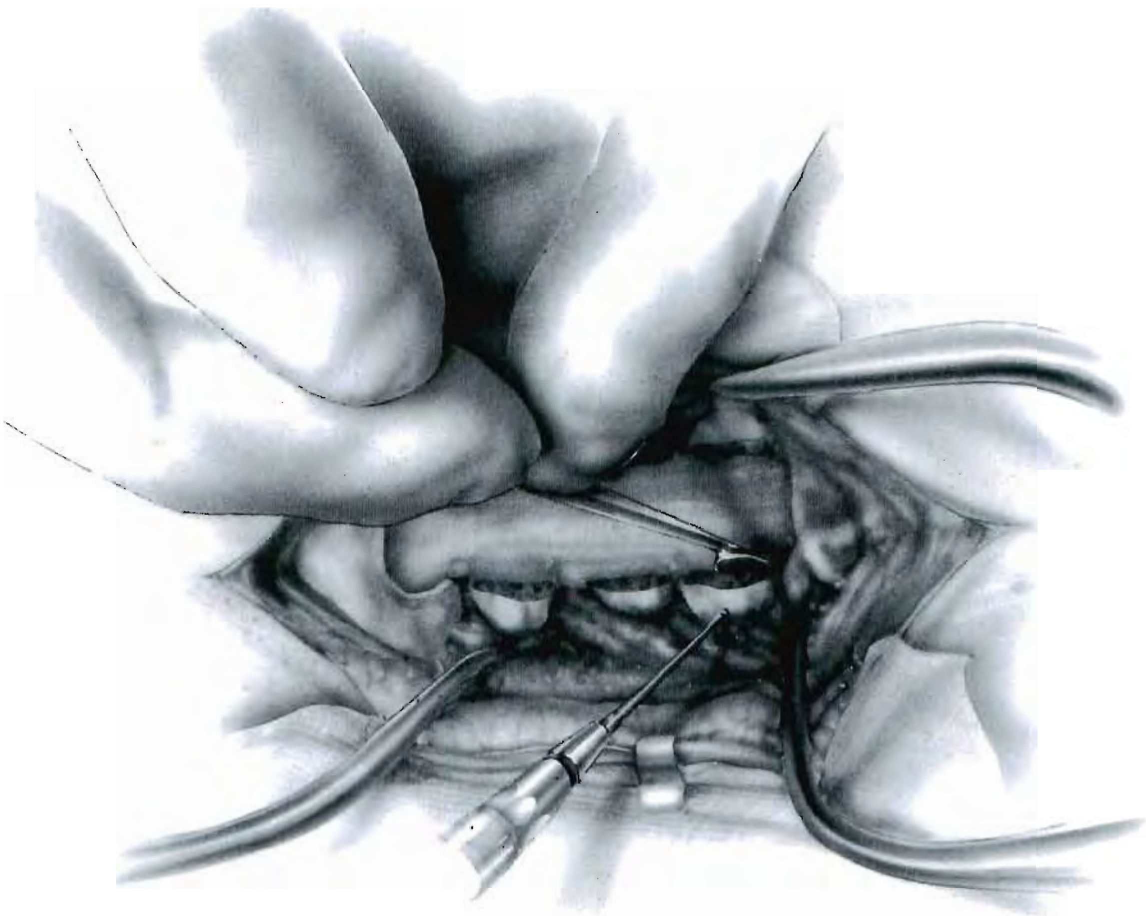

FIGURE 2-139. After completion of the laminectomy, a small periosteal elevator is used to dissect the periosteum off the underside of the remaining portions of the lamina. A small thin elevator is then placed under the lamina to protect the dura.

Using a high-speed drill, a small hole is made in each lamina through which a wire will be passed. Care must be taken to be certain that the elevator is under the portion of the lamina that the drill will penetrate.

If the occiput is included in the fusion, holes are made in the occiput. It is extremely important that this is done by someone who is familiar with the anatomy of the base of the skull to avoid the large venous sinuses in this area. Several techniques for this are described (7,8).

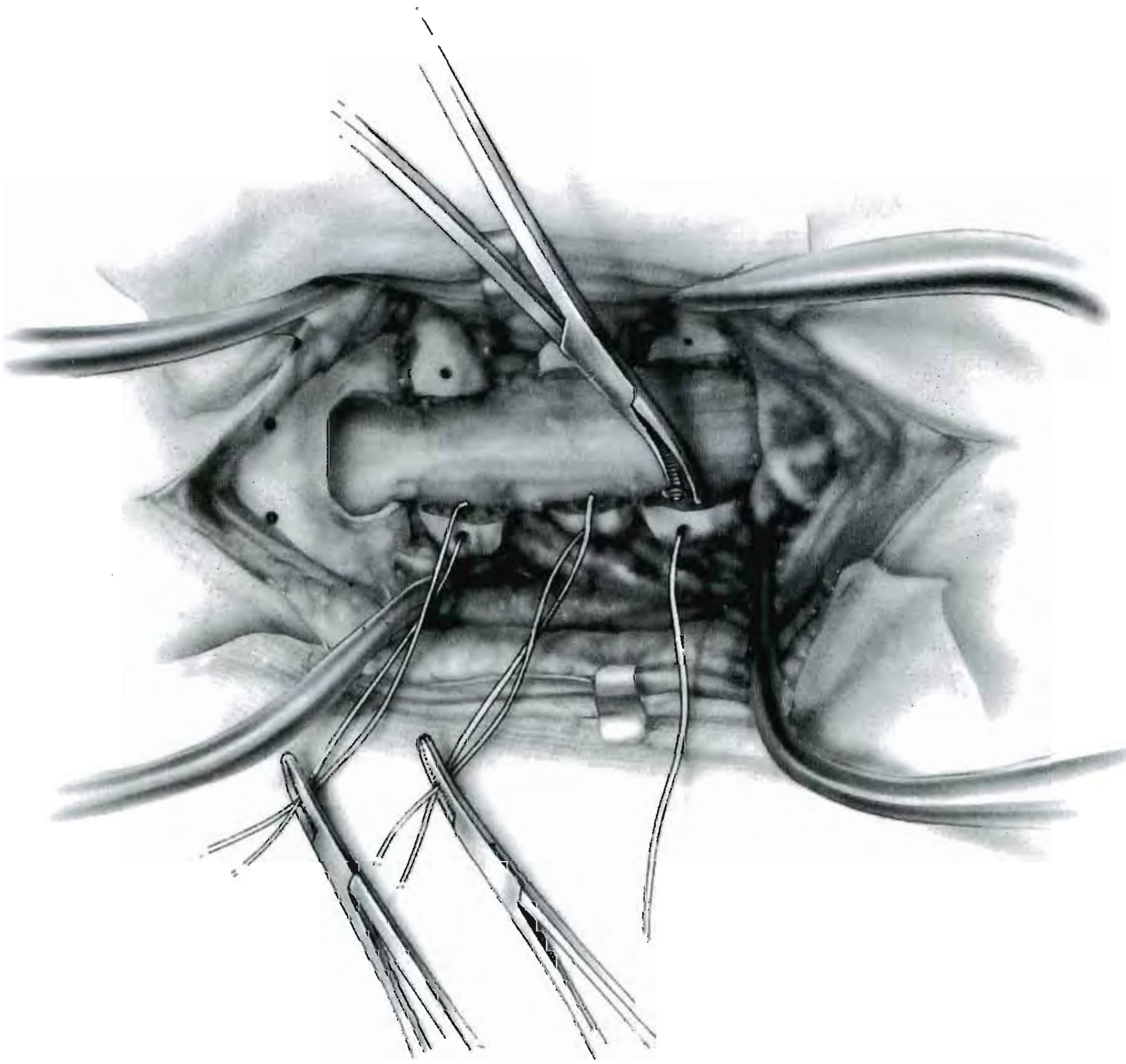

FIGURE 2-140. Depending on the size of the child and the lamina, a flexible wire (22 gauge), braided wire, or flexible cable is passed through each of the holes. If a wire is used, a small hemostat is used to reach under the lamina to grasp it as it comes through. After it is grasped, it is turned acutely so that it will not tear or puncture the dura, and is then pulled through. If the child is large enough, the Songer cables are preferred because they are flexible and easier to use than wire.

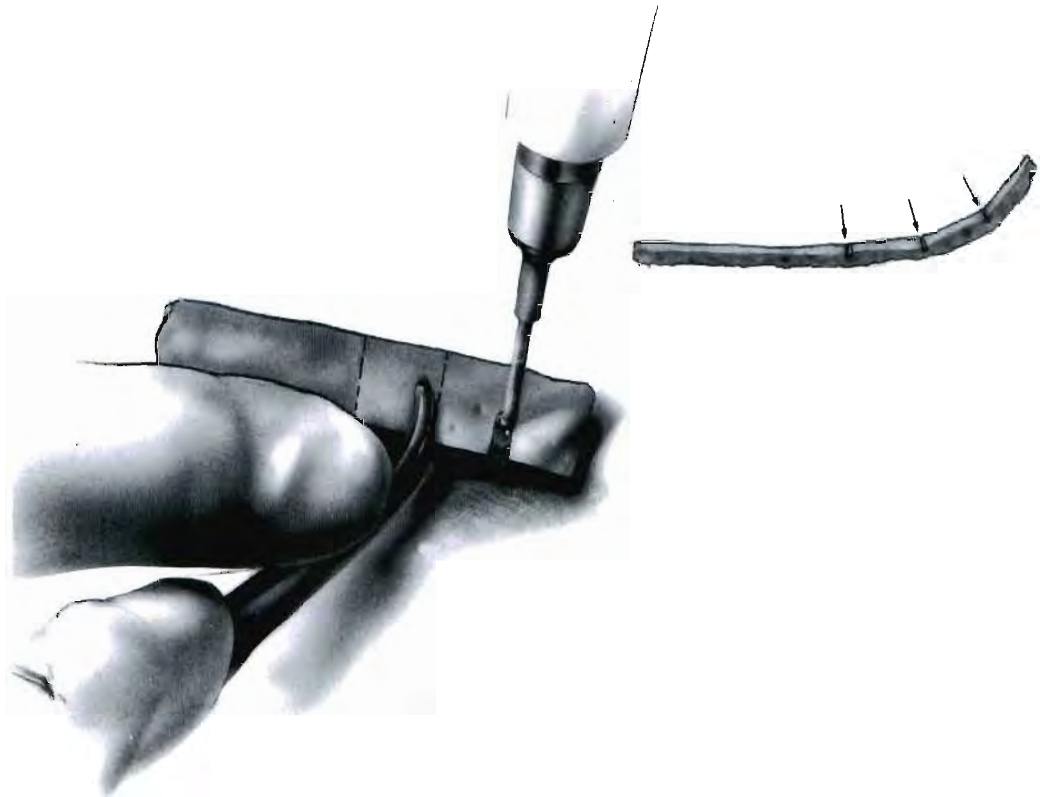

FIGURE 2-141. The bone graft can be either rib or corticocancellous bone from the iliac crest. The advantage of corticocancellous bone is the thick portion of cancellous bone that can be placed directly against the lamina. Rib graft has the advantage of strength, which imparts additional stability to the spine.

Although either the rib or a portion of the iliac crest may have the general contour desired for the cervical spine, it is usually necessary to bend the graft so that more curve is present to bring the graft in contact with the C1 lamina before it turns up onto the skull. This may be accomplished by kerfing the graft. A *kerf* is a cut or channel made by a saw. This can be accomplished by use of the high-speed drill to cut through the cortex on the concave side of the curve in the graft.

After the graft has been harvested, cut, and bent to the desired shape, holes are placed in it to correspond to the holes in the lamina over which it will lie. This can be done by holding the graft over the operative site while estimating the correct placement of the hole or by marking the site with a marking pen and then removing the graft to the back table to cut the holes.

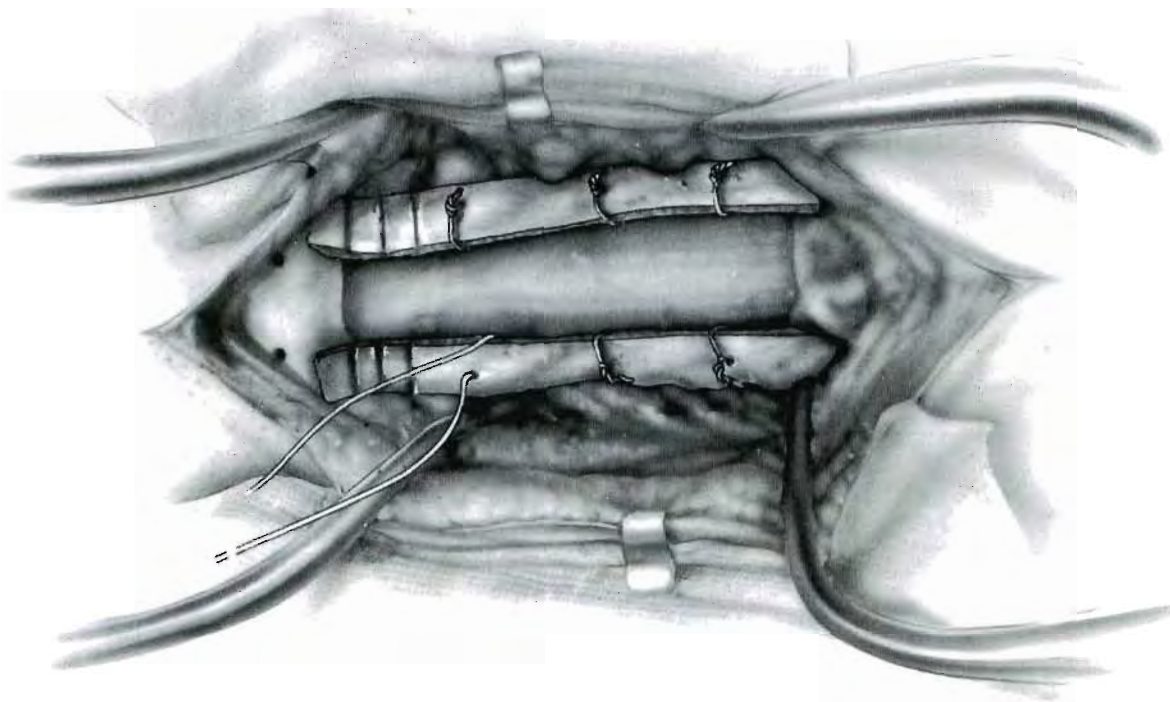

FIGURE 2-142. The portion of the wire or cable coming through the surface of the lamina is drawn through the bone graft. The segment of the wire coming from under the lamina is brought around the graft. This pushes the graft laterally and prevents it from coming to lie over the dura.

If there is no additional internal fixation, the graft is held firmly against the lamina while the wires or cables are tightened.

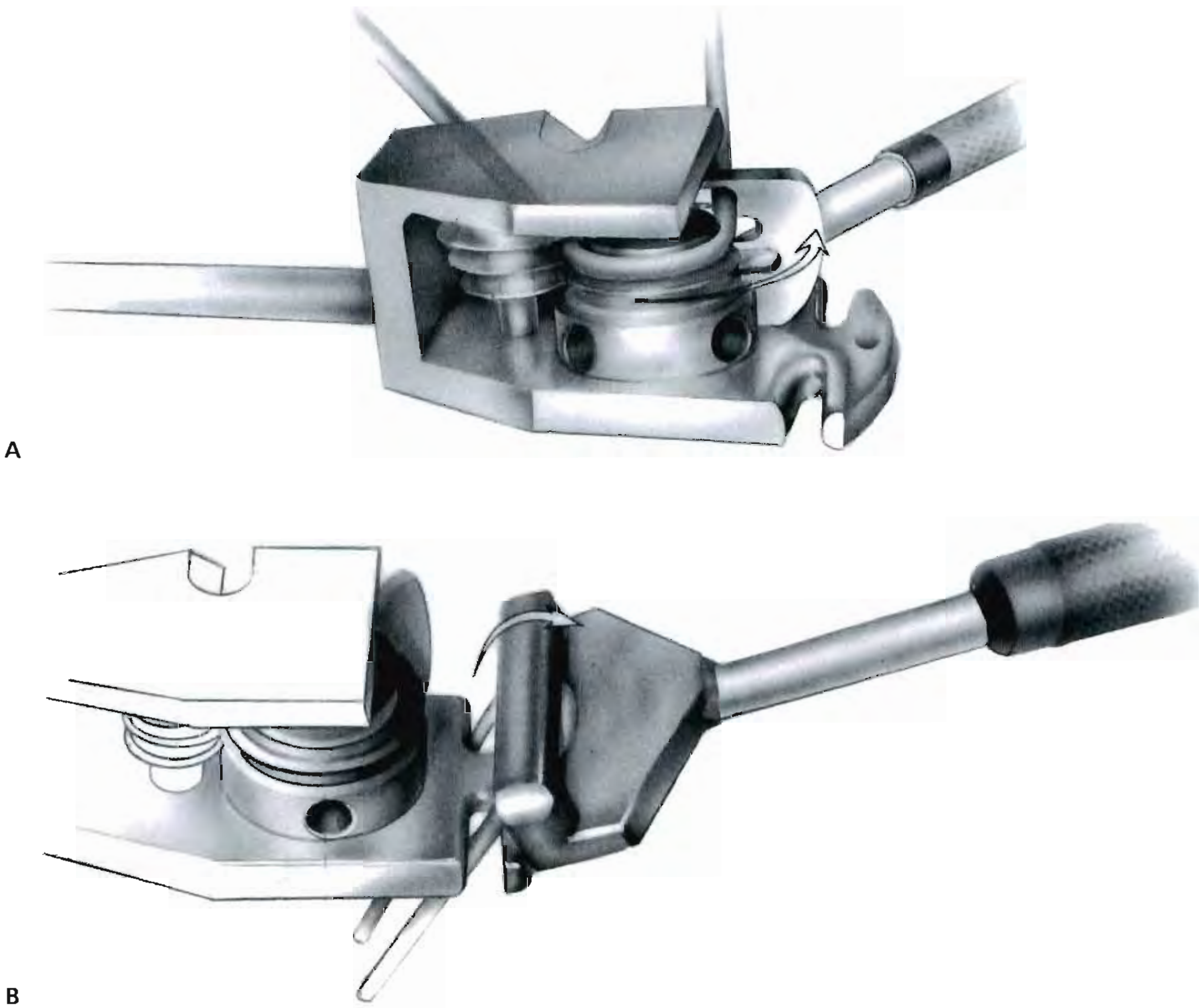

FIGURE 2-143. If internal fixation is used, a 3/16-inch rod is contoured with a device developed for this purpose, known as the Bendmeister (Sofamore Danek USA, Memphis, TN). This permits the creation of both a smooth loop to lie against the skull and the bend, which allows the loop to curve from the spine up onto the skull.

First, the loop that fits against the skull is fashioned. Three different widths of the loop are possible, depending on the need. This is accomplished by passing the rod in one of the three holes, which creates the different size loops, and then bending the rod **(A)**. In the second step, the loop is bent so that the rod goes from the lamina of C1 onto the skull. This is done by placing the limbs of the rod into the holding slots at the end of the device and bending the rod with the special device made for this purpose **(B)**.

Before placing this bend in the rod, it is important to estimate where it should be. The entire process of contouring the rod can be aided by creating a template from a malleable endotracheal tube stylet that has been sterilized.

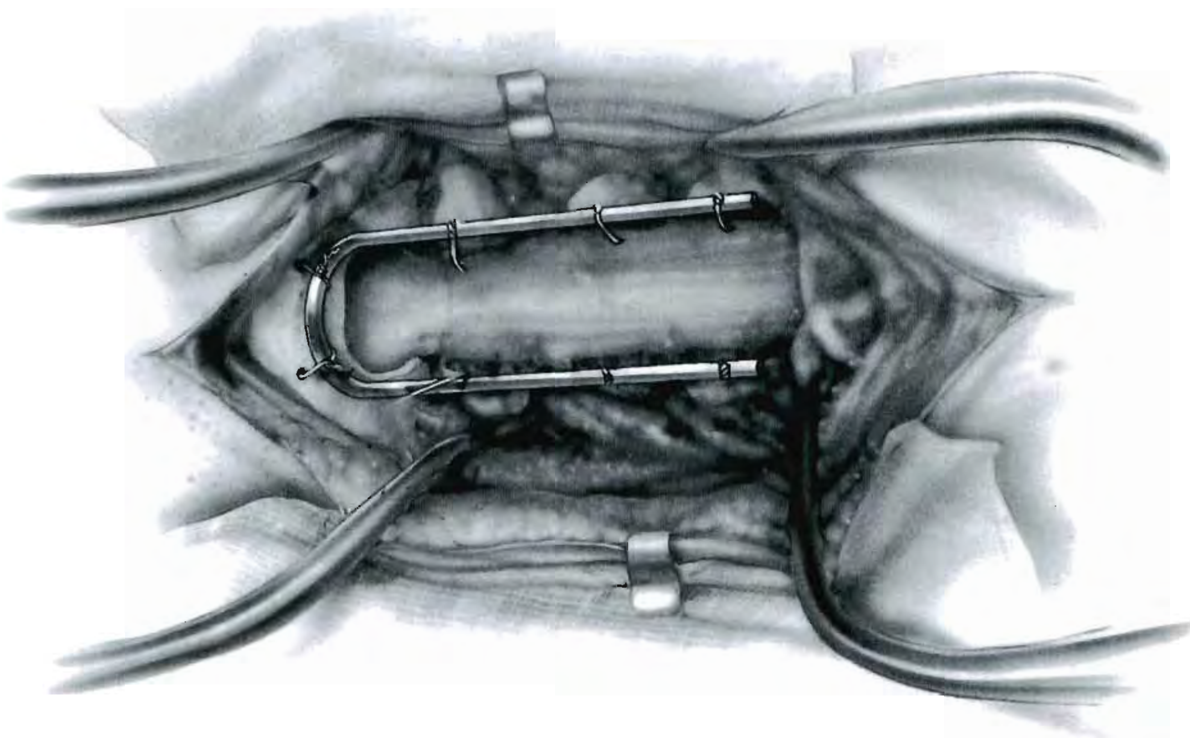

FIGURE 2-144. This contoured rod may be wired directly to the remaining lamina with cancellous bone packed around it. Here it is illustrated lying directly over the rib or corticocancellous graft to hold the graft firmly against the lamina. In this case, the wires are passed through the graft, and the rod is placed over the graft before the wires are twisted. Cancellous bone is then packed under the lateral side of the graft, where the laminae are sloping away.

When inspection demonstrates that everything is secure, the wound is closed. The patient is turned and then placed in the type of external immobilization that the surgeon believes is required.

A

B

C

D

E

FIGURE 2-145. Lateral radiograph **(A)** of a 16-year-old girl with a bone-softening disorder resembling osteogenesis imperfecta clinically but not biochemically. This disorder has produced extreme softening of the bones of the pelvis and at the base of the skull, with the resultant basilar invagination seen on this radiograph. A magnetic resonance image **(B)** demonstrates the reason for the spasticity in the lower extremities. Note that the vertebral body seen on the radiograph in **A** is C3. Skull traction with heavy weight over 1 week failed to produce any improvement in the position of the spine relative to the brain and cord. The patient's spine was fused in situ **(C–E)** using a rib graft and a rigid 3/16-inch rod contoured to fit against the base of the skull and spine. Note that both Songer cables and wires were used to secure the bone graft and the rods to the spine and skull. To maintain distraction on the skull, two Texas Scottish Rite supralaminar hooks were attached to the rod. Because the suboccipital decompression was so wide, the rods were bent across each other to bring them in line with the remaining lamina: this simplified the bends in the rod. After the completion of surgery, the patient was placed in a halo vest.

POSTOPERATIVE CARE

Although the fixation is rigid, the patient should remain in the external immobilization device until radiographic evidence of union is present. This generally takes between 3 and 4 months.

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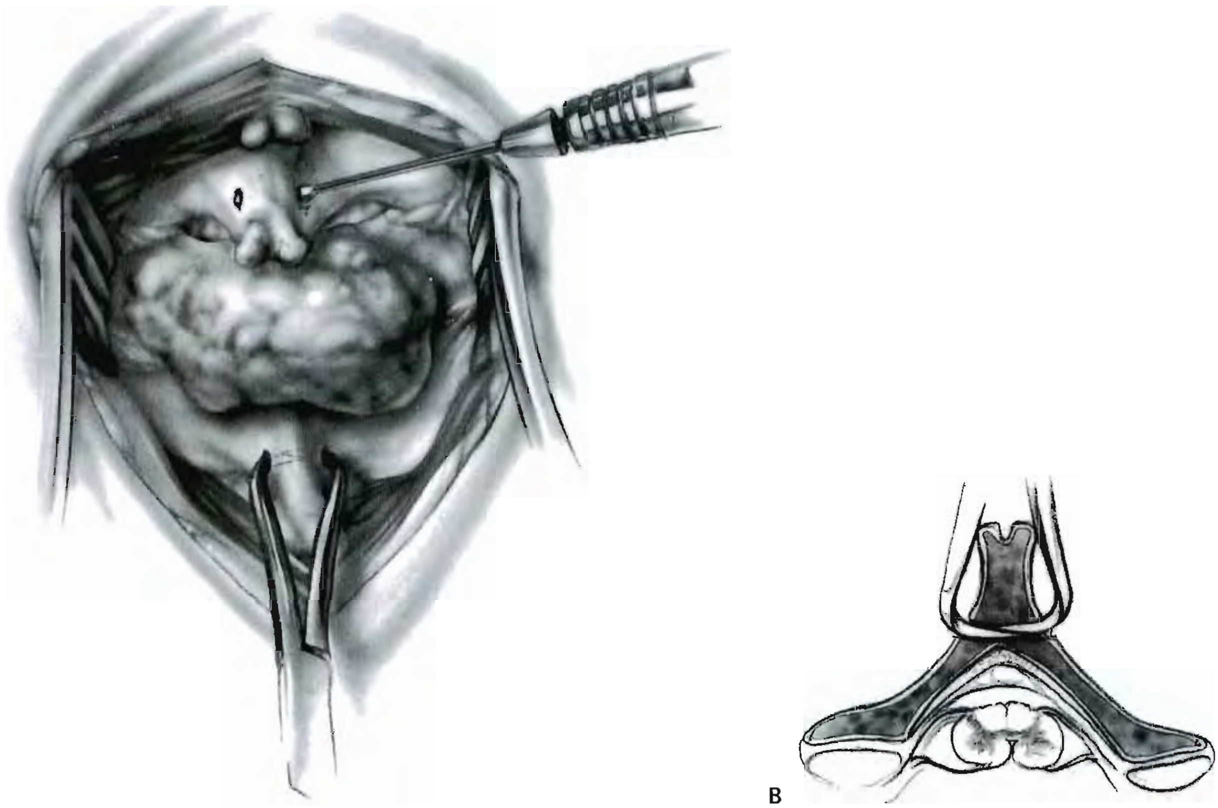
2.19 POSTERIOR ARTHRODESIS C2 TO C7: TRIPLE-WIRE TECHNIQUE

The most common indications for fusion of the cervical vertebrae between C2 and C7 are instability after fracture or limited removal of posterior elements for tumor. The triple-wire technique described is useful for patients in whom the posterior elements are largely intact. In this technique, one wire is used to pull the intact spinous processes together, providing stability, while two additional wires are used to secure the graft.

In most cases, a halo is not necessary, and the patient can be placed in the prone position with the head secured by temporary skeletal fixation. The head should be in slight flexion to facilitate the exposure. The posterior cervical region is shaved and prepared, as is the posterior iliac crest. Both regions are draped into the sterile field (Figs. 2-146 to 2-150).

FIGURE 2-146. A midline incision is made from the spinous process above the vertebra to be fused to the spinous process of the vertebra below. The dissection should remain in the midline, but this can be difficult if care is not given to the retraction of the skin and muscles as the dissection proceeds. After the tips of the spinous processes are identified, the correct level should be identified positively. If necessary, a metal hub needle is inserted into the spinous process, and a lateral radiograph is taken.

Dissection should proceed from the spinous processes out as far as the facet joints in the lateral direction. The surgeon should be careful not to destroy the interspinous ligaments between the vertebrae that are not to be fused. If the spine is unstable, dissection may require sharp dissection with a knife or cautery. Dissection should not involve the vertebrae above or below those to be fused.



A B

FIGURE 2-147. When the dissection is complete, a hole is made in the base of each of the spinous processed to be fused. In the case illustrated, an aneurysmal bone cyst has been removed from the posterior elements of C6. Because of instability, the spinous processes of C5 and C7 will be wired together.

Care must be taken in placing the holes in the spinous process because it is easy to make the holes too low and enter the spinal canal. The hole **(A)** is easily made with a 3-mm high speed bur and connected by an instrument, such as a towel clip **(B)**, which is rocked back and forth in the hole.

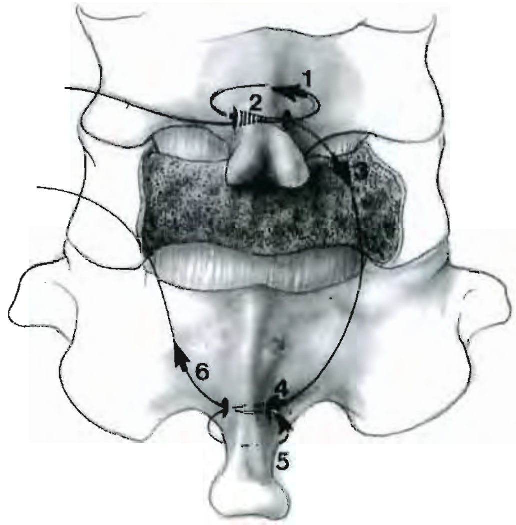


FIGURE 2-148. A 20-gauge wire is used to join the spinous processes. It is first passed through the hole in C5 (1) and then around the cephalad portion of the spinous process (2). Rather than removing the interspinous ligament between C5 and C4, the wire can be passed through this ligament with a needle holder. The wire is then passed back through the hole in C5 (3).

Going to the vertebra below, the wire is passed through the hole in the spinous process of C7 (4), then through the interspinous ligament between C7 and T1 (5), and then back through the hole in C7 (6).

The wire is then tightened to produce the desired position between the two vertebrae. This can be gauged by observing the facets. The twisted end of the wire should be placed and bent so that it does not catch on muscle or be near the spinal canal if it is exposed. Decortication of the lamina and any other exposed bony surface is accomplished with the bur.

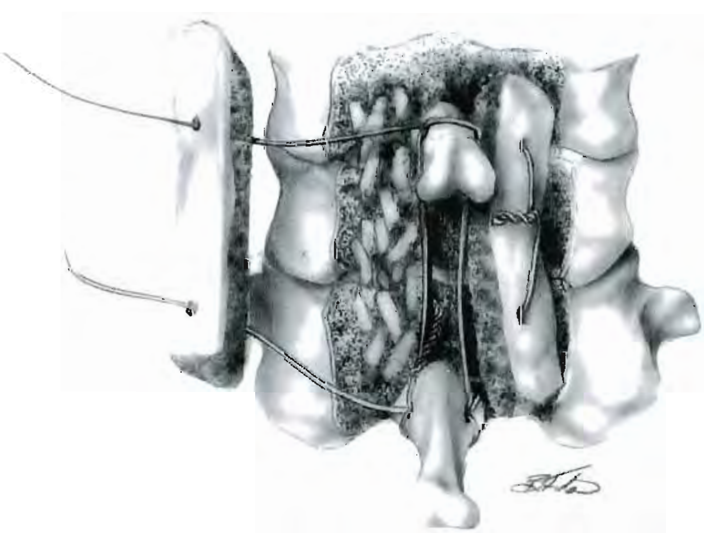


FIGURE 2-149. Two 20-gauge wires are passed through the holes in the spinous processed. Using the 3-mm bur, two holes are made in the corticocancellous grafts that were removed from the iliac crest. These holes should correspond to the location of the wires. Additional cancellous strips are placed on the lamina. The two wires are joined on each side over the graft and tightened to pull the corticocancellous grafts securely against the lamina and spinous processes. They are twisted until the grafts are held firmly in place. Grasping the C5 spinous process with a clamp and moving it should demonstrate that it and C7 move as a unit.

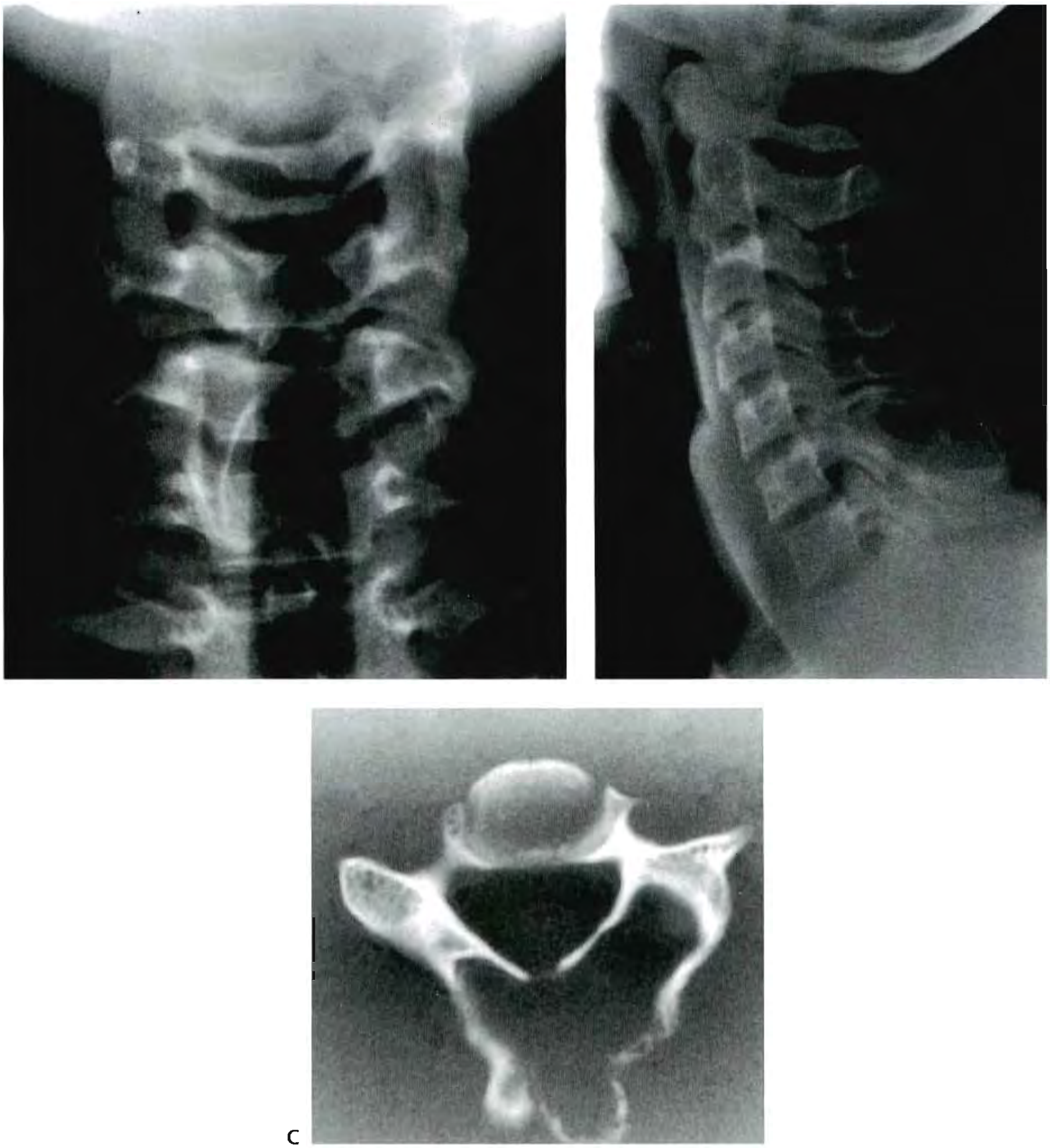
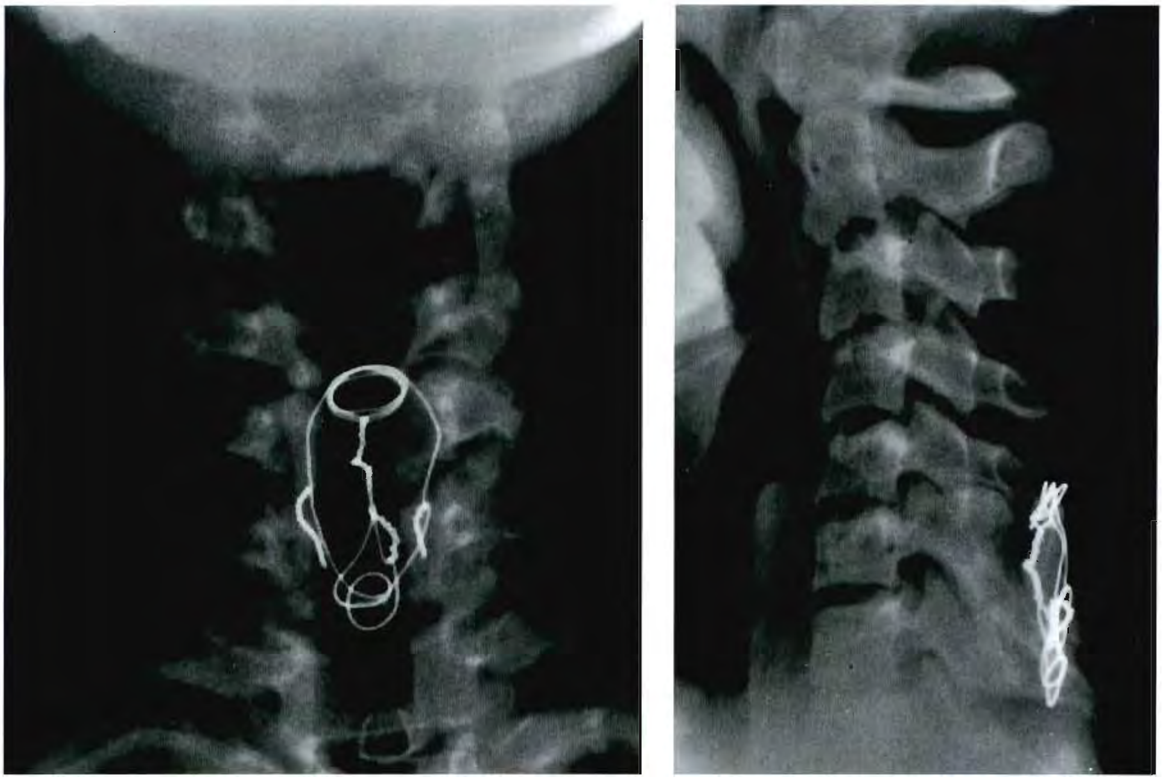


FIGURE 2-150. The anteroposterior and lateral radiographs of a 13-year-old boy who experienced sudden neck pain radiating down both arms while tackling in football demonstrate a large lesion **(A, B)**, which is an aneurysmal bone cyst. The patient experienced weakness in both arms for about 2 weeks. Computed tomography scans **(C)** revealed the extent of the lesion. (*continued*)



D E

FIGURE 2-150. (*Continued*) Solid arthrodesis **(D, E)** was demonstrated 1 year after resection of the lesion and fusion with triple wiring.

POSTOPERATIVE CARE

The patient is immobilized postoperatively in a neck brace, such as a Philadelphia collar, for 2 to 3 months. Unless the patient is uncooperative or very unstable, a halo is not necessary. Fusion is demonstrated radiographically by lack of motion on flexion and extension radiographs in addition to the consolidation of the bone graft.

2.20 POSTERIOR ILIAC BONE GRAFT

There are many needs for autogenous bone in orthopaedic surgery. Because the most common need for large amounts of bone is in spinal surgery, the technique is described here (1). When the requirements are for small amounts of bone, a much smaller incision can be used, or the bone may be more easily obtained from another location. There are two ways to expose the posterior iliac crest during spinal surgery: through the same incision or through a separate incision (Figs. 2-151 to 2-157).

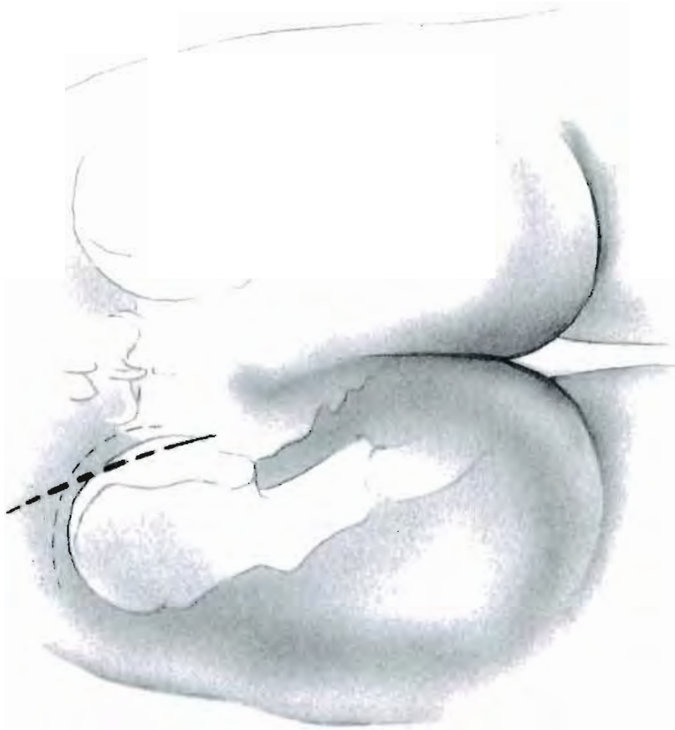


FIGURE 2-151. If the spinal incision is confined to the thoracic region, it may be preferable to use a separate incision over the posterior iliac crest. In this case, there are two important considerations given to placement of the incision: it should not cut the cluneal nerves and vessels, and it should give the surgeon the most direct access to the area of the crest that has the largest amount of bone. This area is the bone adjacent to the sacroiliac joint and the sciatic notch. An incision that follows the top of the iliac crest violates both of these considerations. The incision illustrated is an oblique incision that is centered over the posterosuperior iliac spine. Some surgeons prefer an incision that crosses the posterosuperior iliac spine at 90 degrees to the one illustrated; they think that the former incision gives a better cosmetic result.

FIGURE 2-152. If the incision for the spinal procedure extends into the lumbar spine, it is easiest to continue that incision down to the sacrum and expose the posterior iliac crest from the midline incision. This is done by dissecting on top of the lumbodorsal fascia laterally until the posterosuperior iliac spine can be palpated.

FIGURE 2-153. Although the posterosuperior iliac spine lies directly beneath the fascia, the remainder of the iliac apophysis is hidden. Superiorly, the iliac crest curves anteriorly with the abdominal muscles inserting from above and the abductor muscles inserting from below; the cluneal vessels and nerves run over the top about 2 cm lateral to the posterosuperior iliac spine. To expose this region of the apophysis, a small incision is made in the lumbodorsal fascia just cephalad to the posterosuperior iliac spine. A finger is then inserted along the top of the iliac crest as it curves anteriorly, creating an interval between the insertion of the two muscle groups. The cluneal nerves and vessels lie in the tissue above the finger.

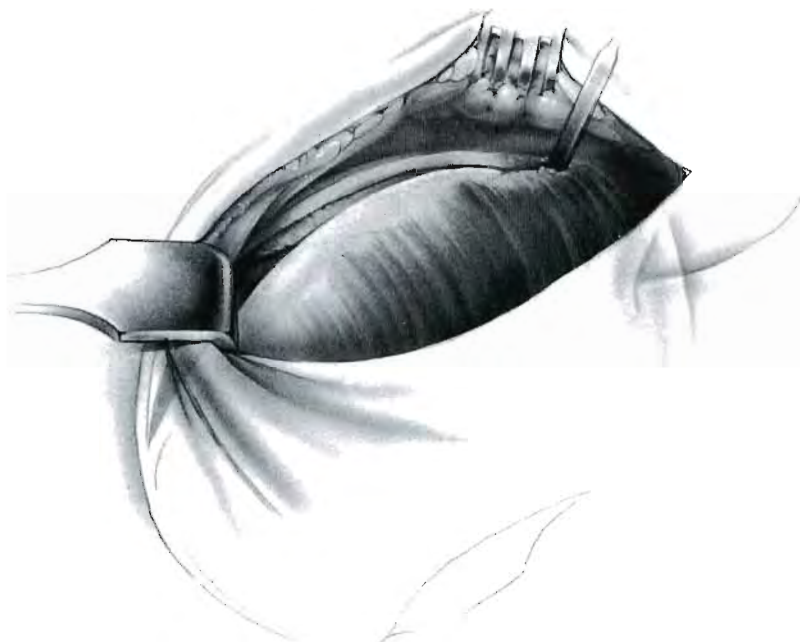


FIGURE 2-154. With a long narrow retractor, such as a small Meyerding, inserted in the plane that has been created, the surgeon can see and palpate the iliac apophysis as it curves anteriorly, making its division easy while the cluneal nerves and vessels are safely retracted. Inferiorly, the apophysis is covered by the attachment of the gluteal muscles. A small portion of this muscle is divided with the cautery by proceeding directly caudad from the posterosuperior iliac spine. Care should be taken not to cut too far in the caudal direction because this is both unnecessary and results in excessive bleeding. The apophysis can be split with the cautery to lessen the bleeding, but a sharp knife should be used to continue the cut down to the bone. The cautery often fails to cut all the way to the bone, making it difficult to begin the subperiosteal dissection.

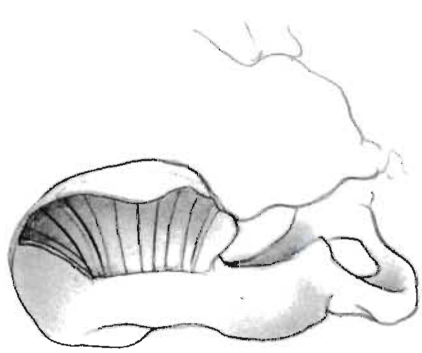


FIGURE 2-155. The subperiosteal dissection should expose the outer table of the iliac crest completely. Care should be taken to expose the sciatic notch without plunging into it with the periosteal elevator. Many large veins and arteries run immediately beneath the fascia that covers the gluteal muscles in this region; if these muscles are cut, bleeding is often difficult to control. Of greater significance is the superior gluteal artery and veins that also course through the sciatic notch along with the sciatic nerve. If these vessels are cut, they may have to be controlled through an abdominal approach.

FIGURE 2-156. After the outer table is exposed, the cortical bone is removed. Insertion of a large Viboch iliac retractor (or a Taylor retractor) facilitates this. This can be done in strips, as illustrated, or as one large piece to be cut into smaller pieces later. A small 1-cm rim of bone may be left at the sciatic notch for safety. Because this is the thickest region of cancellous bone, however, the removal of the cortex should come as close to the notch as possible.

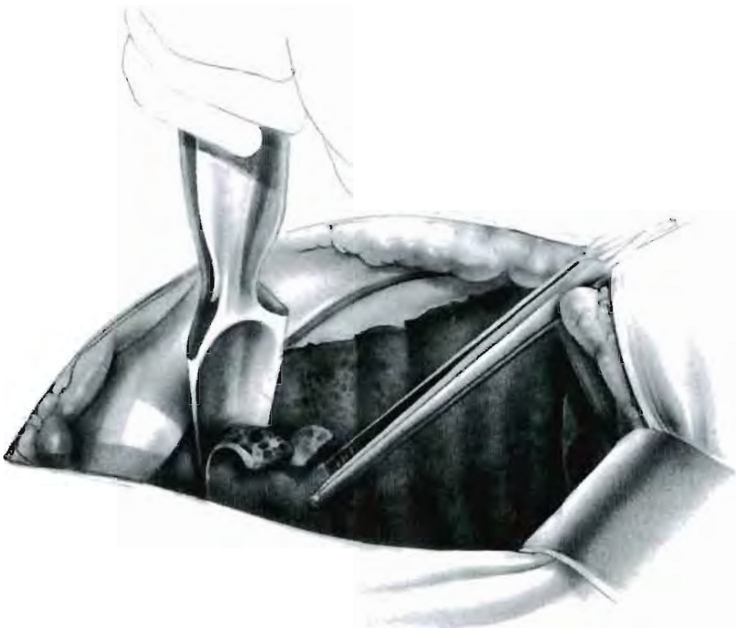


FIGURE 2-157. After the cortical bone is removed, the cancellous bone is harvested separately. The softness of this bone often tempts the surgeon to push the gouge rather than strike it with a mallet. It is much safer to advance the gouge by striking it, however. In this manner, control is much better, and the potential for an uncontrolled plunge with the gouge is lessened. Ring curettes may also be helpful in harvesting cancellous graft. A great amount of cancellous bone resides around the peripheral edge of the ilium and above the sciatic notch. The deep cortex overlying the sacroiliac joint is very thin and easily penetrated by gouges or curettes. This must be avoided or the patient may suffer long-term SI joint pain. After the cancellous bone is completely removed down to the inner table, a paste made from Gelfoam powder is rubbed into the raw bony surface, and the wound is packed tightly with lap sponges. At the completion of the operation, the lap sponges are removed. If there remains any significant bone bleeding, it can be controlled with bone wax. The closure of the wound is in layers: the apophysis; the fascial tissue over the apophysis, which is continuous caudally with the fascia over the gluteal muscles; the lumbodorsal fascia; and the skin. A drain is not necessary unless the crest has been approached from the midline, leaving a potential dead space under the skin.

Reference

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2.21 RELEASE OF STERNOCLEIDOMASTOID MUSCLE

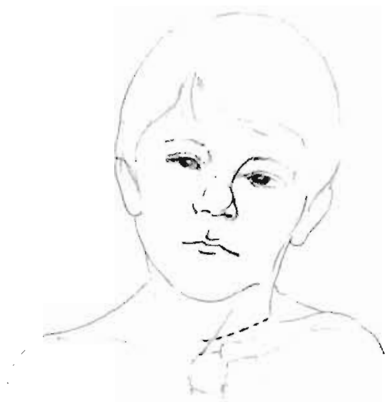

FIGURE 2-158. The incision should be placed in a skin crease a short distance above the clavicle. Because the skin is mobile and can be moved (not stretched) from a medial to a lateral position, the incision can be small, running from the lateral border of the sternal head to the midportion of the clavicular head.

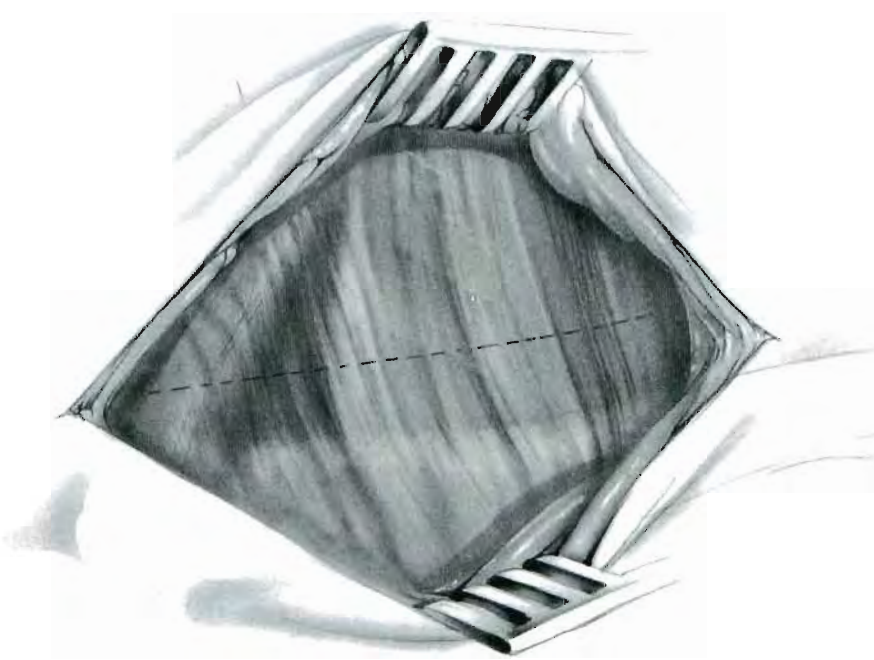

FIGURE 2-159. The platysma muscle should be identified as a separate and distinct layer so that it may be repaired at the time of closure. This helps preserve the contour of the neck and avoids an unsightly depression as a result of the resected sternocleidomastoid muscle.

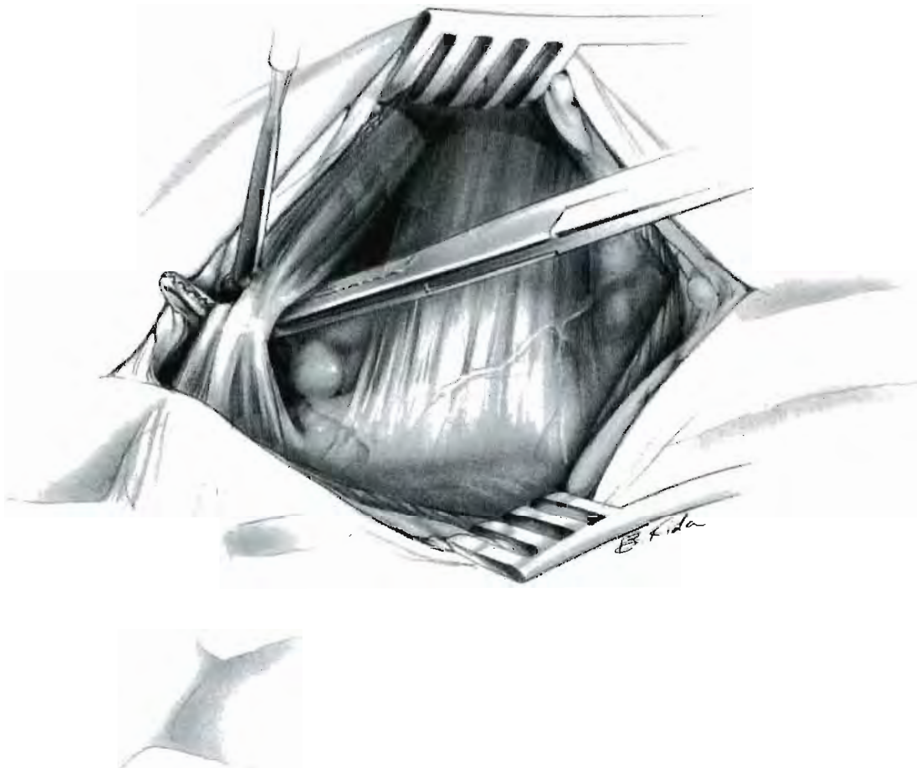

FIGURE 2-160. Beneath the platysma muscle, the sternal and clavicular heads of the sternocleidomastoid muscle can usually be identified as distinct structures. In some cases, the clavicular head is thin and seems of little importance. Failure to divide it usually produces disappointing results. Although the sternocleidomastoid muscle is separated from the deeper venous and arterial structures by a fascial layer, the muscle is usually adherent and should be separated from this fascial layer with care. When isolated, the muscle can be divided with a low cautery current close to the clavicle in its tendinous portion.

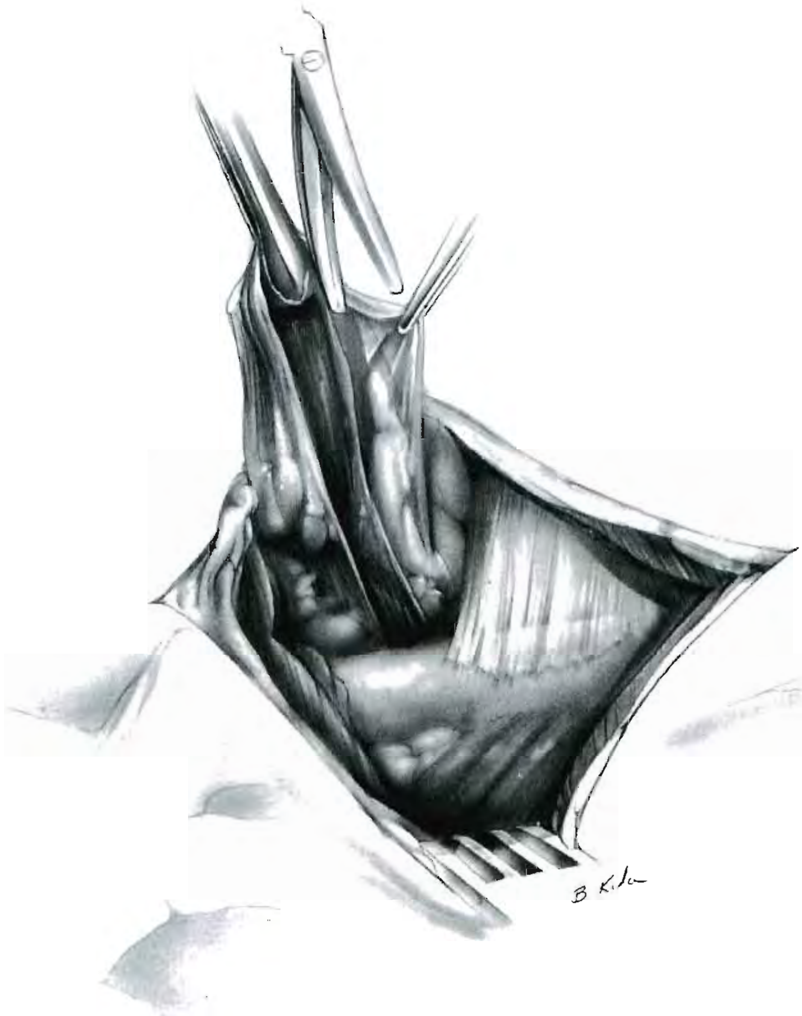

FIGURE 2-161. Because the sternocleidomastoid muscle is adherent to the surrounding fascia, it is not sufficient merely to divide it. Rather, it should be dissected free for a distance of about 2 cm, and the portion that is freed should be resected. In accomplishing this, the adherence of the muscle to the investing fascia is appreciated. If this dissection is not done, the severed muscle ends lie in close proximity after the platysma muscle is repaired, and recurrence is likely.

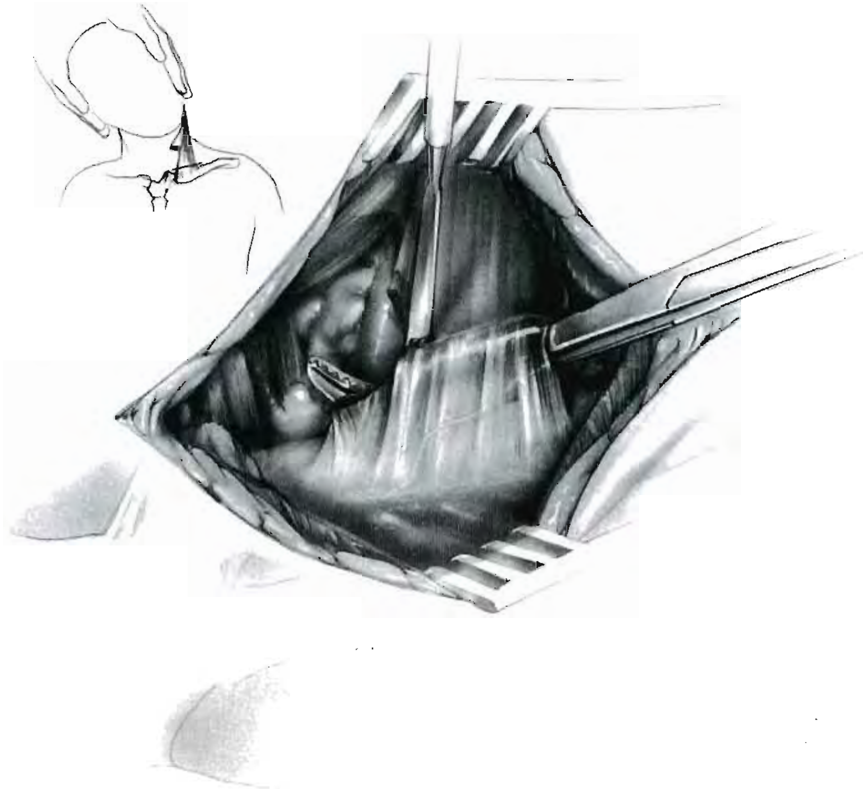

FIGURE 2-162. Next, the clavicular head is divided. If the anesthesiologist is asked to turn the head toward and tilt it away from the operative side, the tightness of this structure becomes apparent. It is divided, dissected free, and resected in the same manner as the sternal head. This is usually much easier, however, because the sternal head is usually the most involved. After both heads have been divided, the head is moved in the direction described earlier while the operative area is inspected and palpated for any remaining tight structures. Often, deep fascial bands are identified; these should be divided. The wound is inspected for bleeding, irrigated, drained with a small Silastic drain, and then closed in layers with particular attention to the platysma muscle.

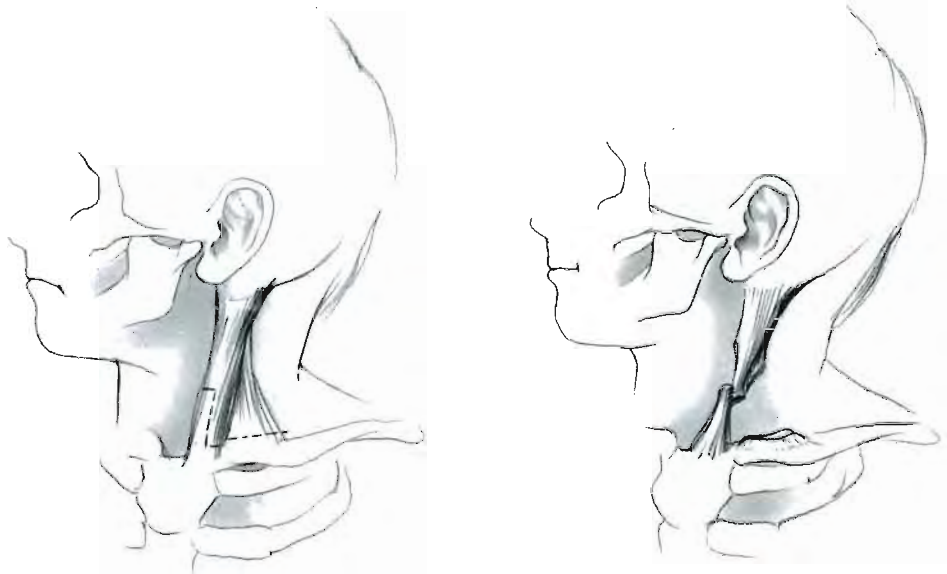

FIGURE 2-163. Two modifications to the method described are frequently used. The first of these is a Z lengthening of the sternal head of the sternocleidomastoid muscle. This is done in an effort to preserve the normal contour that this muscle provides to the neck. Although it can be accomplished easily, it may risk recurrence; in our experience, it has not been necessary if the platysma muscle is repaired properly.

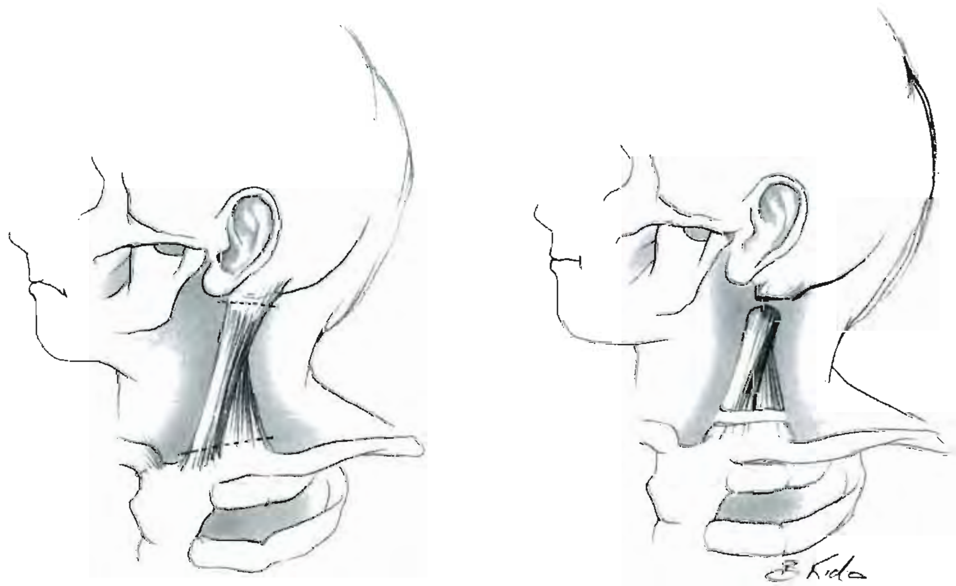

FIGURE 2-164. The second modification is the bipolar release (1). This technique is advocated in an effort to secure a more complete release. In this approach, the incision is made just distal to the tip of the mastoid. We find it helpful to fold the ear over a sponge and tape it anteriorly to get it out of the field. Dissection does not and must not be too distal so that injury to the spinal accessory nerve is avoided. This release is usually necessary only in older patients.

POSTOPERATIVE CARE

The drain is removed the morning after surgery, and the patient is discharged from the hospital. After 1 week, stretching exercises are resumed and continued for 3 months. Collars and orthotic devices have not proved useful in the postoperative management (Figs. 2-158 to 2-164). Results are documented in the literature (2).

References

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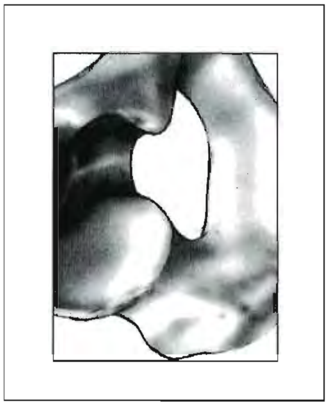

3

THE PELVIS AND HIP

3.1 ANTERIOR DRAINAGE OF THE SEPTIC HIP

Drainage of septic arthritis of the hip is an emergency procedure. The question is not whether to drain a septic hip surgically but whether to approach the hip anteriorly or posteriorly. There are several reasons to prefer an anterior approach, although a posterior approach may be effective. One of the authors uses the anteromedial incision (see Procedure 3.3) for drainage of septic hips.

The transverse anterior incision in the skin is cosmetically superior to a posterior incision. The anterior approach provides a distinct anatomic landmark, the anterosuperior iliac spine, which is not the case in the chubby buttocks of an infant with a septic hip. The same is true throughout the dissection, where anteriorly distinct anatomic intervals are separated. Finally, and perhaps most importantly, the incision should be placed in the anterior capsule. The hip is usually treated in some degree of flexion, whether in traction or a cast. This, plus the natural tendency of the hip to flex and dislocate posteriorly, dictates that the incision is best in the anterior capsule. There is no need for gravity drainage with modern methods of suction or suction-irrigation. In addition, one may question the wisdom of having a rubber drain communicate from the buttocks to the hip joint (Figs. 3-1 to 3-5).

FIGURE 3-1. The patient is placed in the lateral decubitus position as for most other procedures on the hip. The incision, placed about a thumb's breadth beneath the anterosuperior iliac spine, can be smaller and more transverse than that used for other major hip procedures because it is not necessary to expose the outer table of the ilium.

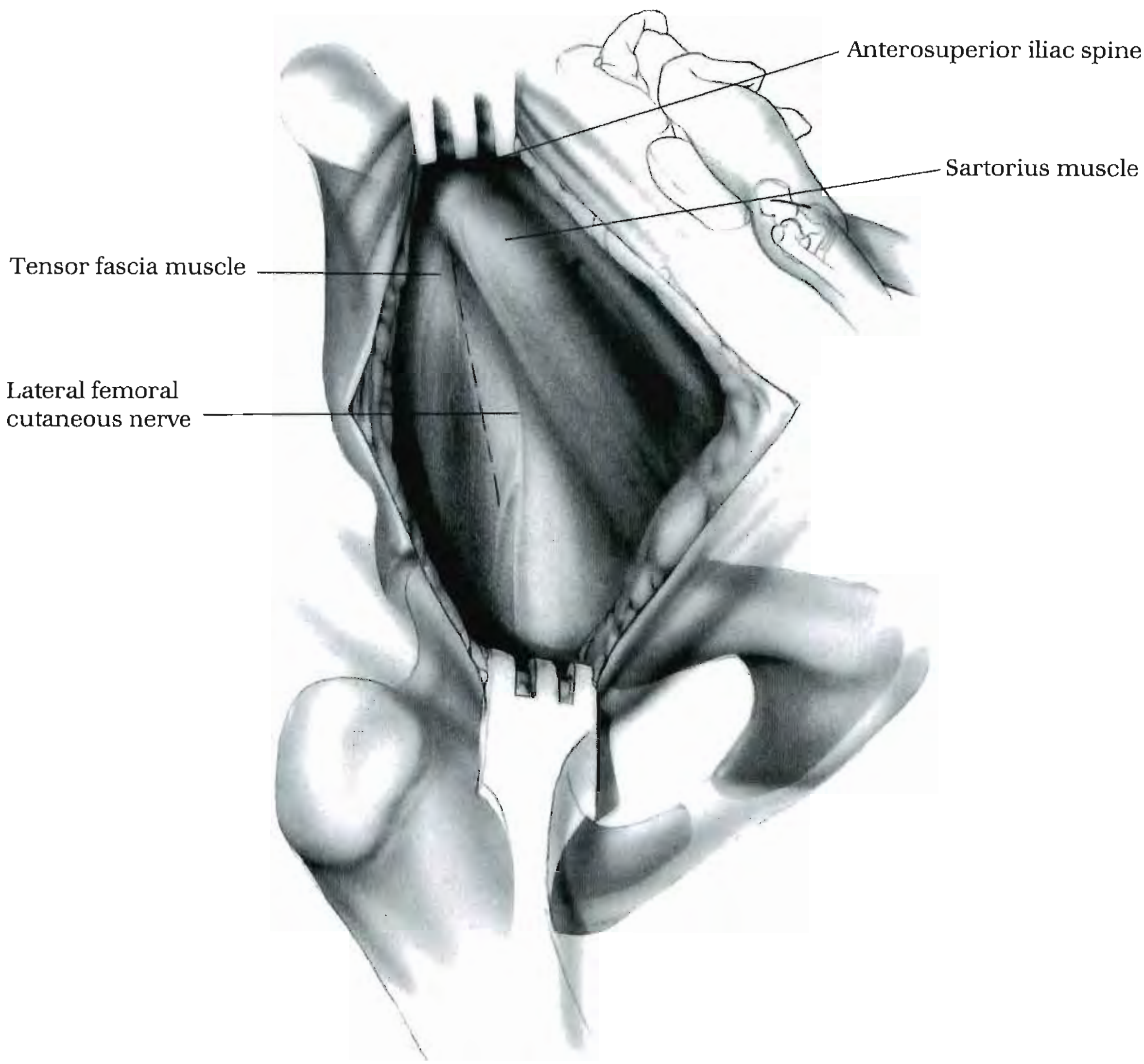

FIGURE 3-2. The interval between the sartorius and the tensor muscles is identified and separated up to the anterosuperior iliac spine. If necessary, the periosteum can be elevated from the outer table of the ilium in the region of the anterosuperior iliac spine; however, after some experience with this approach, this is usually not necessary.

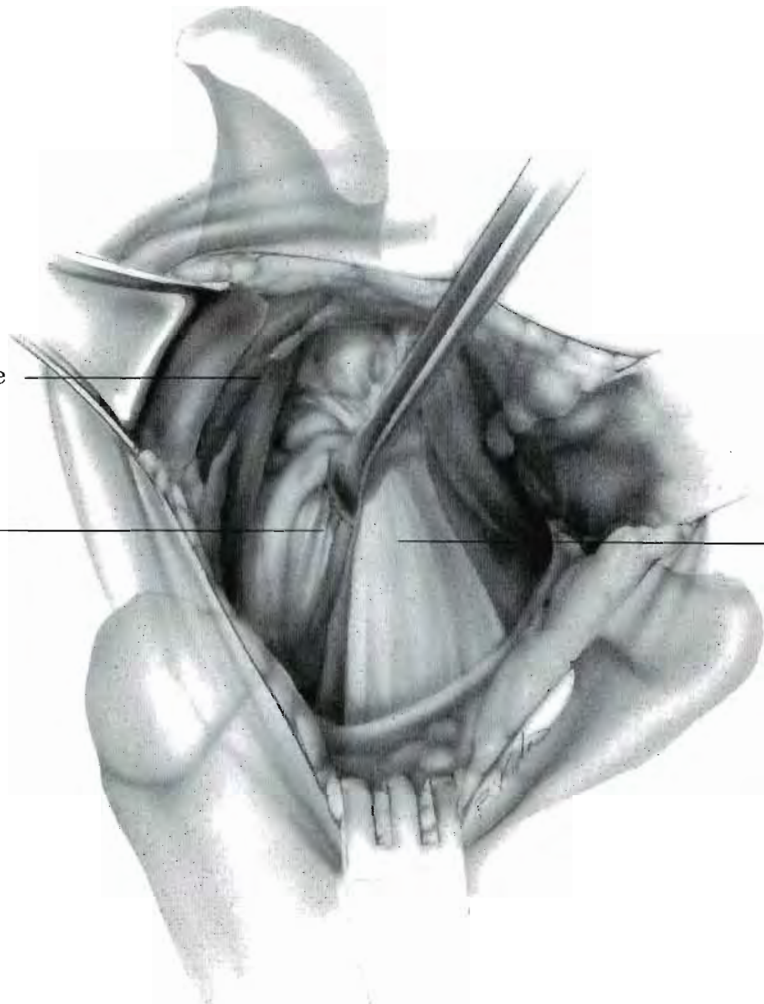

FIGURE 3-3. At the base of the exposure between the sartorius and the tensor muscles is the rectus muscle. In this area, close to the anterosuperior iliac spine, its tendinous portion can be identified. A periosteal elevator can be used to separate the fatty tissue covering this tendon. The lateral border of this tendon with its muscular origin is freed and retracted medially.

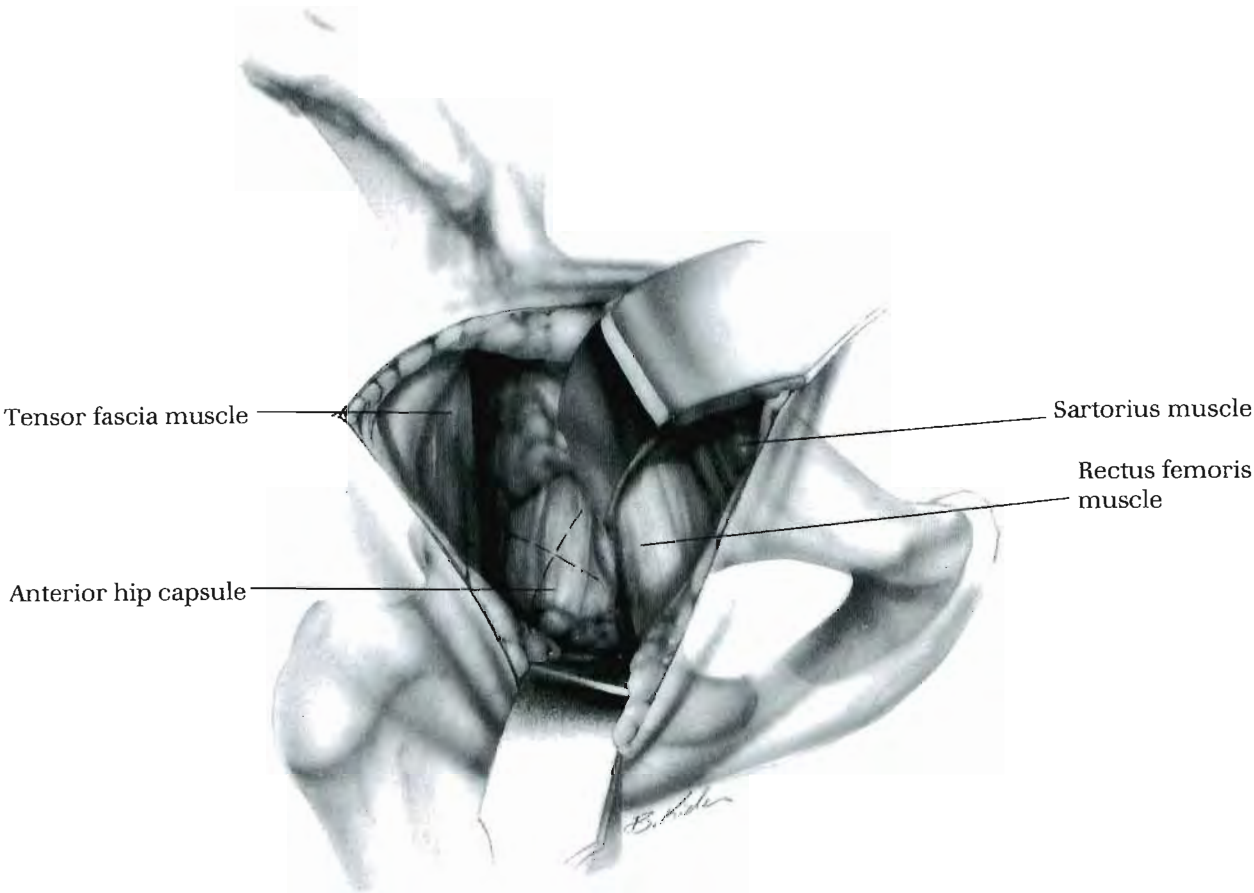

FIGURE 3-4. The hip capsule now lies in the base of the field. It is covered by the precapsular fatty tissue, which may be thick and edematous in the septic hip. This can also be separated with a periosteal elevator exposing the hip capsule. A cruciate incision is made in the capsule, exposing the femoral neck and part of the femoral head. This provides adequate access for inspection and irrigation of the joint.

FIGURE 3-5. A small red rubber catheter, with the multiple perforations at the tip cut off, is passed around the femoral neck and into the various recesses of the joint to provide thorough irrigation. Inspection should ensure that there are no fibrinous clots of inflammatory material remaining in the joint. Often, these have to be removed with a forceps when present.

After complete irrigation and débridement, with placement of drains and irrigation if desired, the muscles are allowed to fall back together, and the deep fascia and skin are closed.

POSTOPERATIVE CARE

There are many options for care after the drainage and débridement, depending on the surgeon's preferences and the circumstances of the case. Whatever method of drainage is chosen, it is rarely necessary for longer than 24 hours. This provides a continuous débridement of the joint. The patient is placed in split Russell traction while intravenous antibiotics are administered. The irrigation tube is switched to suction 12 to 24 hours after surgery, and both it and the drain are removed 12 to 24 hours after that. If the hip is subluxated or dislocated, it is often desirable to achieve a closed reduction at the time of wound closure and to place the patient directly into a spica cast. Many surgeons prefer to treat all children with septic arthritis of the hip with a single-leg spica cast for 2 to 3 weeks to avoid late subluxation secondary to capsular laxity. If the cast is not applied at the time of surgery, it is applied before discharge.

3.2 ANTERIOR APPROACH TO A DEVELOPMENTALLY DISLOCATED HIP

The anterior approach to open reduction of congenital dislocation of the hip is the classic method. It has the advantage of exposing the capsule and both the superior and inferior aspects of the acetabulum, allowing the surgeon to address all possible obstructions to reduction and to perform a capsulorrhaphy to hold the femoral head in the acetabulum. The only disadvantage is the need for technical experience and expertise to avoid all of the pitfalls that can lead to failure (Figs. 3-6 to 3-13).

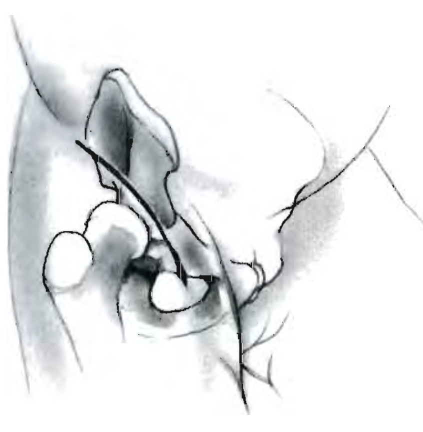

FIGURE 3-6. The patient is placed in the full lateral position with the affected hip up. A sand bag is placed behind the back, not extending to the buttocks. The leg is prepared and draped from the toes to the rib cage past the midline, both ventrally and dorsally. The patient then is allowed to roll back on the sand bag, placing the hip in an obliquely elevated position with the buttocks free.

The incision can be transverse or oblique. It is centered 2 to 2.5 cm below the anterosuperior iliac spine. This permits the same exposure as the classic Smith-Petersen incision with a far better cosmetic result. The incision is carried down through the superficial fascia, and as this is done, the skin is pulled up over the iliac crest so that the crest is exposed. A finger is used to pull the inferior edge of the wound distally, elevating a flap over the interval between the sartorius and the tensor muscles.

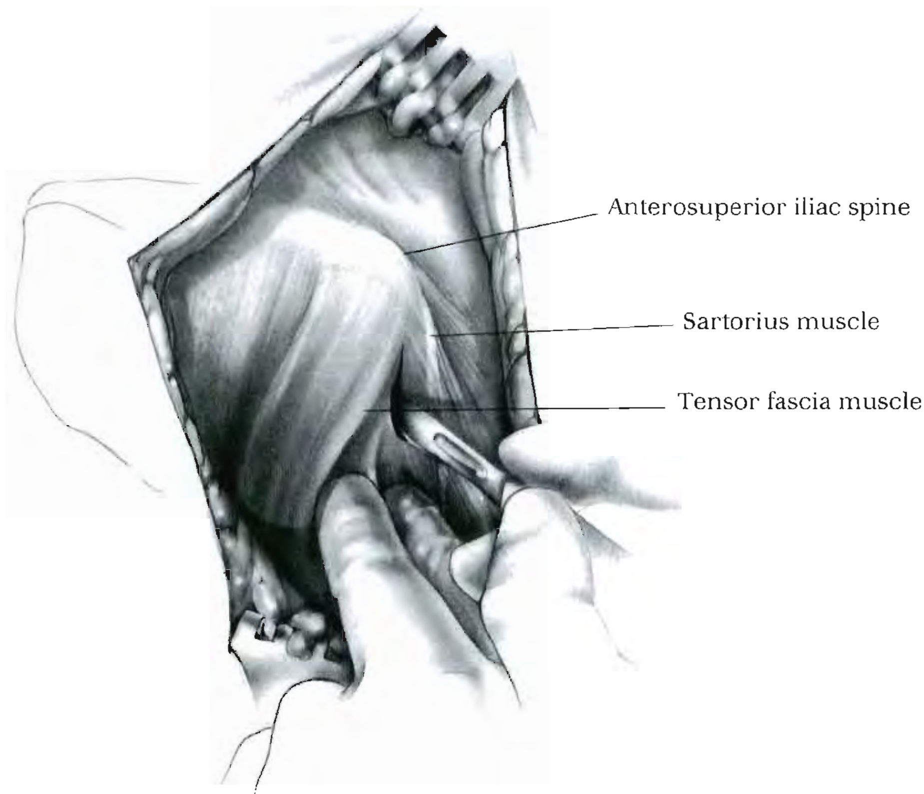

FIGURE 3-7. The sartorius–tensor muscle interval is identified by palpating the depression between these two muscles just distal to the anterosuperior iliac spine. A small stab wound is made through the fascia, and a scissors is used to open this interval from the anterosuperior iliac spine to the distal extent of the exposure, staying toward the tensor muscle to avoid the lateral femoral cutaneous nerve. The nerve should be identified, and this is most easily done about 1 to 2 cm distal to the anterior superior iliac spine. After it is identified, the nerve is taken medially.

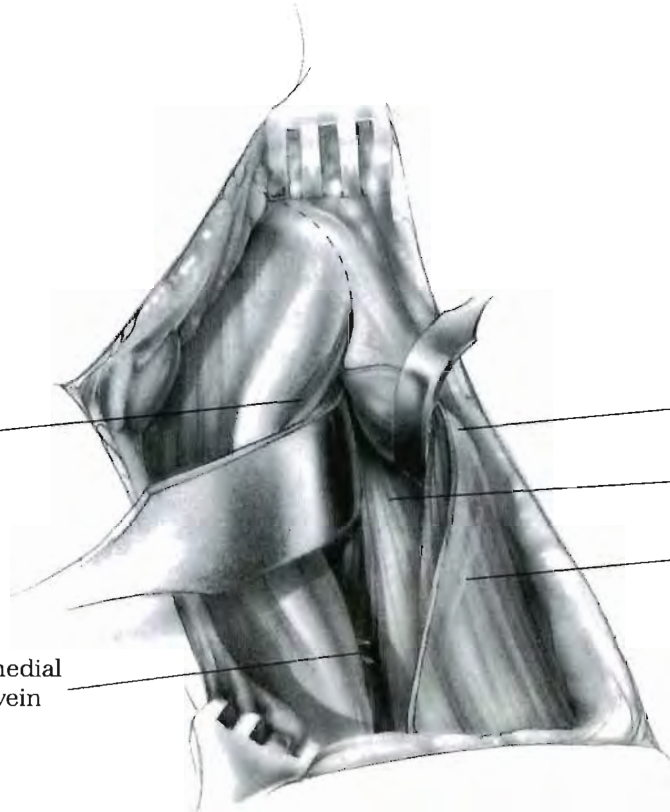

FIGURE 3-8. The sartorius–tensor interval is separated easily by gentle blunt dissection with a Cobb periosteal elevator, pulling the sartorius muscle and the fat that is found in this interval medially along with the lateral femoral cutaneous nerve and the tensor muscle laterally. The rectus muscle forms the floor of this interval. Exposing the tendinous portion of the straight head of the rectus allows identification of the anteroinferior iliac spine.

At the inferior extent of the wound, passing deep between the sartorius and the tensor muscles, the ascending branch of the medial circumflex artery and its accompanying veins should be identified and divided. When this interval is not opened beyond these vessels, there is insufficient exposure to reach the inferior aspects of the acetabulum. Proximally, this interval needs to be opened to the anterosuperior iliac spine.

FIGURE 3-9. The retractors are shifted to expose the iliac crest, and the iliac apophysis is split open down to the bone. This cut begins at about the midportion of the iliac crest and extends down to the anteroinferior iliac spine. The apophysis is then pulled off the iliac crest, and the periosteum is elevated off the outer table, pulling the tensor and the abductor muscles laterally. Bleeding is controlled with cautery and bone wax, and a sponge is packed tightly into the proximal extent of the wound between the abductor muscles and the outer table of the ilium to provide retraction. Elevating the periosteum from the inner table of the ilium aids in the medial exposure.

The straight and reflected heads of the rectus muscle can be identified by a combination of sharp and blunt dissection. The reflected head of the rectus can be followed around the superior capsule by dividing the periosteum off the ilium. This helps expose the superior capsule. The rectus muscle is divided at its conjoined tendon and retracted distally. All that now remains to expose the capsule is to divide and clean the pericapsular fat and fibrous tissue from the capsule. This is best done by dividing it sharply down to the actual capsule and then using a combination of cautery current and dissection with a sharp periosteal elevator.

FIGURE 3-10. If the hip has been dislocated for any length of time, there is a false acetabulum, and the capsule adheres to it. It is essential that the capsule be stripped off the ilium down to the true acetabulum, exposing this false acetabulum. This is performed with the periosteal elevator and leaves a rough area of bone after the adherent capsule has been elevated. When seen from inside the capsule, it is remarkable how much the surface of this false acetabulum resembles the true acetabular cartilage. Unfortunately, many hips have been "reduced" into this false acetabulum.

Before proceeding, it is important to ensure that the capsule has been exposed adequately. Inferiorly, the capsule should be exposed to its insertion into the pubis and ishium. This lies beneath the superiorly displaced iliopsoas tendon. When this is not done, it is difficult to divide the transverse acetabular ligament. Superiorly, the capsule should be exposed around to the posterior aspect. When this is not accomplished, it is difficult to obliterate the redundant capsule, which is part of the capsulorrhaphy.

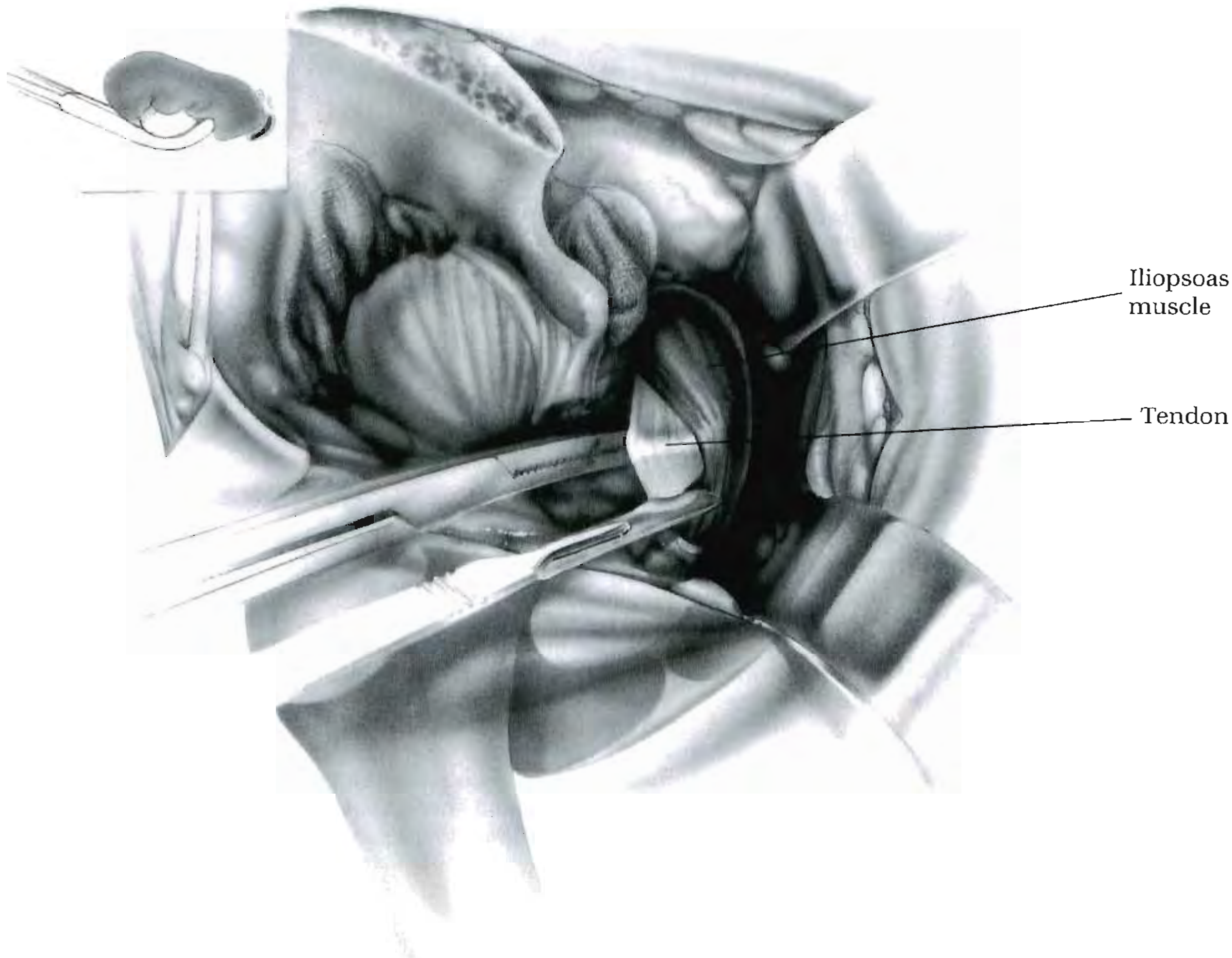

FIGURE 3-11. It is essential that the psoas tendon be divided to allow the hip to be reduced without tension, which could result in avascular necrosis or redislocation. Because the proximal femur is displaced superiorly, the iliopsoas is also displaced superiorly. It can be identified easily as it crosses the pubic ramus just medial to the anteroinferior iliac spine. Cutting the periosteum that was elevated off the inner table of the ilium exposes the iliac portion of this muscle, facilitating identification of the psoas tendon. The tendon is found on the underside of the muscle and is drawn into view by the use of a right-angled clamp *(inset)*. The tendon fibers are divided, leaving the muscle intact. Some care should be used in identifying the tendon because the femoral nerve lies nearby.

FFIGURE 3-12. The proper placement of the incisions in the capsule is important to the capsulorrhaphy. The first incision is parallel to the acetabular rim, extending from the most inferior aspect of the acetabulum to the posterosuperior aspect. A transverse incision is then made in the capsule over the femoral neck. This cut divides the capsule into superior and inferior parts. The ligamentum teres, if present, is identified and sectioned from the femoral head. It is followed down to the inferior acetabulum and excised. It provides an excellent guide to the inferior acetabulum and leads to the transverse acetabular ligament, which can be palpated as a sharp band. This should be divided because it limits the size of the acetabulum and prevents the femoral head from contacting the medial wall of the acetabulum.

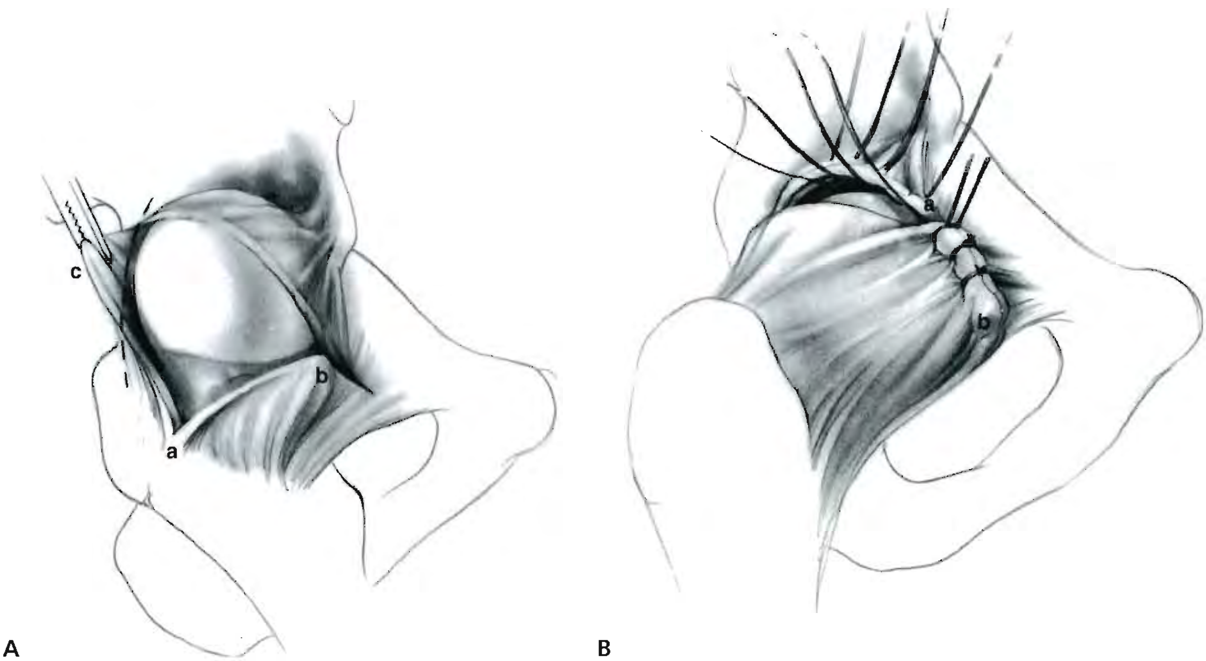

FIGURE 3-13. The femoral head should reduce easily into the acetabulum. Sutures of a strong nonabsorbable material are used to repair the capsule. They should be placed first on the acetabular side with the femoral head retracted laterally to expose the inferior and medial acetabular wall better. These sutures are placed medially beyond the acetabulum into the periosteum for a strong grip. They are then placed in the capsule to suture it in the manner illustrated.

The purpose of the repair is to suture the capsule in such a way that the femoral head is pulled inferiorly and medially. The key to this is to suture the end of the vertical cut in the capsule **(A)** to the pubis inferior and medial to the anteroinferior iliac spine. The redundant portion of the capsule superior to this vertical cut is excised, obliterating the redundant portion of the capsule. The resulting cut edge lies along the acetabular margin, where it is sutured.

After the capsulorrhaphy is completed, the reduction can be checked by a portable radiograph. It should not be necessary to hold the hip in place or resort to the use of transfixing wires; the capsular repair should hold the femoral head securely in the acetabulum. The wound is closed. A one-leg spica cast is applied with the hip in about 30 degrees of flexion, 20 degrees of abduction, and 15 degrees of internal rotation.

POSTOPERATIVE CARE

Although it is less difficult to care for a patient in a one-leg spica, the parents should be familiar with the routine care of their child and the cast. The patient is usually ready for discharge the day after surgery. The cast is left in place for 6 weeks. It is then removed, and the reduction is monitored with an anteroposterior radiograph. A cylinder cast is applied to each leg with the knee bent about 15 degrees, and a bar is secured to these casts to maintain abduction. The patient can begin to sit and crawl. These casts are removed in 4 weeks. Further bracing should not be necessary because the soft tissues will have healed sufficiently to hold the reduction. Ambulation is started. The abduction contracture gradually resolves.

3.3 ANTEROMEDIAL APPROACH TO A DEVELOPMENTALLY DISLOCATED HIP

The anteromedial approach to open reduction for DDH is ideal for a child younger than 2 years of age when concentric reduction cannot be obtained or maintained by closed methods. We use a modification of the approach described by Ludloff (1), which although often referred to as a *medial approach* (2), is in actuality an anterior approach to the hip through an anteromedial skin incision (3). The joint is approached directly over the intraarticular and extraarticular obstacles to reduction. The advantages of this particular approach are avoidance of injury to the hip abductor muscles and the growth plate of the iliac crest, and a scar that is cosmetically acceptable and well hidden. Blood loss is minimal, usually less than 20 mL per hip, and both hips can be operated on safely in the same operative session. Although the approach has been used in children older than 2 years of age, we believe that the anteromedial approach offers more advantages in this group of patients.

Criticism of the anteromedial approach includes poor visualization of the acetabulum and inability to perform secondary procedures at the same operation (4,5). In children younger than 2 years of age, particularly those younger than 18 months of age, it is rarely necessary to perform a secondary procedure, and hence, this criticism is invalid. In addition, if the interval (to be described) between the pectineus and the femoral neurovascular bundle is used, excellent visualization of all structures is easily attained. Complication rates of aseptic necrosis have been comparable in this approach to other series reported in the literature (6) (Figs. 3-14 to 3-19).

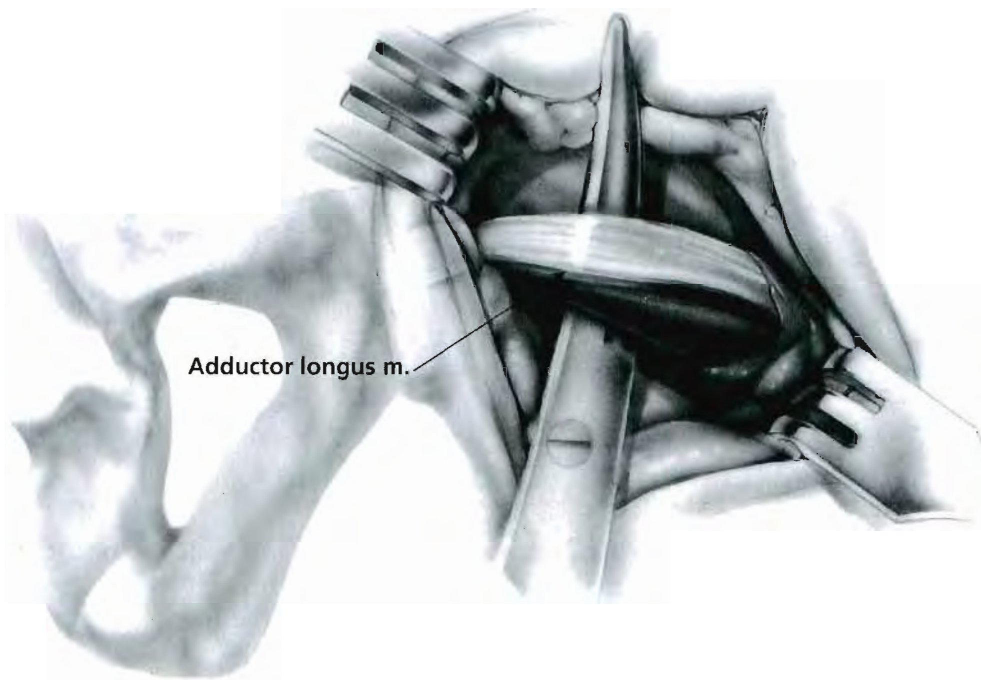

FIGURE 3-14. The procedure is performed with the patient in the supine position. The entire lower extremity, including the hemipelvis on the involved side, is draped free to allow full motion of the hip and knee during the procedure. The hip is next flexed to about 70 degrees in unforced abduction while the neurovascular bundle is identified and the superior and inferior borders of the adductus longus are palpated. The incision should extend from the inferior border of the adductor longus to just inferior to the femoral neurovascular bundle in the groin (see Fig. 3-20). The skin and subcutaneous tissues are incised down to the deep fascia, which is incised longitudinally along the adductor longus in the direction of the muscle fibers. The adductor longus is isolated and sectioned close to its insertion with bipolar cautery. The anterior branch of the obturator nerve is identified as it crosses the adductor brevis muscle. The nerve is followed proximally to its entrance under the thigh beneath the pectineus muscle.

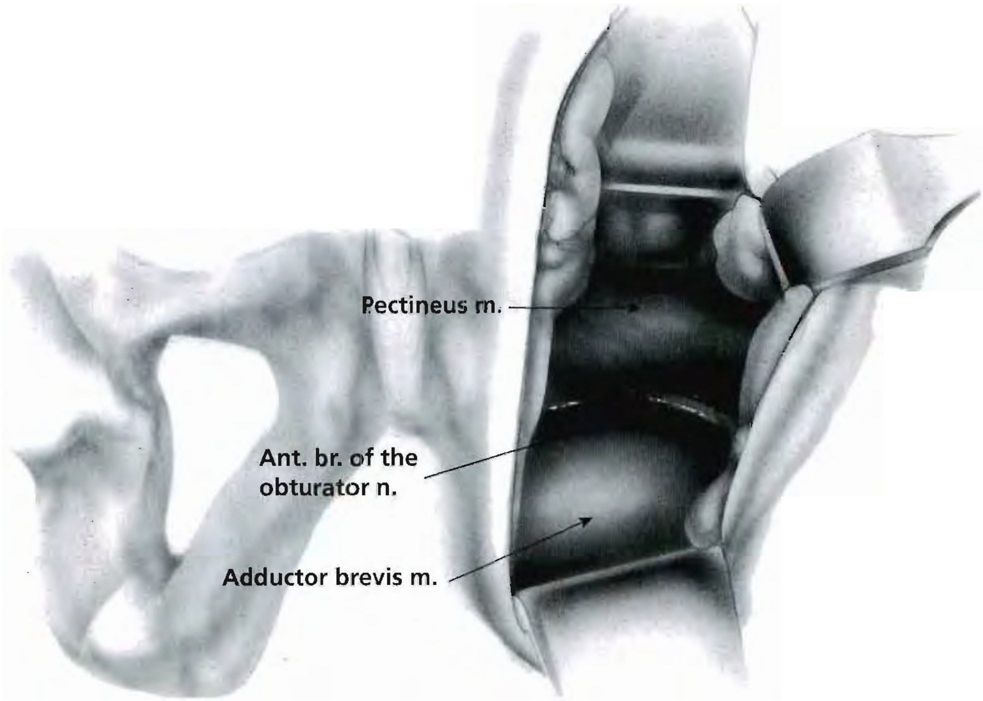

FIGURE 3-15. The thin fascia over the pectineus muscle is then incised, exposing both the superior and inferior borders of the pectineus muscle. The interval between the pectineus muscle and the femoral neurovascular bundle is then identified and bluntly dissected. Great care must be taken in this dissection to avoid injury to the medial femoral circumflex artery, which courses in a superior to inferior direction in the operative field.

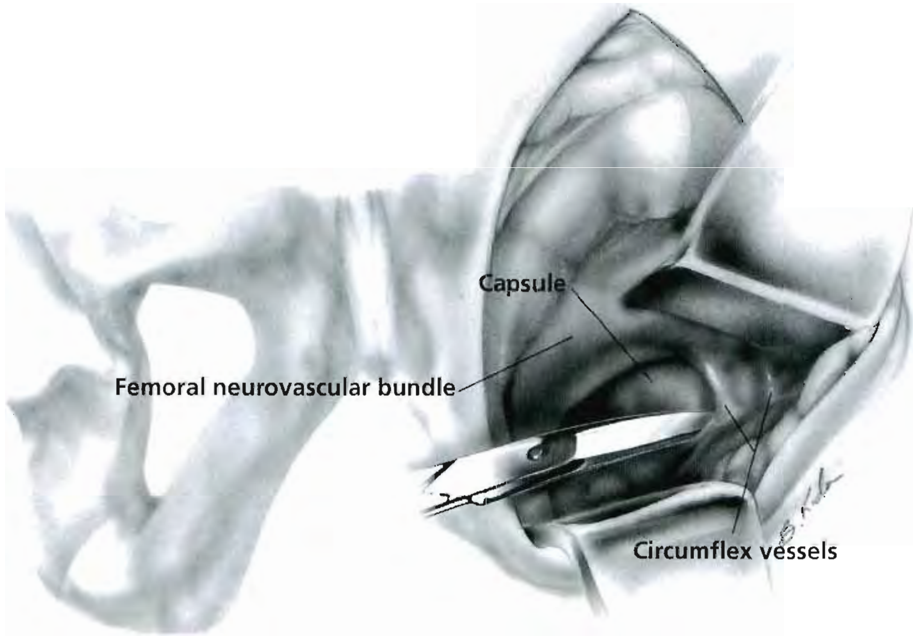

FIGURE 3-16. Retraction on the femoral neurovascular bundle must be gentle to avoid injury to the femoral vein, which is directly under the retractor and the remainder of the neurovascular bundle. Just distal to the medial femoral circumflex artery, the iliopsoas tendon can be palpated. This is greatly facilitated by externally rotating the leg until the lesser trochanter is easily palpable in the operative field.

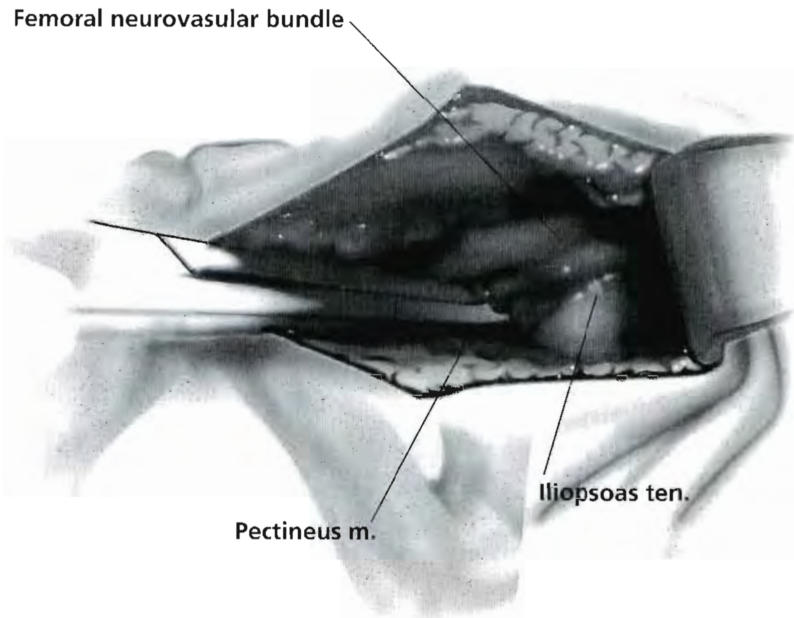

FIGURE 3-17. The iliopsoas tendon is then isolated with a curved hemostat and sectioned sharply at the insertion on the lesser trochanter. With gentle retraction on the femoral neurovascular bundle superiorly and the pectineus muscle inferiorly, the hip joint capsule is isolated with blunt dissection. Retraction should never be in both directions at the same time. When exposing the capsule superiorly, the femoral neurovascular bundle can be retracted. When exposing it inferomedially, the pectineus side can be retracted. It is important to visualize the entire hip joint capsule completely in the field before incising the capsule. The capsule will be visualized both medially and laterally to the medial circumflex vessels in the surgical field. Great care should be used in handling the medial circumflex vessels. Occasional injury to these vessels, however, has not resulted in a higher incidence of aseptic necrosis. In high dislocations, the capsule must be separated carefully from the femoral neurovascular bundle so that the incision may be extended along the posterior superior rim of the acetabulum.

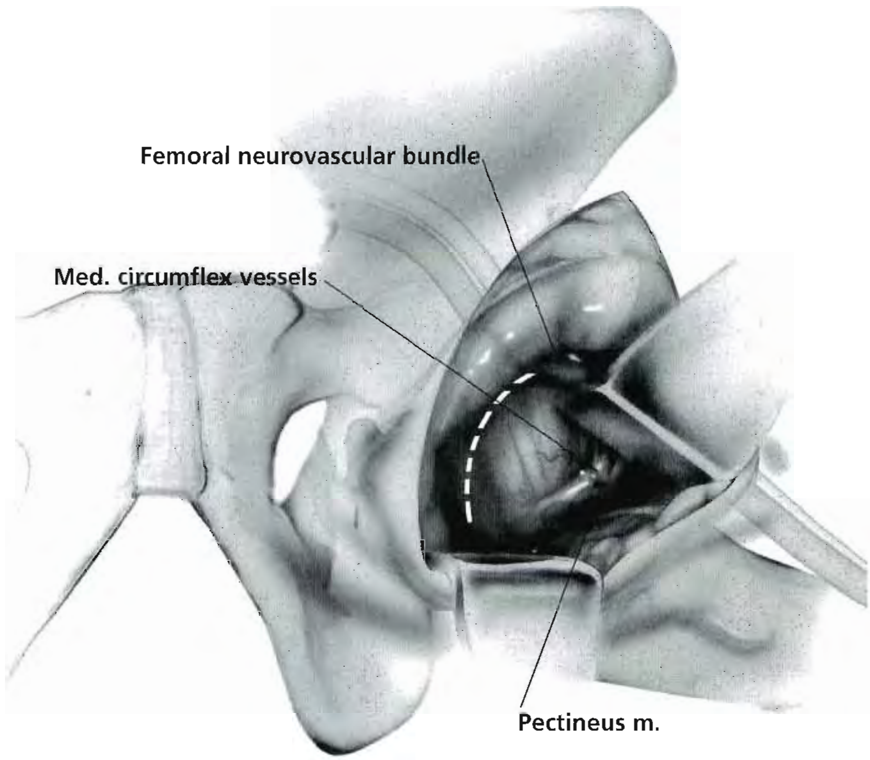

FIGURE 3-18. A small incision is next made in the anteromedial hip joint capsule parallel to the anterior acetabular margin. After the capsular incision is made, the ligamentum teres can be visualized, grasped with a Graham hook, and delivered into the wound. The capsular incision can then be extended along the ligamentum teres to locate the ligament's insertion on the femoral head. The leg can be rotated to facilitate bringing the head into the operative field. After the ligamentum teres is detached sharply from the femoral head, the stump can be grasped with a hemostat and the interval between the ligamentum teres and the anterior inferior medial aspect of the joint capsule identified.

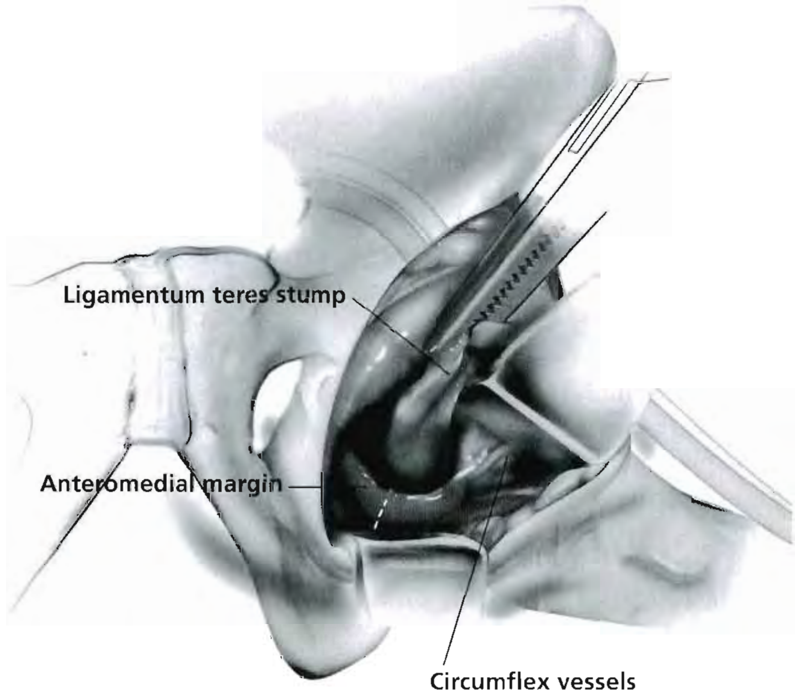

FIGURE 3-19. With a dissecting scissors in the interval between the ligamentum teres and the anteromedial joint capsule, the capsule is incised sharply. After the entire anteromedial capsule is incised, the ligamentum teres, along with the transverse acetabular ligament, is excised sharply either with a knife or dissecting scissors. The acetabulum can now be completely visualized. The fibrofatty tissue of the pulvinar can be removed with pituitary ronguers and the posterior, superior, and inferior walls of the acetabulum inspected. In the rare instance when an inverted labrum is seen, the labral tissue can be separated from the nonarticular medial wall of the acetabulum with a blunt nerve hook. No portion of the peripheral acetabulum should be excised during the procedure. Now that the anatomic obstacles to reduction have been removed, the head can be reduced directly into the acetabulum (see Fig 3-25). It is on occasion necessary to "T" the joint capsule in high longstanding dislocations. In this case the "T-ing" of the capsule is very similar to that done in the anterior approach extending from the anteroinferior spine distally. After the head is reduced, stability is assessed and closure completed. We prefer to place the hip in about 110 degrees of flexion and 35 to 40 degrees of abduction. No drains are used. The hip capsule is left open. Only the deep fascia of the thigh is approximated with a running absorbable suture. Subcutaneous tissues are also closed with an absorbable suture, and the skin is closed with a subcuticular absorbable suture. The wound is dressed with a bioclusive dressing, and the patient is placed in a postoperative well-molded one and one-half leg spica cast extending from the nipple line to just above the ankle on the involved side and just above the knee on the noninvolved side. The cast must be well molded dorsal to the greater trochanters to prevent redislocation.

POSTOPERATIVE CARE

On the day of surgery, a single-cut computed tomography scan is obtained to document the reduction. Patients are usually discharged on the day of surgery. Parents are instructed about cast care and that we are relying on the cast to maintain the reduction obtained at surgery. Most patients require little analgesia postoperatively. We generally recommend that the patients are nursed in a sitting position during the day as well as during the night. The parents are encouraged to pick up the children not under the arms but rather under the cast to prevent "shucking," which may cause cast sores. Six weeks after surgery, the cast on the involved side distal to the knee is removed to allow some motion of the knee and some rotation at the hip. Three months after surgery, the entire cast is removed, and an abduction brace is applied that is structured to maintain the hip in the same position it was in the plaster cast. Patients then wear the abduction orthosis full-time except for bathing (during which time the hips are kept in abduction). At about 5 months after surgery, the patient is gradually weaned from the brace to wearing it only at night and nap time until acetabular development is normal. The brace is usually worn for an average of 11 to 23 months after surgery.

References

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3.4 MEDIAL APPROACH FOR OPEN REDUCTION OF A DEVELOPMENTALLY DISLOCATED HIP

The medial or anteromedial approach to the reduction of a congenitally dislocated hip was initially reported in the American literature in 1913 (1). Not until 10 years after the reports of Mau and colleagues (2) and Ferguson (3) in the early 1970s was this procedure used widely in the United States.

In principle, the operation is designed to remove certain obstacles to closed reduction, such as a tight iliopsoas tendon, a constricted capsule, and the transverse acetabular ligament. Unlike the anterior approach, a capsulorrhaphy is not possible, and it is difficult or impossible to deal with the cranial structures, such as the labrum.

This procedure is most appropriate for children younger than 18 months of age who experience failed closed reduction. The types of cases in which this procedure is applied by different physicians (i.e., their definition of failed closed reduction) are described in recent reports. Mankey and colleagues (4) believe that the procedure should be used in any patient in whom a concentric reduction could not be achieved with less than 60 degrees of abduction, whereas O'Hara and colleagues (5) applied it only to those who had a persistent medial dye pool on arthrogram at the time of reduction.

There are several variations on the medial approach. The most common approach, and the one described here, is between the pectineus muscle anteriorly and the adductor longus and brevis muscles posteriorly. Ferguson (3) dissected between the adductor longus and brevis muscles anteriorly and the gracilis and adductor magnus muscles posteriorly (Figs. 3-20 to 3-25).

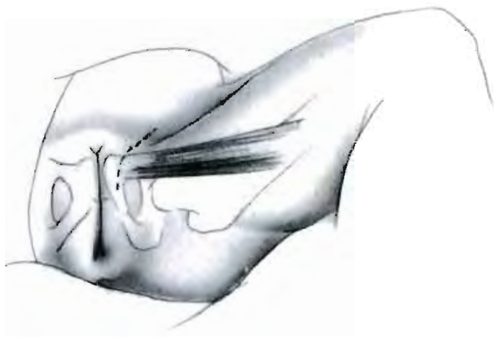

FIGURE 3-20. A transverse incision 3 to 4 cm in length and 1 cm distal to the groin crease is made with two thirds of the incision superior to the adductor longus tendon. This incision is similar to that used to release the adductors in cerebral palsy.

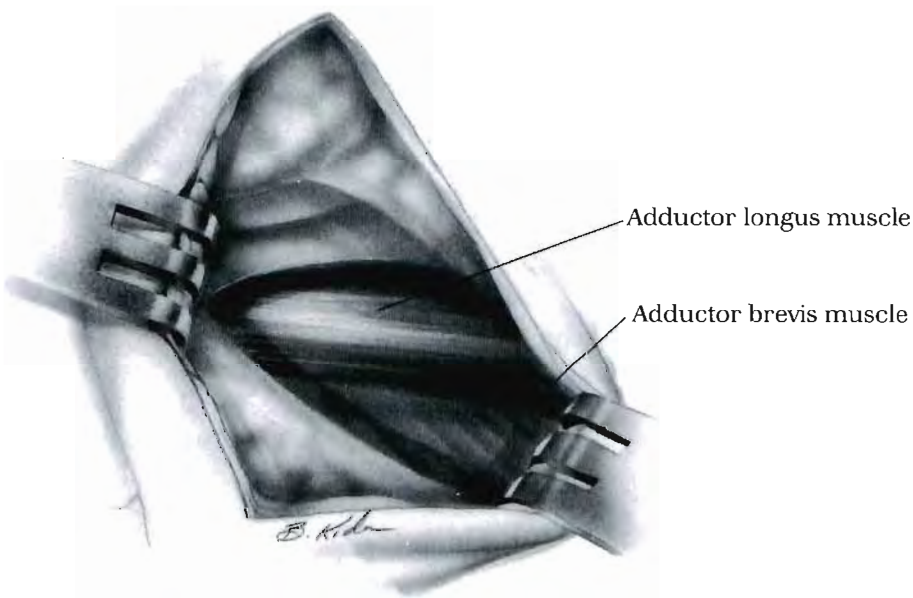

FIGURE 3-21. The fascia along the superior border of the adductor longus is opened, and this muscle is isolated and divided close to its insertion on the pelvis and retracted distally.

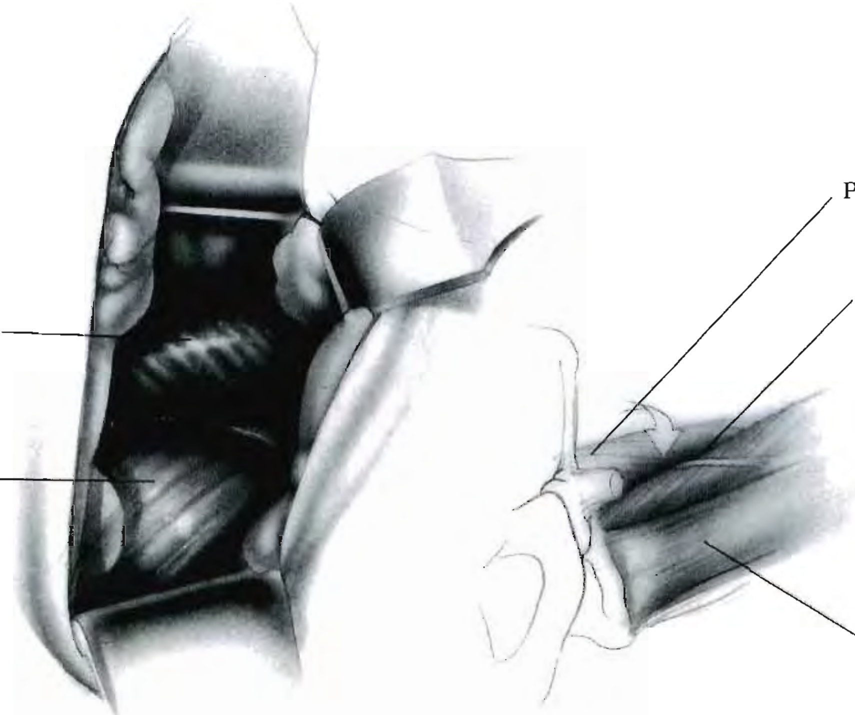

FIGURE 3-22. The cut muscle is retracted distally, exposing the adductor brevis muscle in the inferior part of the wound and the pectineus muscle in the superior part of the wound. The branches of the anterior obturator nerve can be seen on the surface of the adductor brevis muscle. Blunt dissection follows this nerve beneath the pectineus muscle.

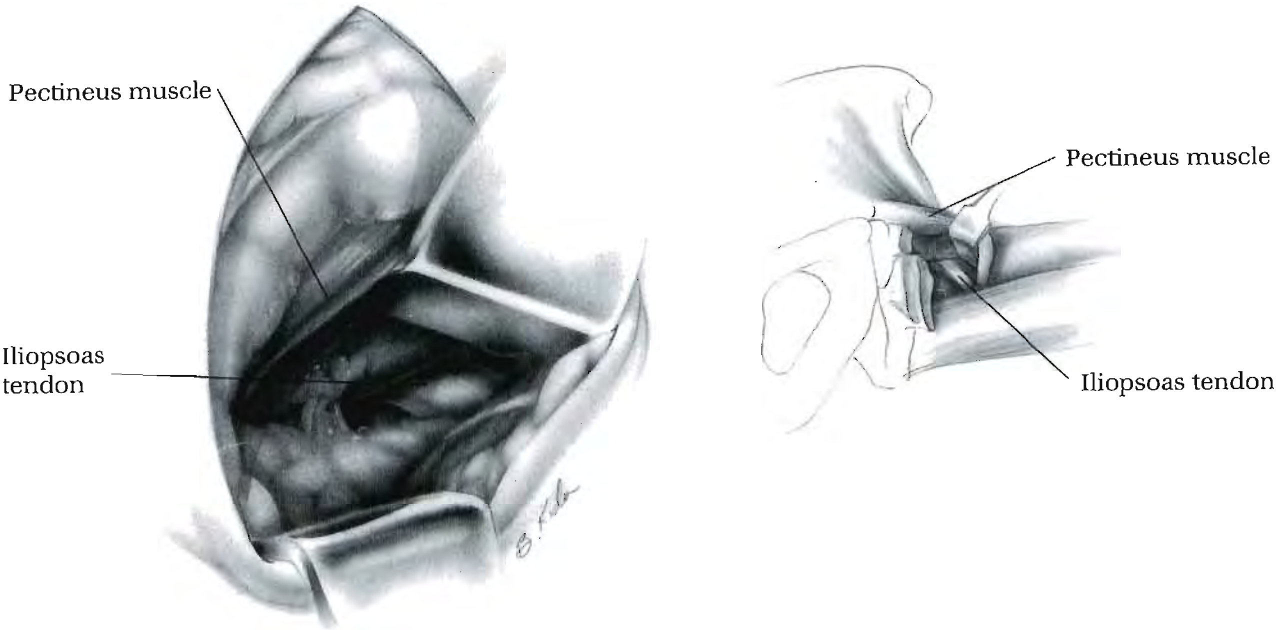

FIGURE 3-23. The posterior border of the pectineus muscle is freed proximally to its insertion on the pelvis as well as distally. This step is essentially the same as that in performing a iliopsoas tenotomy through the medial approach, except that in this case, more proximal dissection is required. A retractor is placed beneath the pectineus muscle, retracting it superiorly. The lesser trochanter and the iliopsoas tendon can be felt but not easily seen. This is because the tendon is surrounded by a fascial layer that must first be opened. When the tendon is seen, it can be pulled into the wound with a right-angled clamp and sharply divided.

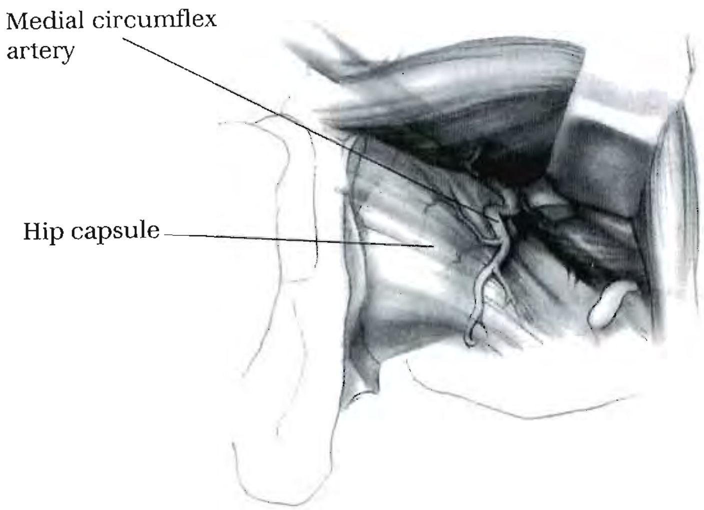

FIGURE 3-24. After the iliopsoas tendon is divided, clearing the precapsular fat from the capsule is all that remains before opening the capsule. This is accomplished with blunt dissection. A small branch of the medial circumflex artery is seen crossing the capsule inferiorly. This can be dissected free and spared, on occasion, although its ligation has not resulted in an increase in avascular necrosis (6).

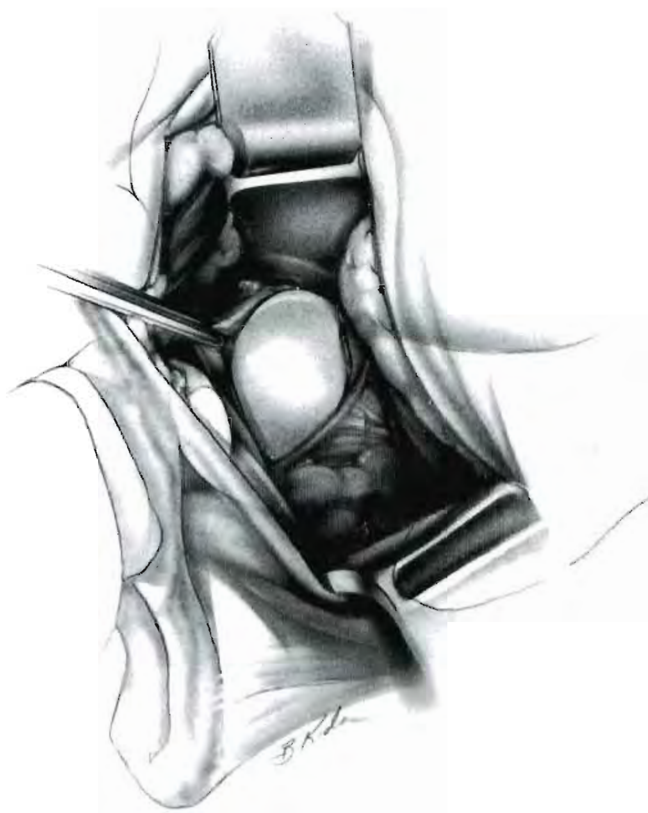

FIGURE 3-25. The capsule is cut open in the direction of the femoral neck. The transverse acetabular ligament is readily identified and can be sectioned. The ligamentum teres can be seen. Additional release of the capsule can be performed if necessary, but in most cases, the hip reduces easily into the acetabulum.

The hip should be reduced and held in various positions to determine the best position for postoperative immobilization. This is because it is not possible to perform a capsulorrhaphy to hold the hip in place. This is accomplished as in closed reduction by the cast. It is particularly important to note what degree of flexion causes the hip to subluxate inferiorly. Finally, the deep fascia and the skin are closed.

POSTOPERATIVE CARE

A one and one-half leg spica cast (double-leg spica cast if both hips are opened) is applied while the patient is still under anesthesia. The hip is placed in the position that was determined best by inspection. This is is similar to the human position of Salter that is used in closed reduction but with less flexion.

The patient should be maintained in the cast for the same amount of time as for a closed reduction. This varies considerably with the age of the child and the surgeon's reliance on methods of abduction splinting other than the spica cast. Development of the lateral edge of the acetabulum is a useful sign of a stable reduction.

References

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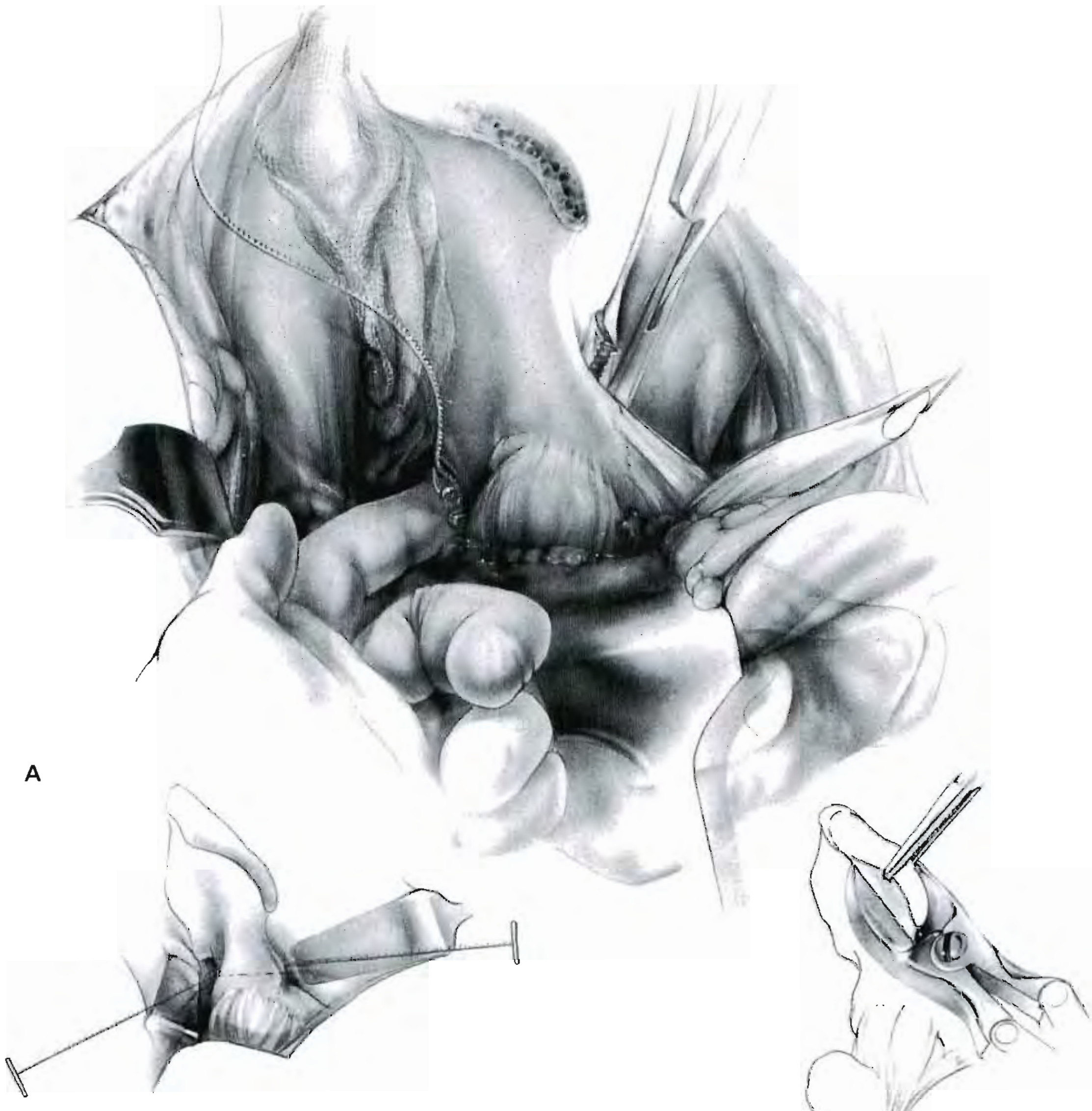
3.5 INNOMINATE OSTEOTOMY OF SALTER

In 1961, Salter described an operation based on a new principle: redirection of the entire acetabulum as a unit. This was accomplished by performing a transverse osteotomy of the ilium just above the acetabulum and opening the osteotomy anterolaterally by hinging and rotating the acetabular segment on the symphysis pubis (1). It was designed to preserve the normal acetabular structures and shape while correcting the abnormal anterolateral facing of the acetabulum seen in late cases of congenital dislocation of the hip.

This is probably the most widely used and written about pelvic osteotomy in the treatment of congenital dislocation of the hip. Salter and Dubos' (2) results have largely been confirmed by subsequent reports (3,4). Because of the apparent ease with which this procedure can be performed, however, it is also the most poorly performed and misapplied. The judgment involved in the application of Salter osteotomy and its proper technical execution are not easy (5). The prerequisites, contraindications, and potential errors have all been described (6). One of the most obvious and common errors is the failure to obtain a concentric reduction before performing the osteotomy.

The biomechanical aspects of the osteotomy have been studied. With computer modeling, Rab (7) estimated that the Salter innominate osteotomy provides about 15 degrees of lateral coverage and 25 degrees of anterior coverage, although many clinicians believe that more lateral coverage can be obtained. Wong-Chung and colleagues (8) have demonstrated that there is no significant lateralization of the hip in a properly performed osteotomy.

The patient is positioned as for open reduction of the hip through the anterior approach, and the same incision and approach are used. If an open reduction of the hip is not to be performed at the same time, it is not necessary to expose the hip capsule (Figs. 3-26 to 3-29).



A

B C

FIGURE 3-26. The inner and outer table of the ilium are exposed. The periosteum is elevated carefully from the sciatic notch with a curved periosteal elevator, such as a Crego elevator. A right-angled forceps is passed medial to lateral while the finger of the other hand is used to push the periosteum down and away from the sciatic notch on the outer table. A Gigli saw is grasped in the forceps and pulled through the sciatic notch **(A)**.

Retractors are placed in the sciatic notch on each side of the ilium to provide wide retraction and protection of the soft tissues. The osteotomy is performed with the Gigli saw, which emerges at or just above the anterior inferior superior iliac spine. While using the Gigli saw **(B)**, the hands should be spread as far apart as possible and constant tension kept on each end of the Gigli saw because it has a tendency to bind.

The bone graft that is used to hold the osteotomy site open is taken from the anterior iliac crest. This can be done with a bone biting forceps in young children **(C)** but is facilitated with a power saw in older children.

At this point, it is imperative to perform an intramuscular tenotomy of the iliopsoas, as described in the anterior approach to the congenitally dislocated hip.

FIGURE 3-27. Towel clips are used to grasp the two fragments. The proximal fragment is grasped and held, not to help pull open the osteotomy site, but rather to stabilize the pelvis. Any upward movement of this proximal fragment creates spurious correction and the appearance of a high iliac crest simulating a leg-length inequality. The distal fragment is grasped as far posteriorly and as close to the hip capsule as possible **(A)** so that there is not a tendency to break off a piece of bone.

If the hip capsule has not been opened, the leg can be used to produce the desired correction in the acetabulum. This is done by placing the foot on the opposite knee in the figure-four position. Pushing down on the knee and pulling the heel toward the patient's chin **(A)** produces the desired rotation. If the capsule has been opened **(B)**, the towel clip grasping the distal fragment is used to rotate this fragment downward, in line with the ilium **(C)**. At the same time, this fragment, which probably slipped posteriorly after the osteotomy, should be pulled forward. It is this rotation that accounts for the difference in shape of the obturator foramen, which is seen on the postoperative radiograph.

The bone graft is tailored to fit tightly in the gap that has been created in the osteotomy and is inserted. This graft should be relatively stable after it is inserted. Its stability can be tested by pulling on the graft with a Kocher clamp. After the graft is inserted, the posterior aspect of the osteotomy should be closed, and the distal fragment should not be displaced posteriorly relative to the proximal fragment. Kalamchi (9) has suggested a modification, placing a notch in the posteriorly cut surface of the proximal fragment and inserting the posterior edge of the distal fragment into the notch. This tends to increase stability and helps avoid posterior displacement of the distal fragment.

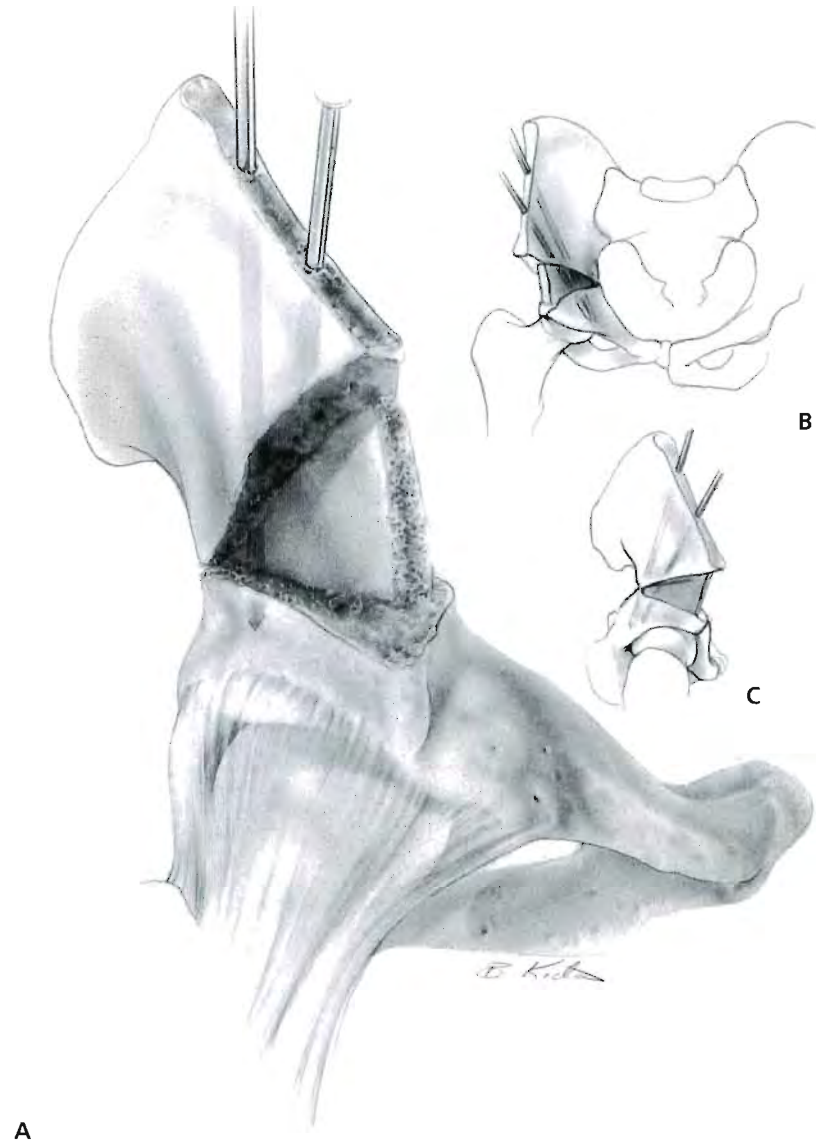


FIGURE 3-28. Although the graft should be secure, it is not secure enough to leave without fixation. Do not use smooth or thin wires. Two heavy threaded Kirchner wires should be used and passed from the proximal fragment into the distal fragment **(A)**. In the distal fragment, they should lie medial and posterior to the acetabulum **(B, C)**, and this determines their starting point in the proximal fragment. There is a danger of passing one of the wires into the hip joint when the capsule has not been opened, as in the treatment of acetabular dysplasia. This and the fact that properly placed pins appear to penetrate the hip joint on the postoperative radiograph make it imperative that the surgeon has a good grasp of the pelvic anatomy and that he or she carefully moves the hip to feel and listen for crepitus. After this, the wound is closed. A drain is usually not necessary when only an innominate osteotomy has been performed.

A

B

C

FIGURE 3-29. MP is a 2-year, 9-month-old girl **(A)** in whom there have been no signs of acetabular remodeling 18 months after closed reduction of a congenitally dislocated hip. In addition, there is excessive femoral anteversion. It was decided to correct these problems with an innominate osteotomy, as described by Salter.

Six weeks after the osteotomy **(B)**, certain features are observed. The posterior aspect remains closed, and posterior displacement of the distal fragment was avoided. The pins could have been inserted further, continuing down into the ischium behind the hip capsule. Also, there was more lateral than anterior rotation achieved, as evidenced by only a slight asymmetry of the obturator foramen.

At 6-years, 1-month old **(C)**, the resulting containment is good, as evidenced by the development of the hip.

POSTOPERATIVE CARE

Immobilization depends on the circumstances. In older children and teenagers who are deemed reliable with a three-point, partial weight-bearing crutch gait, no immobilization and early ambulation can be permitted. Young or untrustworthy children should always be immobilized for 6 weeks before weight bearing is permitted. If an open reduction is performed at the same time, the hip is immobilized in accordance with the treatment for that procedure.

References

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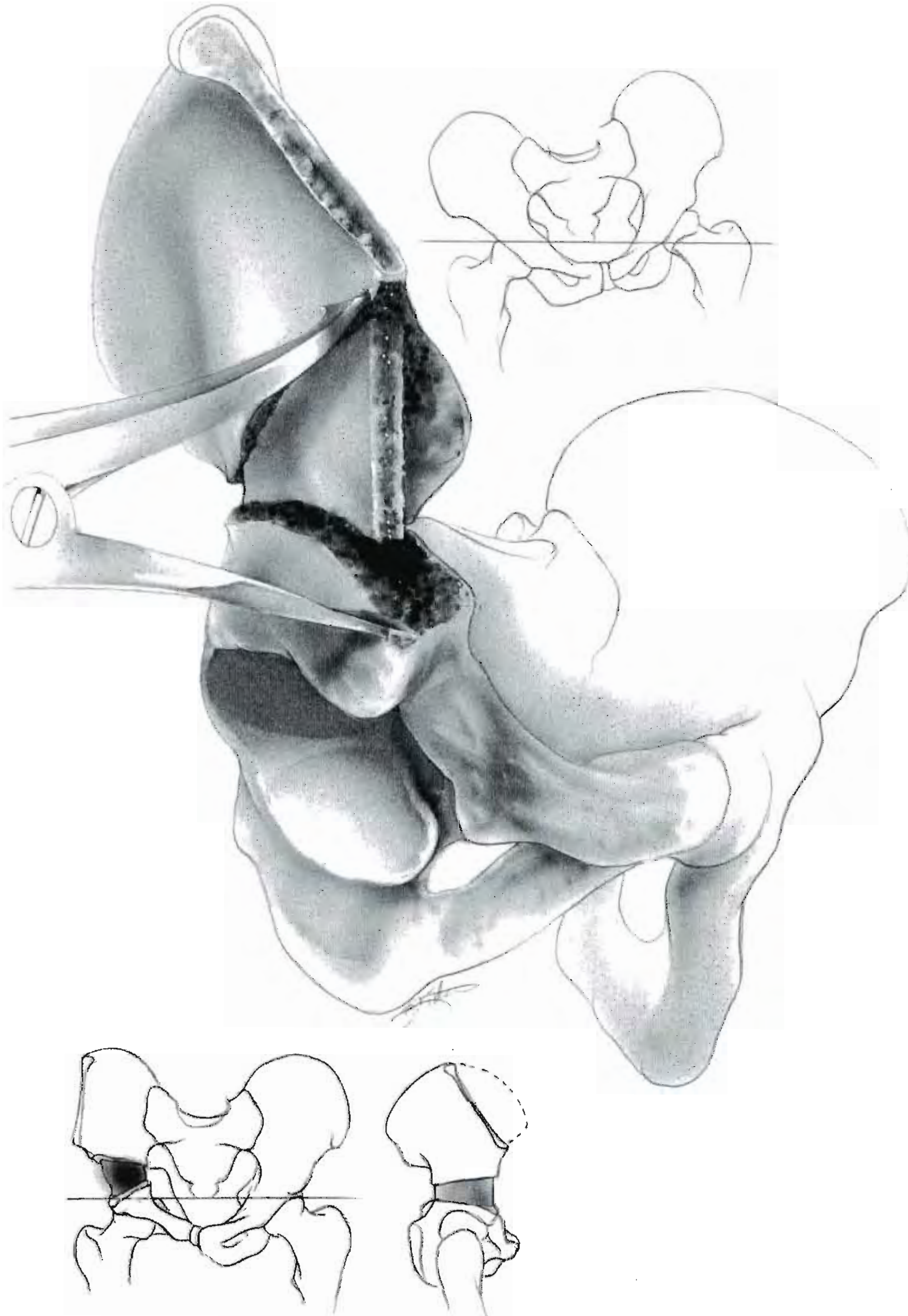
3.6 TRANSILIAC LENGTHENING OF THE LOWER EXTREMITY

Millis and Hall (1) have proposed a modification of the Salter innominate osteotomy to increase the length of the lower limb. This procedure is best suited for the patient who has an acetabular dysplasia associated with an ipsilateral shortening of the leg of 2 to 2.5 cm. Barry and colleagues (2) reported on its use in 23 patients (Figs. 3-30 to 3-31).



◀ **FIGURE 3-30.** The innominate osteotomy of Salter is performed. Unlike the procedure described by Salter, however, opening of the posterior aspect is required rather than prohibited. It is this opening or distraction between the two fragments that produces the lengthening of the lower extremity. If correction of the acetabular dysplasia is also desired, the distal fragment must be rotated. This is accomplished by a combination of forces: distally directed pressure to prevent the proximal fragment from moving cephalad, manual distraction of the limb, and rotation of the distal fragment. The distraction is held with a spreader. Time should be spent to allow the tissues to stretch. The distraction can take place over 20 to 30 minutes depending on the desired amount of distraction and the patient's age.

The graft that is shaped to hold the osteotomy open is not triangular, as in the classic Salter osteotomy, but rather quadrangular, with the width above the hip joint equal to the amount of lengthening achieved and the wider anterior portion holding the rotation of the distal fragment. This graft is under extreme tension and requires at least two heavy threaded Kirchner wires to hold it in place. Because of this lengthening, it is imperative that an iliopsoas tenotomy be performed, as described for the anterior approach, to open reduction of the dislocated hip.

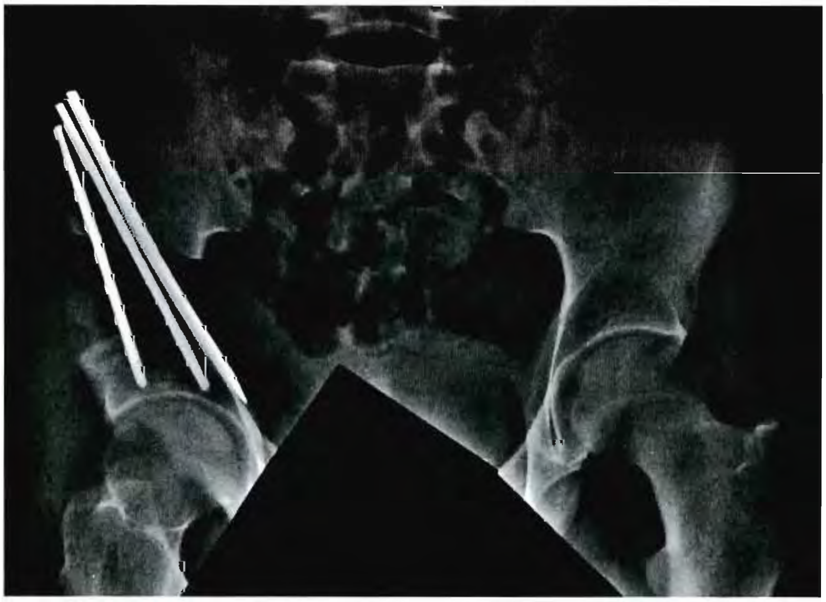


FIGURE 3-31. The radiograph of a patient 6 weeks after a transiliac leg lengthening of 3 cm show the wide distraction of the posterior aspect of the osteotomy. Also notice the increased number of pins used for fixation. (Courtesy of Michael Millis, M.D., Children's Hospital Medical Center, Boston, MA.)

POSTOPERATIVE CARE

The patients are placed in a balanced suspension with traction on the leg and the hip flexed. Range of motion of the hip is started the day after surgery. When the patient has gained sufficient motion, usually 4 to 5 days after surgery, ambulation with three-point touchdown weight bearing is begun. The patient is protected with crutches for a minimum of 3 months. The pins should not be removed until there is radiographic evidence of solid healing. This usually takes 6 to 12 months, depending on the age of the patient.

References

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3.7 PERICAPSULAR ILIAC OSTEOTOMY OF PEMBERTON

The pericapsular osteotomy was developed by Pemberton to address two problems that he saw in the older child with subluxation or dislocation of the hip: the acetabulum not only was "shallow" but also was facing forward and lateral, and in the dislocating hip, the femoral head was usually small in relation to the acetabulum, whereas in the subluxating hip, the acetabulum was large relative to the femoral head. The osteotomy was designed to hinge in the acetabulum through the flexible triradiate cartilage. He also observed that the direction of coverage obtained could be varied depending on the direction of the osteotomy of the ilium (1,2).

The eclectic surgeon recognizes the value of this procedure in the treatment of the subluxating or dislocated hip with an acetabulum that is relatively large in relation to the femoral head, such as the subluxating hip or in some of the neurogenic dislocating hips. At the same time, this can be a disadvantage if there is not a relative size discrepancy between the acetabulum and femoral head. The ability to vary the direction of the coverage is an additional advantage, especially when more lateral than anterior coverage is desired. A final advantage is that the bone graft is stable without additional pins, obviating the need for subsequent pin removal. Follow-up of 52 hips treated from 1968 to 1984 has been reported (3).

The prerequisites for the operation include a concentric reduction of the hip and triradiate cartilage that is open to the extent that it is sufficiently mobile. In normal children, the triradiate cartilage is sufficiently mobile until 7 or 8 years of age. In children with severe cerebral palsy or myelomeningocele, in whom this is often a useful operation, mobility in the triradiate cartilage can be present until 10 years of age or later.

A combination of the Pemberton and Salter osteotomies has also been described, the Pember-Sal osteotomy (4). The osteotomy continues past the triradiate cartilage into the body of the ischium; it does not break through into the sciatic notch. A Pember-Sal osteotomy is used most often and incorrectly to describe an osteotomy in which the osteotomy has not stayed within the ilium but rather has broken into the sciatic notch before reaching the triradiate cartilage.

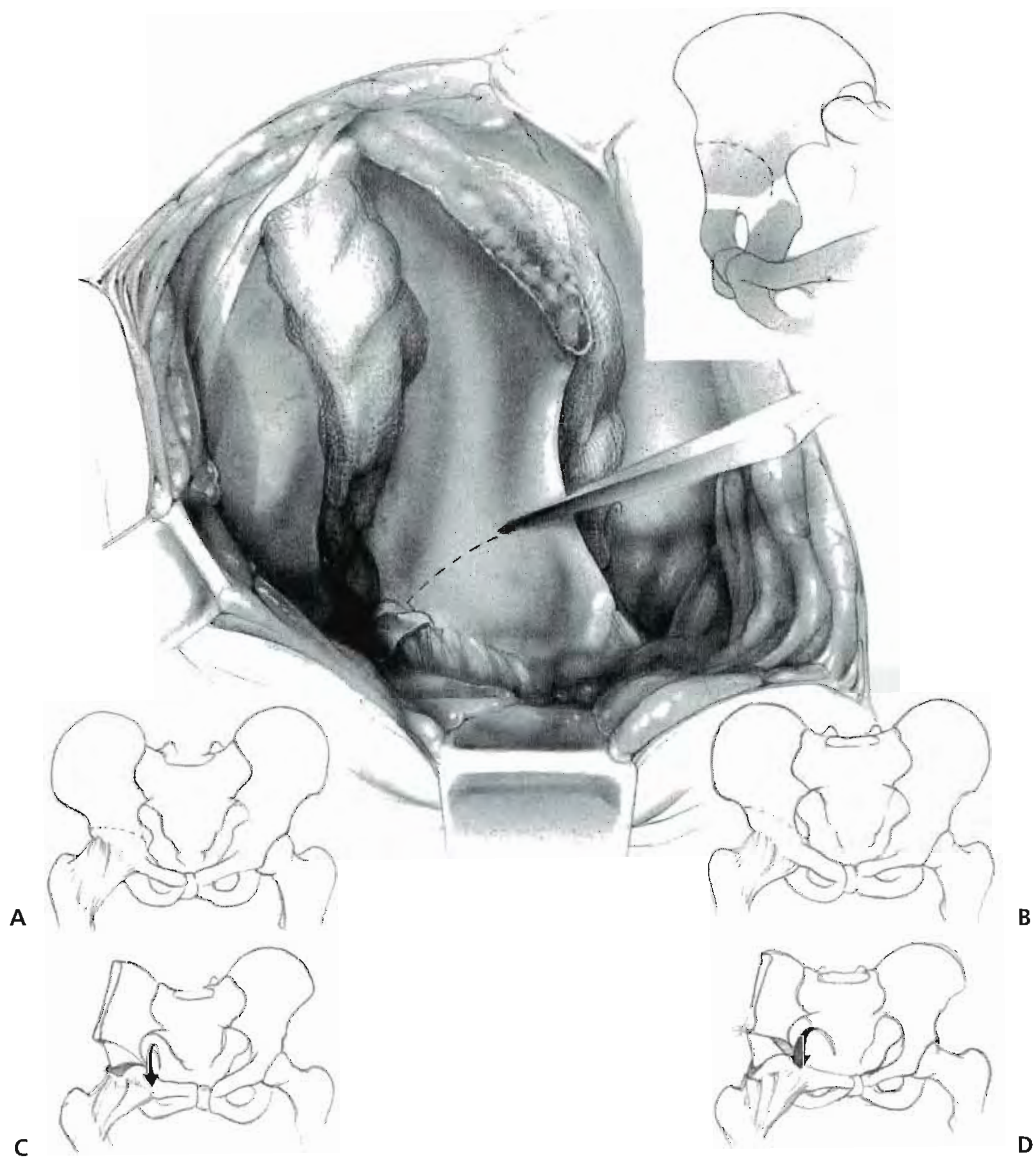
As in all acetabular redirections, the matter of incongruity must be considered. Although minor degrees of incongruity between the acetabulum and the femoral head will remodel, the extent of this process depends on the age of the child. To produce the best results, it is probably wise to apply the criteria that Salter uses for his innominate osteotomy.

The patient is placed in the same position as for open reduction of the hip joint through the anterior approach, and the same incision and approach are used (Figs. 3-32 to 3-35).

FIGURE 3-32. After th iliac apophysis is split, the inner and outer tables of the ilium are exposed subperiosteally, which is sufficient to expose the sciatic notch on both sides. It is not necessary to expose the capsule of the hip joint unless an open reduction is performed at the same time. Likewise, it is not necessary to divide the combined head of the rectus femoris muscle. Although Pemberton (1,2) did not recommend division of the psoas tendon, it may be advisable to do this, as in Salter's innominate osteotomy.

The osteotomy is planned depending on the direction in which coverage is needed. If more anterior coverage is desired **(A)**, the plane of the osteotomy is more transverse. If lateral coverage is desired **(B)**, the plane the osteotomy is inclined more laterally. After this is determined **(C)**, a small, 1/4-inch osteotome can be used to outline the osteotomy by cutting the cortex of the inner and outer table.

The osteotomy is begun about 1 cm above the anteroinferior iliac spine and proceeds posteriorly, keeping about 1 to 1.5 cm away from the attachment of the joint capsule. As the osteotome proceeds posteriorly and then inferiorly through the outer table, it disappears from sight in the soft tissue attachments behind the posterior aspect of the capsule, and there is a strong tendency for the osteotome to cut into the sciatic notch. Care in exposing the sciatic notch as far inferiorly as possible makes this error easier to avoid by seeing the portion of the ilium that lies between the sciatic notch posteriorly and the capsule of the hip joint anteriorly. It is not possible, necessary, nor advisable, however, to expose this down to the triradiate cartilage. The same problem exists when cutting the cortex of the inner table, but not to the same extent. No capsule is present **(D)**; therefore, it is sufficient to stay slightly anterior to the sciatic notch. A cobra retractor can be placed in the sciatic notch. By twisting it, the tissue is retracted, giving good exposure to the posterior area distal to the sciatic notch where visualization is most difficult.


A
B
C
D

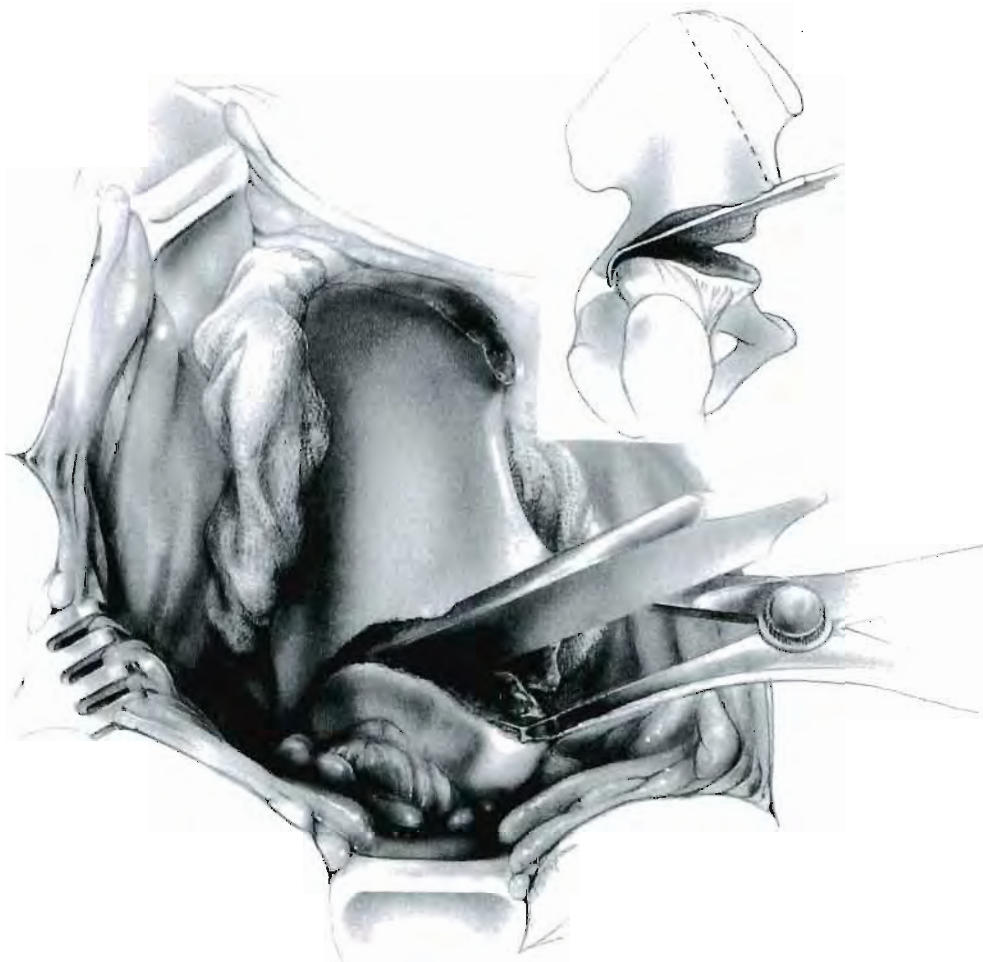


FIGURE 3-33. After the inner and outer cortices of the ilium are divided as far as can be seen, a wider curved osteotome is used to connect these two cuts. As the osteotome proceeds posteriorly, it becomes apparent that it is not able to make the sharp turn inferiorly to avoid cutting into the sciatic notch. At this point, an osteotome with a right-angled curve, available on special order from Zimmer (Zimmer Co., Warsaw, IN), is inserted into the osteotomy. This can be made easier by prying down on the acetabular roof with an osteotome and inserting a small lamina spreader to hold the osteotomy apart. The special osteotome is used to complete the cut into the triradiate cartilage. It is not possible to see the tip of the osteotome as it completes the osteotomy. It is not necessary and usually not possible to see the triradiate cartilage unless the acetabulum is levered down excessively. When the osteotomy is complete, the acetabular roof can be levered down into the desired position and held there with a lamina spreader.

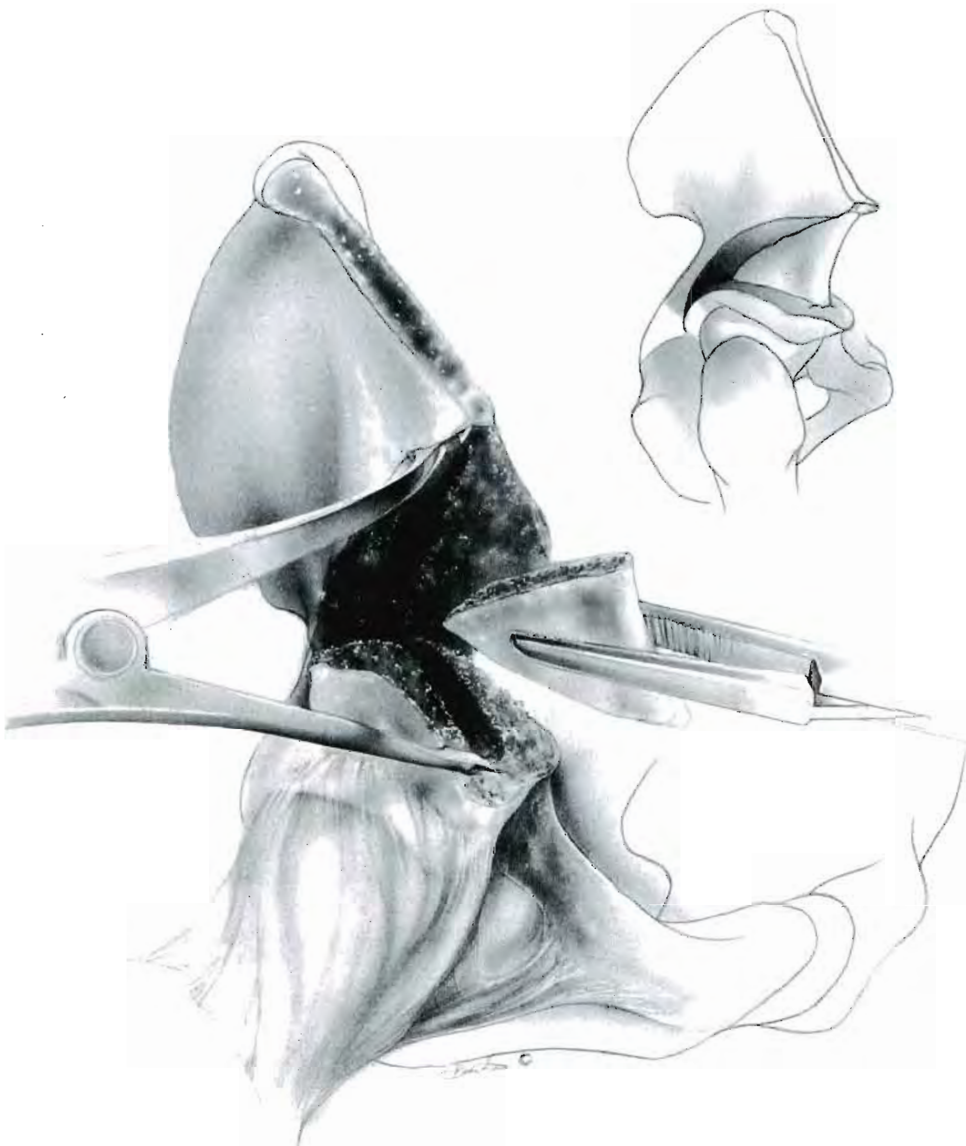
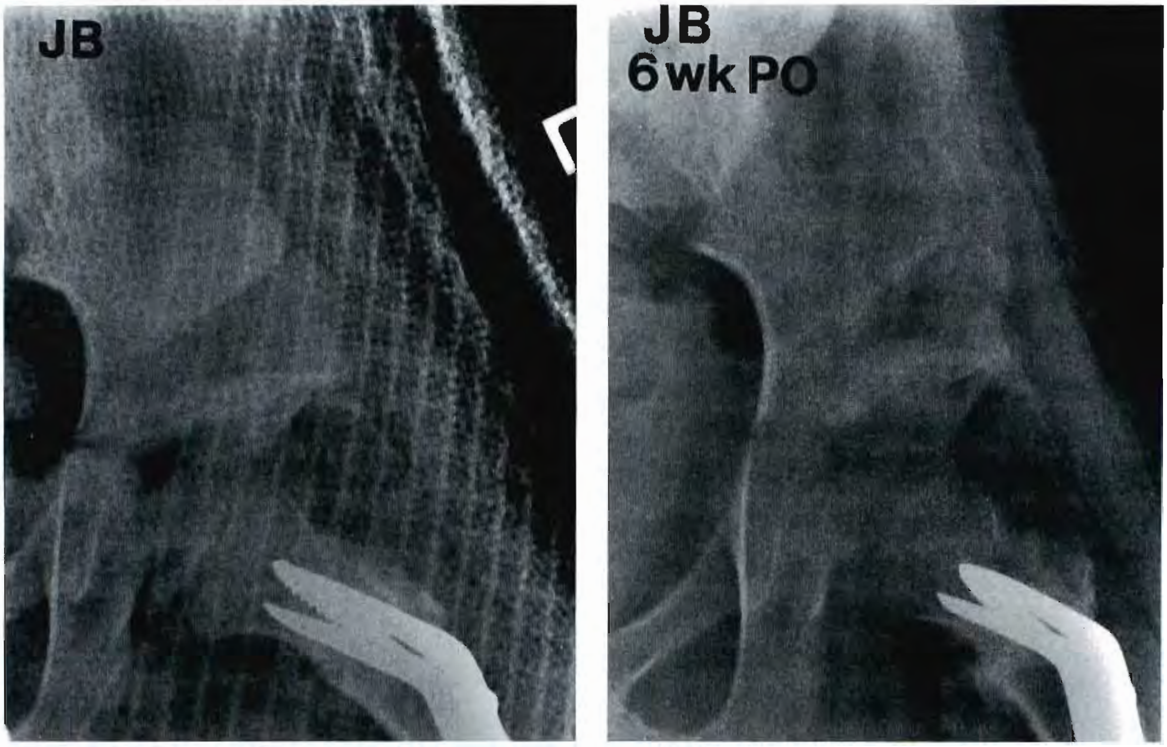


FIGURE 3-34. Grooves are prepared in the cancellous surface on each side of the osteotomy to provide secure fixation of the bone graft. This can be done with a curette. A triangular wedge of bone is cut from the anterior iliac crest. It should be larger than the gap it is designed to span because it will be recessed into the cancellous bone. When in place, the bone graft should be secure and stable, and this can be verified by attempting to dislodge the graft. The wound is closed in a routine manner.

A



B

C

FIGURE 3-35. JB is a 4-year-old boy who had an open reduction, femoral shortening and rotation, and a Pemberton osteotomy for spastic dislocation. A radiograph immediately after surgery **(A)** demonstrates the osteotomy extending into the triradiate cartilage and not breaking into the sciatic notch. Radiographs at 6 weeks **(B)** and 6 months **(C)** demonstrate the rapid healing and the excellent containment of the femoral head.

POSTOPERATIVE CARE

Because of the usual young age at which this osteotomy is performed, the patient is immobilized in a single leg spica cast. The length of immobilization depends on the other procedures done, but 6 weeks of immobilization is usually sufficient to allow protected weight bearing and physical therapy to regain motion.

References

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3.8 THE PERICAPSULAR PELVIC OSTEOTOMY OF DEGA

In the first edition of this atlas (1), the Dega osteotomy was described as being similar to the osteotomy described by Albee (2). Mubarak and colleagues (3), in their initial report on a pelvic osteotomy used in the treatment of the dislocated hip in cerebral palsy, described the Dega osteotomy as similar to the Albee shelf procedure. Lee and Carroll (4) had alluded to a similar osteotomy, which they attributed to Albee, that they had been using for several years in the child with myelomeningocele and a subluxating or dislocated hip. Much of this confusion was due to the incorrect illustrations in Dega's report (5). These show the osteotomy extending through the sciatic notch without leaving a hinge, and they do not show division of the medial wall of the ilium. Subsequently, Mubarak and associates (6) clarified their impression of the differences between the osteotomy they reported, the Albee osteotomy, and the Dega osteotomy.

Dega developed his osteotomy in the treatment of developmental dislocation of the hip to fill the need for anterolateral coverage. In concept, the Dega osteotomy is more like the Pemberton than any other osteotomy: it is an incomplete pelvic osteotomy, it alters the shape of the acetabulum, it has a posterior hinge, it can provide a variable amount of anterolateral coverage, and it cannot increase the posterior coverage sufficiently because that is where the hinge remains. Whereas the Pemberton osteotomy ends in the ilioischial limb of the triradiate cartilage and completely divides the iliac bone from anterior to this point, the Dega osteotomy ends just above the horizontal portion of the triradiate cartilage (the ilioischial and iliopubic portions) and leaves a posterior portion of both the inner and outer iliac cortex just anterior to the sciatic notch intact, forming its hinge (Figs. 3-36 to 3-40).

A

B

FIGURE 3-36. The positioning and exposure is the same as for the other pelvic osteotomies. The sciatic notch should be clearly visualized posteriorly **(A)**, the false acetabulum identified, if present, and the true acetabular edge identified. As described, it is not necessary to expose the inner aspect of the ilium. Because this takes only a minute and adds little to the morbidity of the case, however, this additional exposure might be advisable until experience is gained.

The osteotomy **(B)** begins on the lateral cortex along a curvilinear line, which starts just above the anteroinferior iliac spine, continues to arch posteriorly, staying above the acetabulum, and ends posteriorly 1 to 1.5 cm before reaching the sciatic notch.

If the surgeon desires, guide pins can be used. These pins can be helpful if the surgeon is not sure of the location of the correct exit point on the medial side. Because of the difficulty in viewing such a complex three-dimensional structure as the acetabulum in two dimensions on a radiographic screen, three pins should be used. One pin is placed anteriorly, one at the highest point above the acetabulum, and one posteriorly.

FIGURE 3-37. After the outer cortex is cut, a straight osteotome is directed medially and caudally. The steeper the acetabular slope, the higher the starting point is above the acetabulum so that the medial cut always emerges above the horizontal portion of the triradiate cartilage. The osteotome should exit medially, just above the horizontal limb of the triradiate cartilage, which is composed of the ilioischial and iliopubic portions.

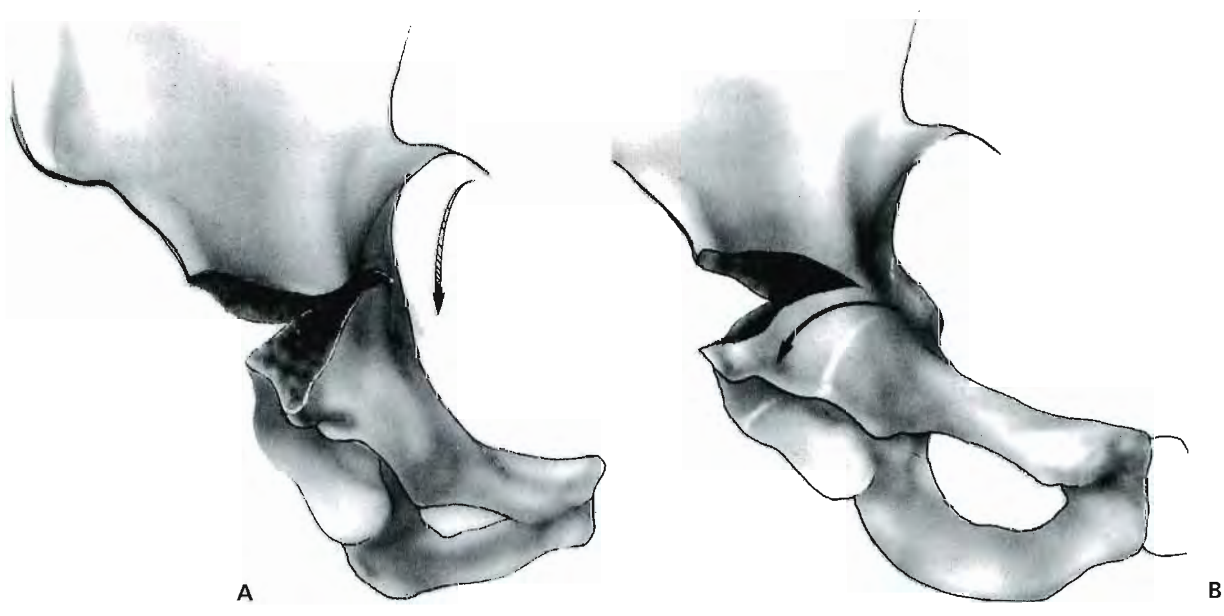

FIGURE 3-38. The direction of the rotation is determined by the extent of division of the inner cortex on the inner wall of the ilium. If more anterior coverage is needed, then the inner wall is divided, except for the 1-cm posterior hinge just anterior to the sciatic notch. This **(A)** permits the distal fragment to be rotated anteriorly. If more lateral coverage is needed, however, about one third of the inner cortex is left intact. This **(B)** now moves the hinge to the medial wall of the ilium and determines that the rotation will be anterior and lateral. The rotation becomes more anterior as more of the inner wall is divided, and the rotation becomes more lateral as more of the inner wall is left intact.

FIGURE 3-39. The osteotomy is pried open with the osteotome. The osteotomy can be held open with a lamina spreader while the bone graft is inserted. As in the Pemberton osteotomy, if a femoral shortening has been performed at the same time, this bone can usually be used. If not, tricortical bone from the iliac crest is used. The larger graft is anterior, and the smaller graft is posterior. The graft should be stable, and no internal fixation is needed. The wound is closed over drains in the routine fashion.

FIGURE 3-40. A: A left dislocated hip in an 18-month-old boy. **B:** The radiograph taken after a femoral shortening, an open reduction of the hip, and a Dega osteotomy. The bone that was removed from the femur is used to hold the osteotomy in position. It is difficult to tell from this radiograph the difference between this osteotomy and a Pemberton osteotomy, although they are performed in an entirely different manner. **C, D:** The remodeling of the acetabulum 1 year and 2 years and 3 months, respectively, after surgery. (Courtesy of W. Timothy Ward, M.D., Pittsburgh Children's Hospital, Pittsburgh, PA.)

POSTOPERATIVE CARE

Because of the usual age and reasons for performing this operation, the patient requires a spica cast. Healing of the pelvic osteotomy should usually be sufficient after 6 weeks to permit motion and weight bearing. Dega removed the anterior portion of the cast after 6 weeks to start motion, and then the entire cast was removed at 12 weeks.

References

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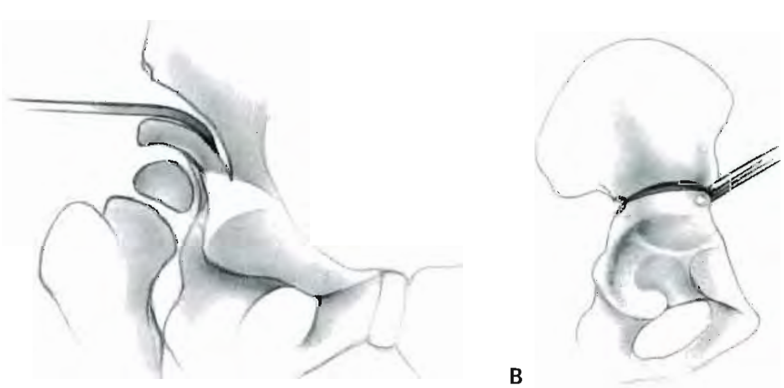
3.9 THE ALBEE SHELF ARTHROPLASTY

In the first edition of this atlas (1), the procedure described here was attributed to Dega because of the report of Mubarak and colleagues (2). This was not a true description of Dega's osteotomy, but the confusion is understandable when reviewing the illustrations in his report (1). Subsequently, Mubarak and colleagues (3) have clarified their understanding of the differences between the osteotomy they described and that actually performed by Dega, and they describe their osteotomy as a modification of the osteotomy of Dega. As further clarification of Dega's osteotomy has occurred through surgeons who actually worked with him, it has become clear that the operation described by Mubarak and colleagues (3) is more a modification of the shelf procedure described by Albee (4) than it is of the Dega osteotomy.

Albee performed his osteotomy in a time of limited surgery and no intraoperative radiographic control. During this period, shelf procedures were the only procedures used to add coverage to an acetabulum; the entire subject was in its infancy. Much of the subsequent discussion about the differences between Albee's osteotomy and those of others concerned how deep and exactly where the osteotomy went. This is impossible to know. Trevor and associates (5) described a procedure that they attributed to A. O. Parker. Albee is not credited, although the description is strikingly similar. For several years, Lee and Carroll used an operation they attributed to Albee for the treatment of acetabular deficiency in children with myelomeningocele. They recognized the need for posterior coverage in these paralytic hips and understood that this osteotomy would provide this posterior coverage (6). Mubarak and colleagues (3) reported on the use of an osteotomy similar to that of Albee in the treatment of the hip in cerebral palsy. Their report provides the first useful description of this osteotomy along with modifications that have popularized this procedure. In a recent report on the use of this osteotomy in the one-stage correction of the dysplastic hip in cerebral palsy, it was referred to as the *San Diego acetabuloplasty* (7) (Figs. 3-41 to 3-45).

FIGURE 3-41. The exposure of the ilium is the same as for the Salter osteotomy. Soft tissue release, open reduction, and femoral osteotomy can be performed at the same time to gain the concentric reduction of the femoral head, which is a prerequisite for this and most other osteotomies.

The osteotomy is begun about 0.5 to 1 cm above the acetabulum on a line that extends from the anteroinferior iliac spine to the sciatic notch. The cortex is completely divided with a straight osteotome along the desired line.



A B

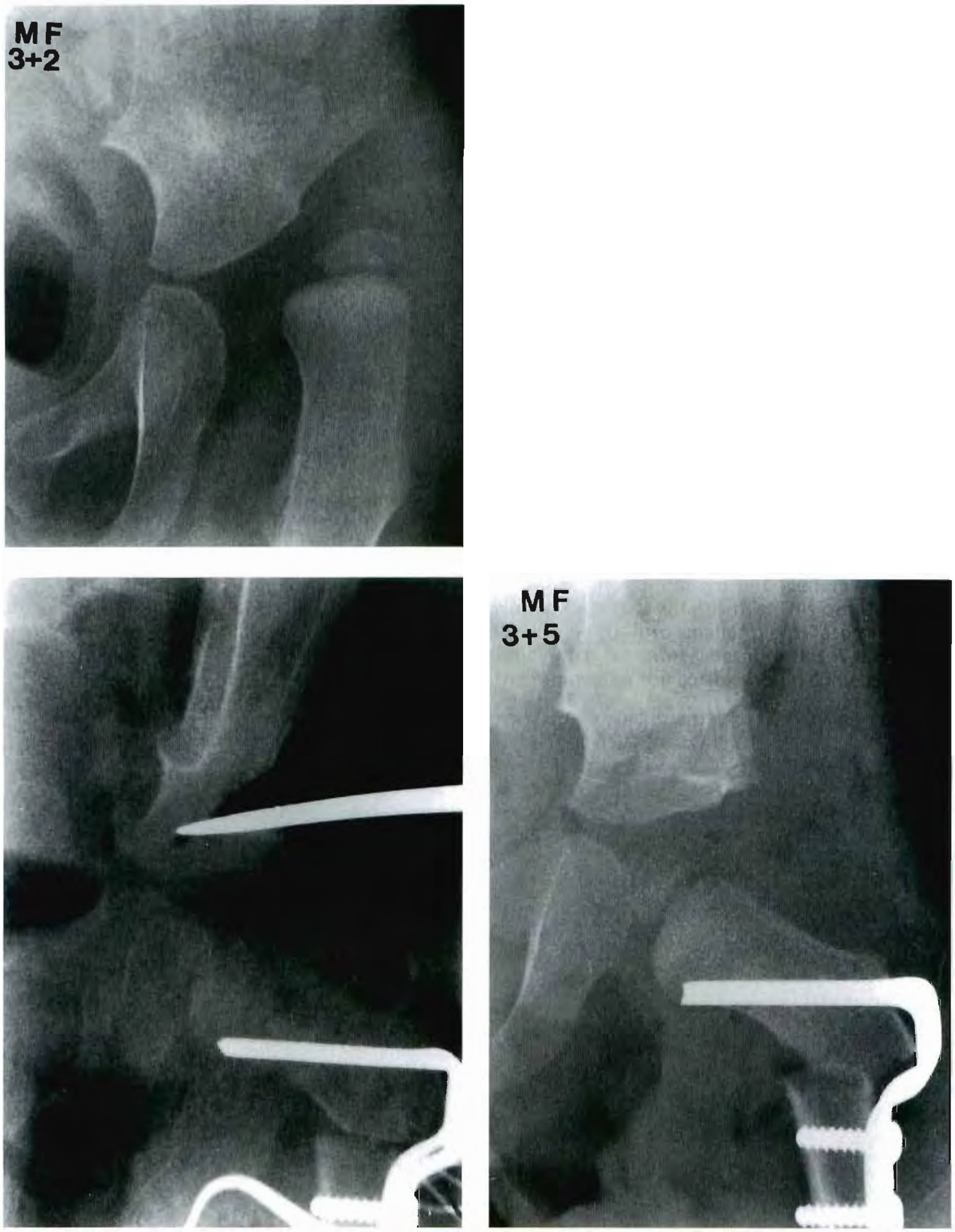
FIGURE 3-42. Using a combination of straight and curved osteotomes, the osteotomy is deepened, heading medially and caudally behind the acetabulum. This cut must proceed between the medial wall of the ilium and the medial wall of the acetabulum. This can be monitored on an image intensifier. Mubarak and colleagues (2,3) describes the osteotomy as going to but not through the triradiate cartilage. In our experience, the osteotomy does not have to be carried to the triradiate cartilage, as illustrated here. In the soft bone of the usual child with paralytic hip disease, there is sufficient mobility without using the triradiate cartilage; in fact, the osteotomy can be used **(A)** in some cases in which the triradiate cartilage has closed.

Next, a Kerrison rongeur is used to remove the cortex anteriorly and posteriorly as it extends around to the medial iliac wall. This is essential to allow the fragment to bend freely. In contradistinction to the Dega osteotomy, which cuts a considerable portion of the medial iliac cortex, these two areas removed with the Kerrison rongeur **(B)** are the only cuts in the medial wall.

FIGURE 3-43. When the osteotomy is completed, the superior aspect of the acetabulum can be hinged downward by prying with a broad curved osteotome and inserting a small lamina spreader. If the fragment does not move freely, there are two possible explanations: the cortex of the ilium as it wraps around the medial wall anteriorly and posteriorly has not been sufficiently removed, or the osteotomy within the cancellous bone has not been completed far enough caudally or is missing some portion anteriorly or posteriorly.

FIGURE 3-44. A piece of the ilium in the region of the anterosuperior iliac spine is removed, and three tricortical triangular pieces of bone are fashioned. These are wedged securely in the osteotomy site, which is held open with a lamina spreader. The amount of correction and where it occurs vary slightly with the size of the grafts and the site of placement of the largest and smallest grafts. Usually, the largest graft is anterior. It has seemed difficult to attempt to get more posterior coverage by placing the largest graft posteriorly.

The amount of coverage should be verified, and the surgeon should be certain that the grafts are secure. No internal fixation is necessary. The wound is closed.



A B C

FIGURE 3-45. **A:** A dislocated hip in a young boy with spastic cerebral palsy. Note the significant acetabular dysplasia. **B:** An image obtained with the image intensifier during the Albee Shelf osteotomy shows the direction of the cut. It appears that the osteotomy has cracked into the triradiate cartilage. **C:** After 2 months, the osteotomy is healed and the coverage of the femoral head excellent. (Courtesy of Scott Mubarak, M.D., Children's Hospital of San Diego, San Diego, CA.)

POSTOPERATIVE CARE

After wound closure, a hip spica cast is applied: one leg or one and one-half leg, depending on the surgeon's preference. This should be maintained until radiographic healing, which usually lasts 6 to 8 weeks, depending on the age of the patient.

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3.10 TRIPLE INNOMINATE OSTEOTOMY

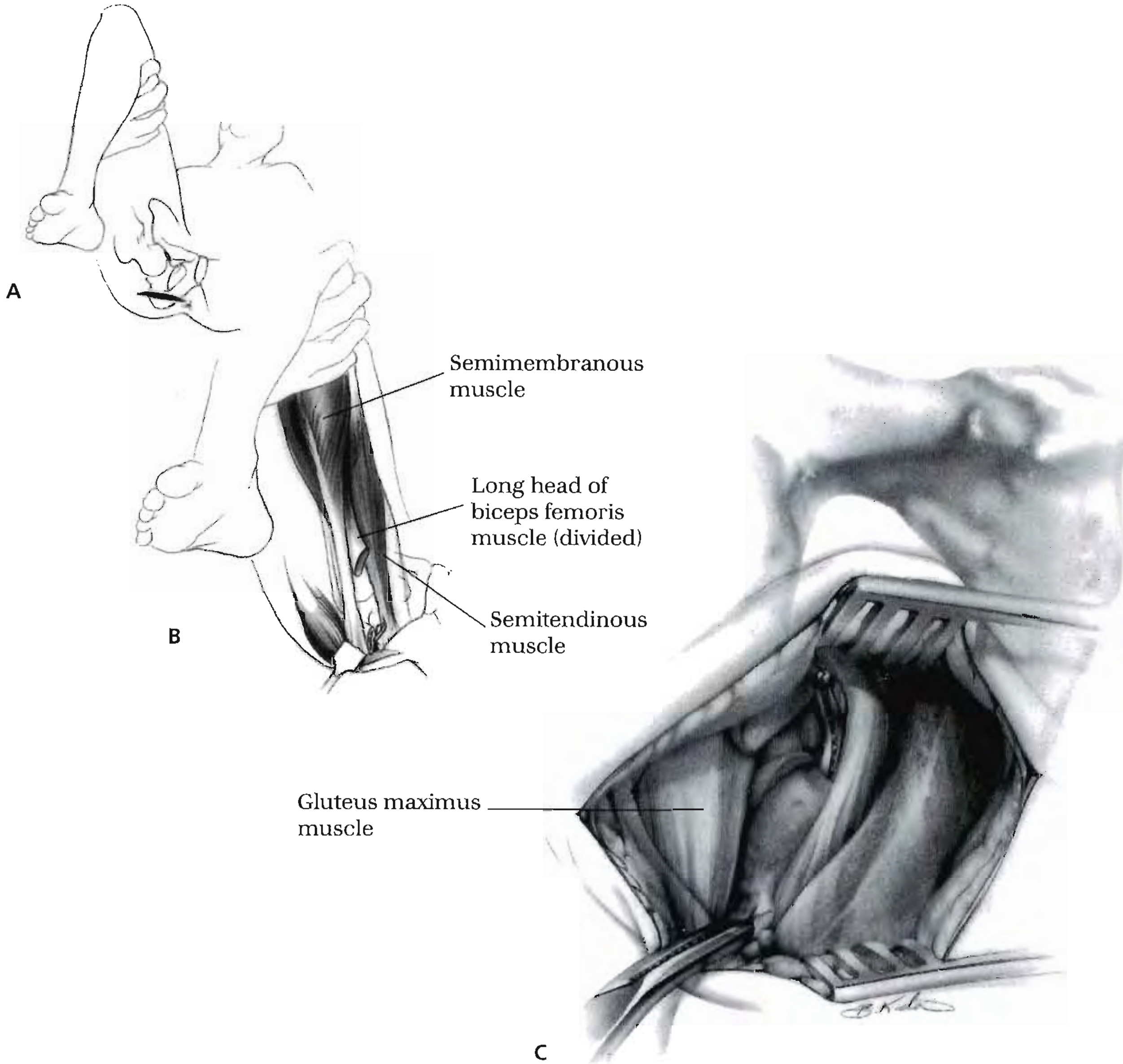
The triple innominate osteotomy of the pelvis divides the iliac bone, as in the Salter osteotomy, while additionally dividing the pubic and ischial bones. It is a reconstructive procedure because it uses the articular cartilage and the subchondral bone of the acetabulum. In this respect, it is similar to the osteotomies of Salter and Pemberton. It differs from these osteotomies, however, in that there is no hinge: the acetabular fragment is completely free. This permits a greater degree of mobility in obtaining anterior and lateral coverage. Subsequent reports have demonstrated the effectiveness of this procedure (1,2).

As in the Salter and Pemberton osteotomies, a prerequisite for the triple innominate osteotomy is that the femoral head and the acetabulum are congruous after the osteotomy is completed. It is indicated when this condition can be met but when adequate containment of the femoral head cannot be achieved with the Salter or Pemberton osteotomy. Preoperative traction or femoral osteotomy with or without shortening can be used to ensure a concentric reduction of the femoral head.

The operation, as originally described by Steel (3), used a separate incision in the buttocks to divide the ischium while dividing the pubic ramus through the same incision that is used to divide the iliac bone. Division of the ischium is difficult because the surgeon must "do a handstand" while an assistant holds the leg up, and the pubic ramus is difficult to reach from the transverse incision anteriorly. Some surgeons have adapted the approach used by Le Coeur (4) in his osteotomy to divide the ischium and the pubis through a groin incision similar to that used in adductor myotomy or proximal hamstring release. Tonnis (5) has described a triple innominate osteotomy in which the ischium is divided closer to the acetabulum than in the Steel osteotomy (Figs. 3-46 to 3-52).

FIGURE 3-46. The patient can be positioned in the lateral decubitus position, as described for anterior open reduction of the hip. If the surgeon desires, the entire first part of the procedure can be done with the patient in the lateral position and the hip flexed to 90 degrees. This also facilitates the remainder of the procedure because the flexion and internal rotation of the hip facilitate the pubic osteotomy, in particular. ▶

In the operation described by Steel (3), the entire leg and buttocks area are prepared and draped free. The operation starts with a transverse incision **(A)** about 1 cm cephalad from the natal crease. This incision is deepened down to the gluteus maximus muscle. It is important to gain a wide exposure in all directions at this point, or the remainder of the exposure will be difficult. The medial border of the gluteus maximus



muscle is identified and freed, allowing the muscle to be retracted laterally, exposing the muscle attachments to the ischial tuberosity.

The biceps femoris and the semitendinous muscles insert with a common tendon. The tendinous insertion of the semimembranous muscle lies lateral to this, and the sciatic nerve lies lateral to the semimembranous insertion. If the long head of the biceps femoris is dissected free and detached **(B)**, the interval between the semitendinous and the semimembranous muscles can be identified. This interval is the ideal site for the osteotomy of the ischium. It is best to expose this osteotomy site sufficiently so that at least 1 cm of bone can be removed. This ensures that no periosteum is holding the bone ends together, a situation that may limit mobility of the fragment. In addition, it allows some medial displacement of the acetabular fragment, which tends to be lateralized with this procedure.

The ischial ramus is dissected subperiosteally. It is usually not possible to stay subperiosteal all the way around, but care must be taken to remain in close proximity to the bone. A curved kidney pedicle forceps or retractor, such as a wide curved Crego retractor, is passed around the ischium and out through the obturator foramen to elevate the obturator muscles and protect the internal pudendal vessels and nerve **(C)**. The initial cut can be as that described by Steel (3); however, many surgeons find it easier to remove a section of bone with a rongeur. This has the added advantage of providing more mobility for the fragments, which tend to be held together by the thick periosteum and the surrounding ligaments. When this is completed, the wound is closed.

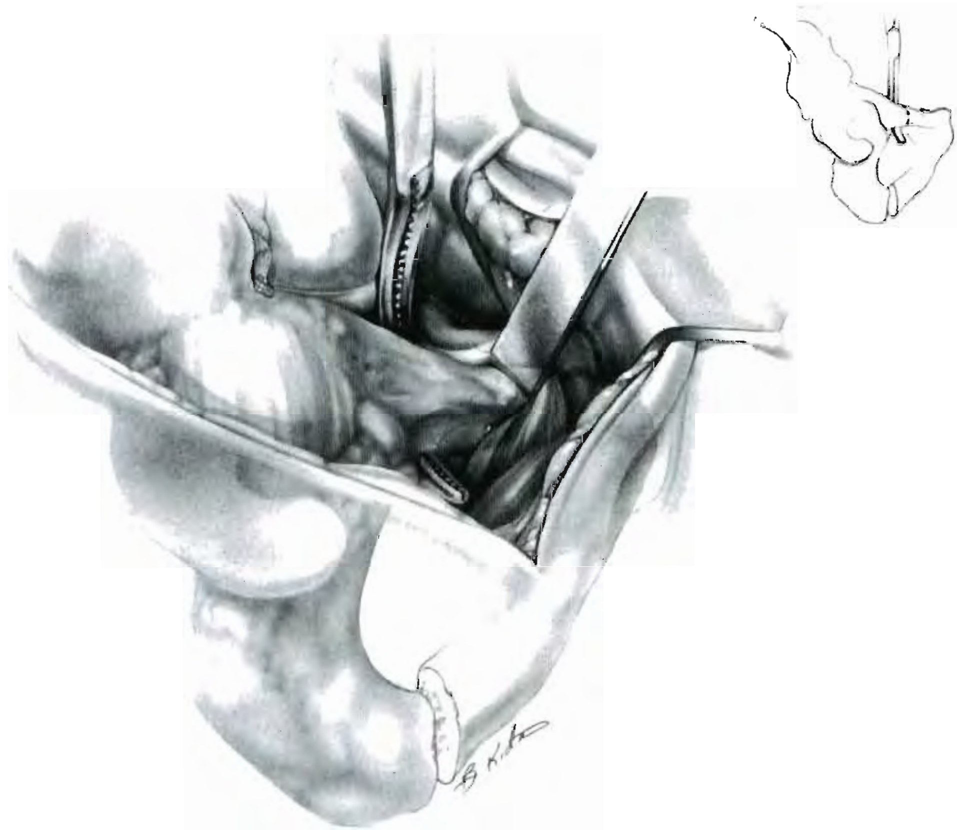


FIGURE 3-47. An oblique incision is made, and the innominate bone is exposed, as in the Salter osteotomy. The osteotomy of the pubis requires a medial exposure of the pubic ramus that taxes the limits of the incision. This exposure is facilitated by having the assistant push the leg across the table in flexion and adduction. This pushes the patient into a more lateral position while relaxing the anterior structures, making it easier for the surgeon and the assistant.

A major pitfall in this exposure is when the surgeon believes that the exposure is medial enough and begins the osteotomy only to discover that it extends into the anteromedial acetabulum. It is important that the pectineal tubercle is identified and that the pectineus muscle is reflected off it. The osteotomy should be medial to this pectineal tubercle. As for the ischium, a curved forceps or retractor is passed around the pubic ramus superiorly and out of the obturator foramen inferiorly while staying in contact with the bone. The osteotome is directed medially to cut the pubic ramus. A rongeur can also be used to create the osteotomy.

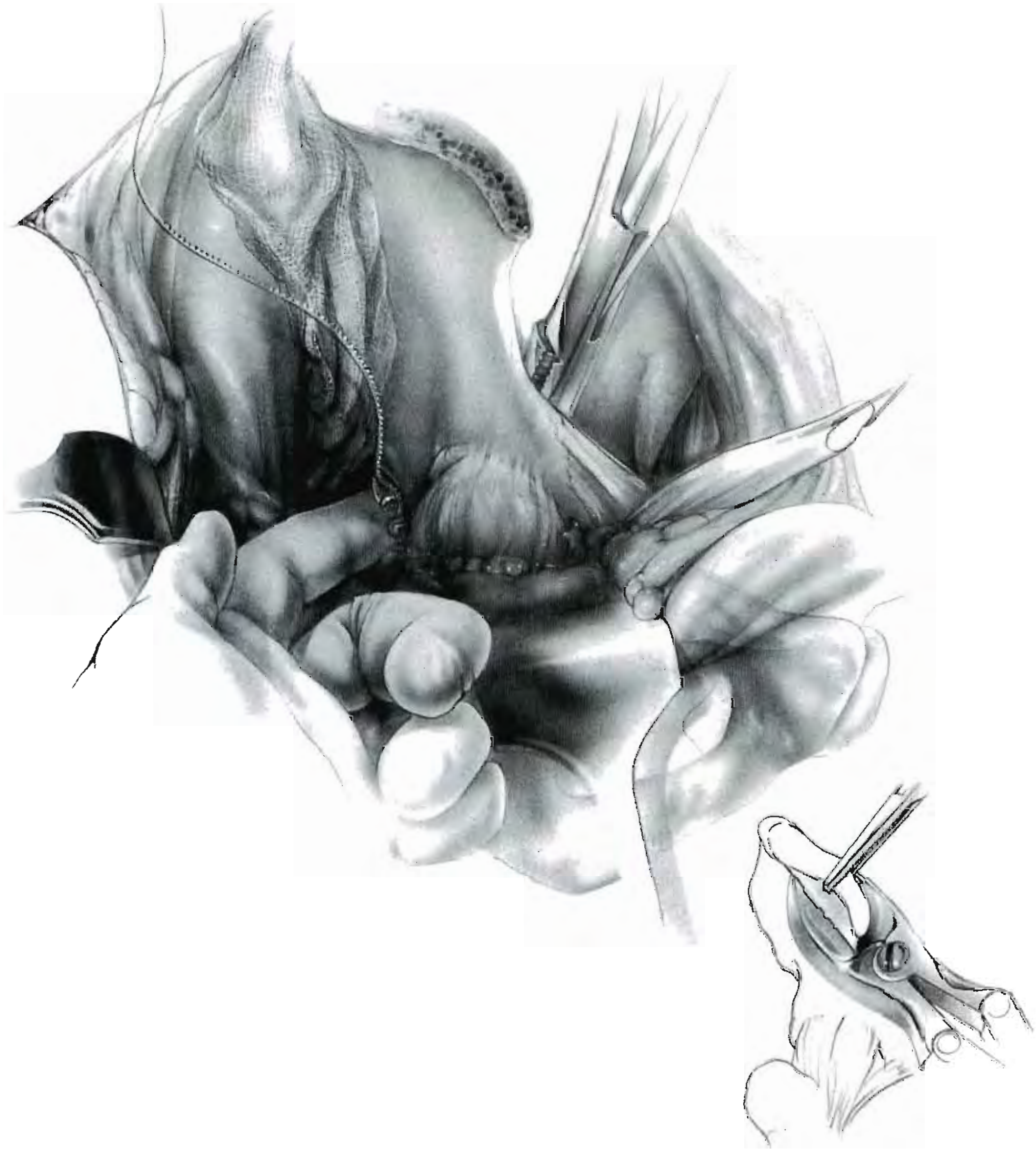


FIGURE 3-48. There now remains only one of the three osteotomies, that of the iliac bone. This is accomplished exactly as described for the Salter osteotomy.

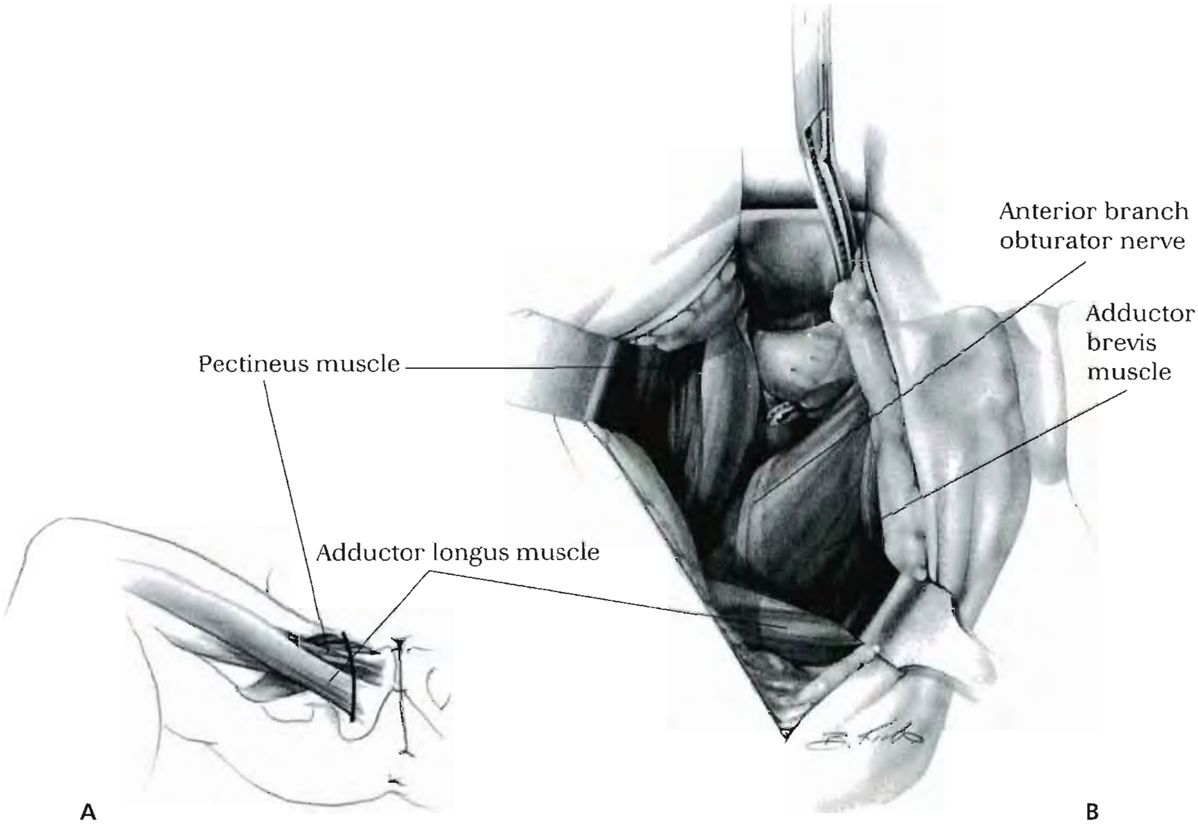


FIGURE 3-49. An alternative exposure to divide the pubic and ischial ramus is through a groin approach. The incision is transverse. It is placed about 1 cm from the groin crease **(A)**, starting 2 cm anterior to the adductor longus tendon and extending back to the posterior border of the gracilis muscle. The adductor longus tendon is isolated and retracted posteriorly. The pectineus muscle, which lies superior to the adductor longus tendon, is identified, and its border is dissected free up to its insertion on the pubis. The anterior branch of the obturator nerve lies deep in this interval, between the adductor longus and the pectineus, and should be protected. The femoral vessels and nerve lie just lateral to the pectineus muscle. This approach places the surgeon medial to the pectineal tubercle without strenuous retraction, as is needed when this area is approached from the transverse iliac incision. At this point, a subperiosteal dissection of the pubic ramus is accomplished. A suitable curved forceps, retractor, or elevator is placed around the back side of the pubic ramus after the periosteum and obturator muscle origins are elevated **(B)**. An osteotome cutting toward the protecting forceps completes the osteotomy.

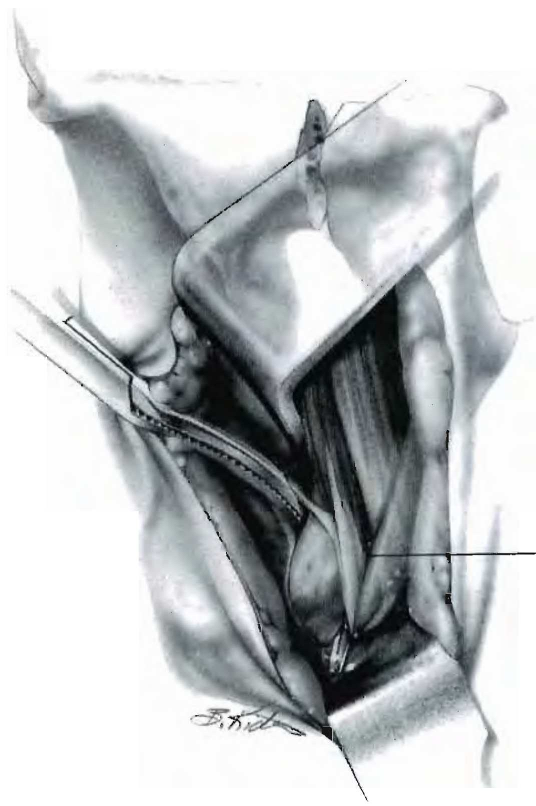


FIGURE 3-50. The next part of the exposure is similar to that for proximal hamstring release, but it must be accomplished through a wider exposure. The gracilis is separated from the crural fascia, and its posterior border is identified. The adductor magnus muscle lies deep and anterior to this posterior border. The interval between the posterior border of the gracilis and the adductor magnus muscles anteriorly and the proximal insertion of the hamstrings posteriorly is opened. It requires sharp dissection to open this interval sufficiently.

After the insertion of the hamstrings into the ischium is visualized, exposure is carried superiorly along the ramus of the ischium. At this point, the periosteum is incised and elevated. A forceps is passed around the ischium to protect the structures beneath, and an osteotome is used to divide the ischial ramus.

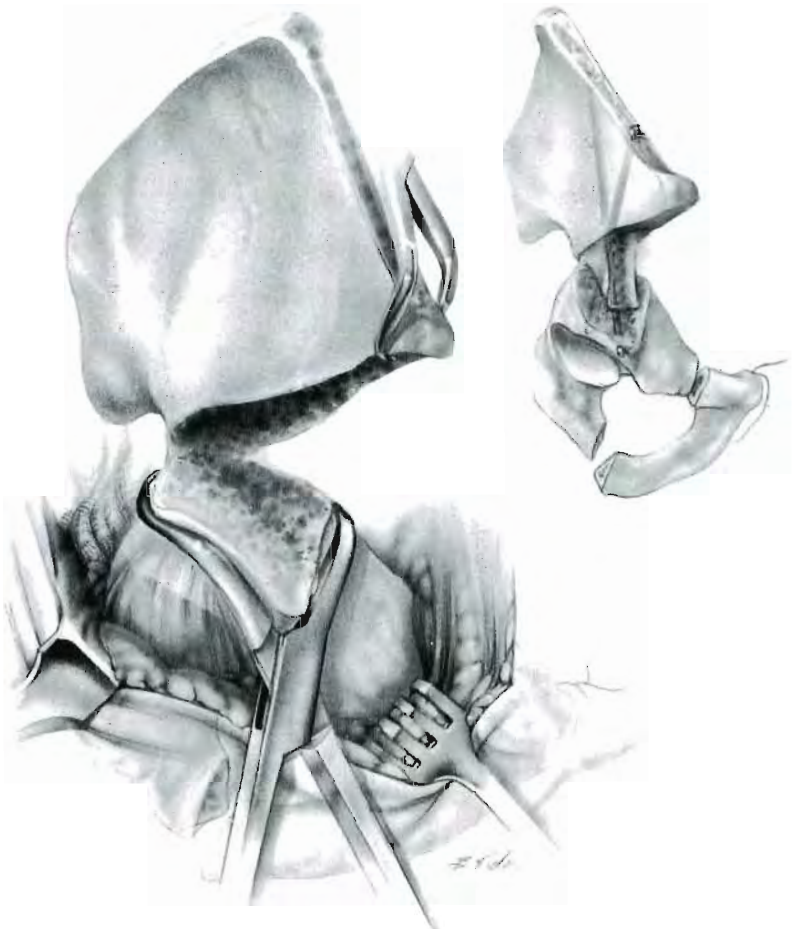


FIGURE 3-51. With the acetabular fragment completely mobile, the fragment is grasped with a large towel clip in the same manner as for a Salter osteotomy. Another technique is to insert a large threaded Steinmann pin or Schanz screw into the distal fragment parallel to the osteotomy to use as a joystick. It should be possible to rotate it freely as far anteriorly and laterally as desired. Care should be taken to gain only the correct amount of coverage because excessive rotation, especially anteriorly, could block motion. Unlike the Salter osteotomy, a lamina spreader can be used to separate the osteotomy in the iliac bone. This is because the fragment is free and does not exert excessive upward pressure on the sacroiliac joint. When the desired correction is obtained, a bone graft from the anterior crest of the ilium is fashioned to fit in the gap in the iliac osteotomy. Fixation of the osteotomy and graft ideally are done with 7-mm cannulated screws. One or two are passed from the cephalad to caudal direction, as in the Salter osteotomy, and another from the caudal direction, near the acetabular edge of the distal fragment, to the proximal direction. The osteotomy of the ischium and the pubis is not fixed. The wound is closed, and a drain is used at the surgeon's discretion.

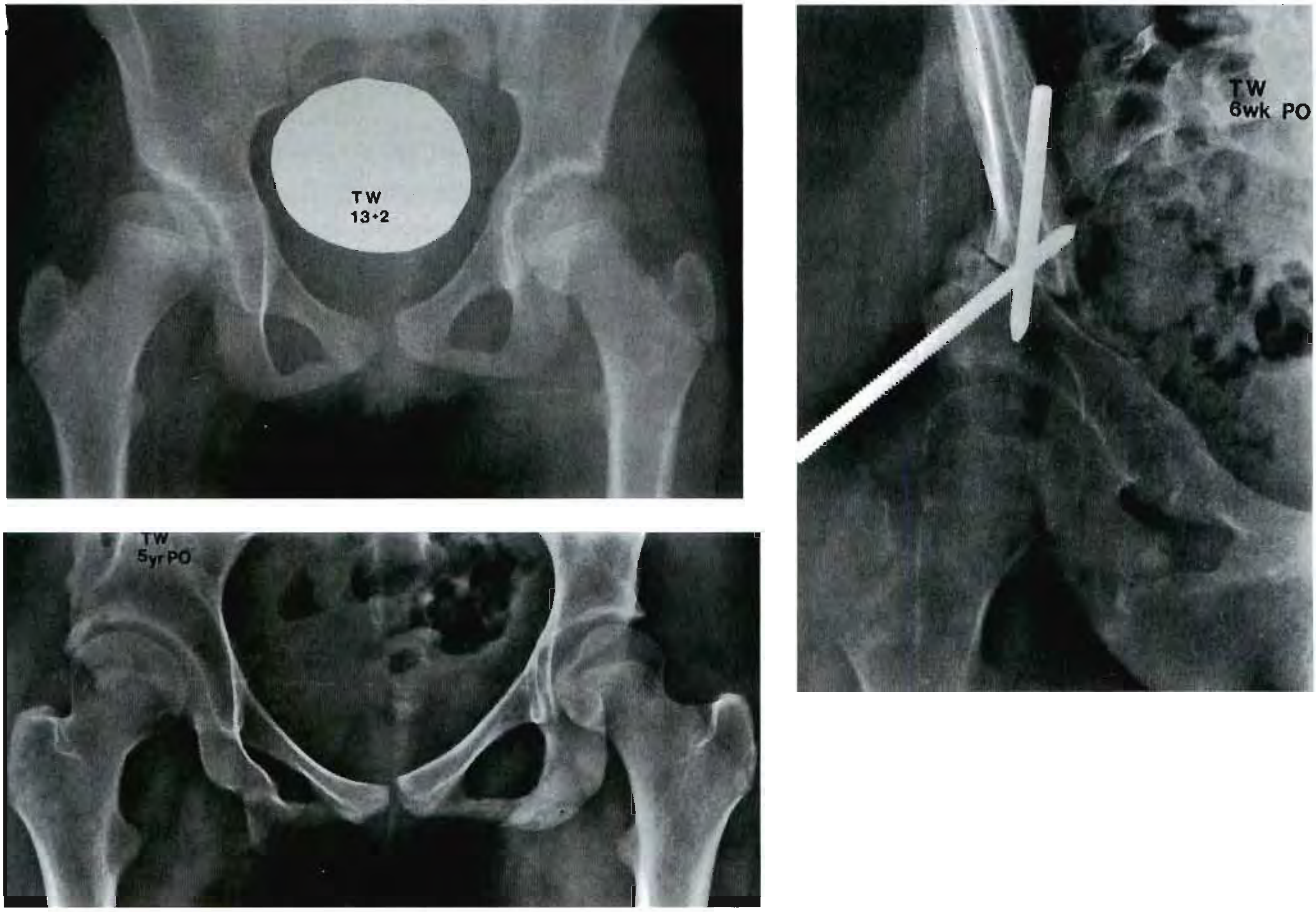


FIGURE 3-52. TW is a 13-year, 2-month-old girl who presented with a history of 6 months of increasing right hip pain. She was treated for congenital dislocation of the right hip at 3 months of age with a closed reduction. She has type II avascular necrosis **(A)** and acetabular dysplasia of the right hip. She was treated with a triple innominate osteotomy fixed with two 5/32-inch threaded pins. **(B)** We now use the 7-mm cannulated screws. They are stronger, can be removed percutaneously with radiographic control, or left buried. Five years postoperatively **(C)**, the patient remains symptom free, with good radiographic containment of the hip.

POSTOPERATIVE CARE

The patient is usually placed in a spica cast. In the more reliable patient, this can be a single-leg spica. In older patients who rely on crutches and in whom the fixation is secure, balance suspension can be used immediately after surgery until motion and comfort are restored, and then a partial weight-bearing crutch gait is begun. The healing time for this osteotomy depends on the age of the patient but generally is longer than the healing time of the Salter osteotomy for people of the same age. Young children can heal in 8 weeks, whereas healing may take 12 weeks or longer in young adults.

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3.11 CHIARI MEDIAL DISPLACEMENT OSTEOTOMY OF THE PELVIS

Unlike operations that redirect the acetabular cartilage and the subchondral bone and are called *reconstructive* procedures, the Chiari medial displacement osteotomy is a *salvage* procedure that uses the cancellous bone of the ilium with interposed hip joint capsule to contain the femoral head and bear weight. It accomplishes this by a single osteotomy through the ilium just above the hip joint capsule with medial displacement of the hip joint and its capsule under the superior iliac fragment.

The operation is primarily indicated in the older patient with a subluxated hip who is experiencing pain and in whom one of the reconstructive procedures that redirects the acetabulum is not possible. It is not necessary to achieve a concentric reduction of the femoral head to perform this procedure, and it can be used in the presence of a persistently subluxated hip. If the hip is subluxated too far cephalad, however, the Chiari osteotomy does not produce sufficient coverage. This is because of the anatomy of the pelvis. The cross-sectional area of the pelvis decreases the more cephalad from the acetabulum it is measured. There is insufficient width to the proximal fragment to provide adequate coverage.

The same anatomic consideration makes this osteotomy less successful in young children, especially those with myelomeningocele and other paralytic conditions that result in a small thin pelvis. In addition, most young children are good candidates for one of the reconstructive procedures.

Study of an anatomic model of the pelvis demonstrates that the Chiari osteotomy is unable to give much coverage to the posterior part of the femoral head. This has been demonstrated on three-dimensional computed tomographic reconstruction (1). The recognition that the width of the proximal fragment may be insufficient to produce adequate coverage has led to the use of bone graft to augment the lateral coverage (2–4). Because so much of the anterior femoral head is usually uncovered by the ilium, a strong case can be made for always augmenting a Chiari osteotomy in this fashion.

Long-term follow-up of patients treated in adulthood for residual acetabular dysplasia has been reported (5,6). These and similar reports have made the operation popular for the adolescent and young adult with subluxation of the hip because it does not require reduction of the hip and gives excellent pain relief in most series. Results in this younger age group, however, and particularly in children, are harder to find (7,8). It has a biomechanical advantage: it medializes the hip and reduces the force through the hip joint. This also shortens the abductor lever arm, however, and produces increased gluteal weakness and consequent limp. The biggest problem with the operation is that it appears simple, but the postoperative radiographs may not accurately reflect the amount of coverage obtained (9).

The incision and the exposure of the ilium are the same as those described for the Salter osteotomy. Although Chiari did not expose the inner wall of the ilium, this adds no morbidity to the procedure, whereas it increases safety and aids in orientation (Figs. 3-53 to 3-57).

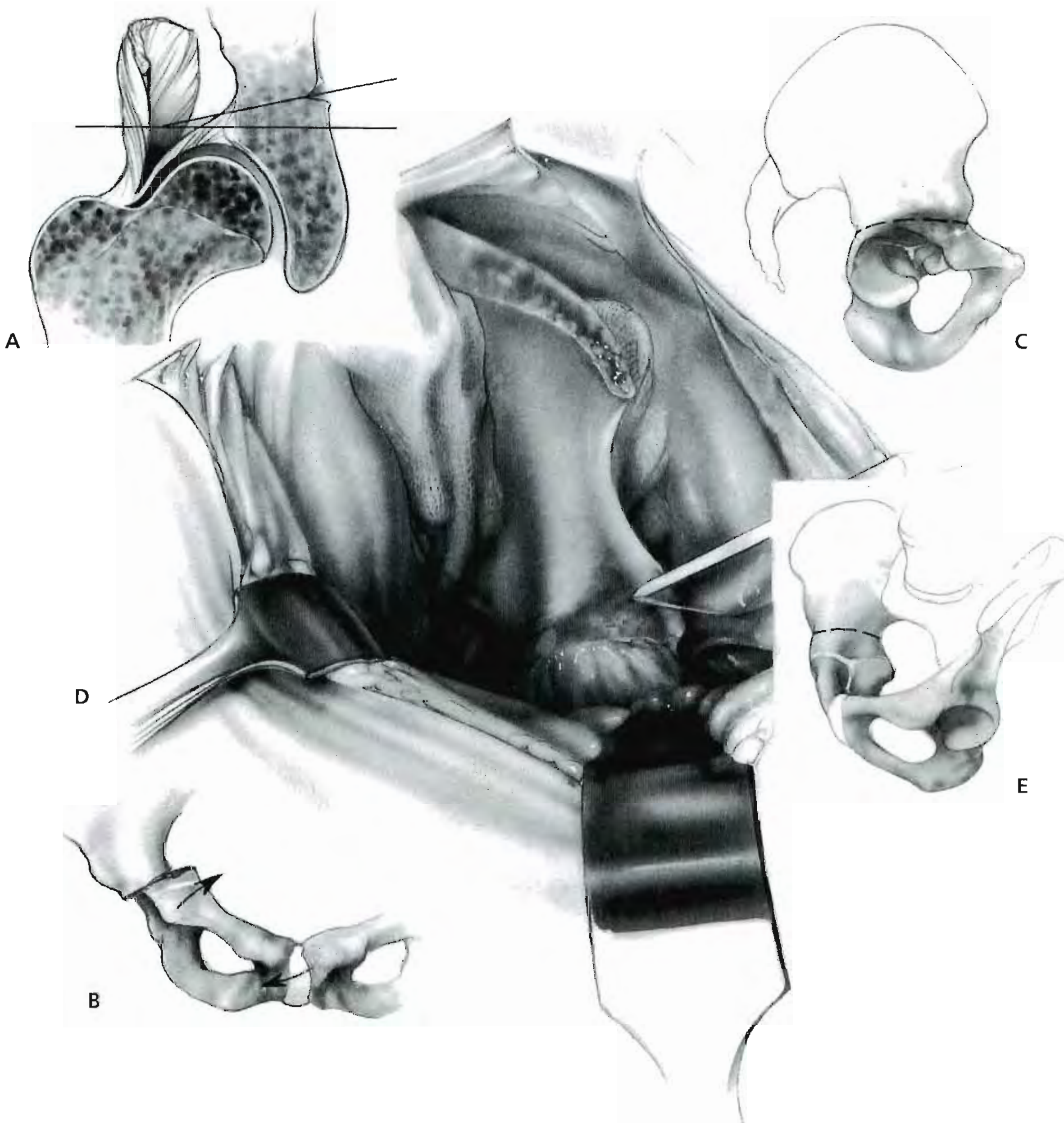
FIGURE 3-53. The placement of the osteotomy is crucial to the success of the operation. If it is too high, it does not provide coverage for the hip, and if it is too low, there is not sufficient capsule between the femoral head and the ilium. Therefore, it is important that the superior aspect of the hip capsule is well exposed anteriorly to posteriorly. In addition, it is necessary to know where the roof of the acetabulum lies. This may be difficult in many subluxated hips because of a markedly thickened capsule. In some cases, it may be necessary to thin this capsule. ▶

Understanding how the distal fragment is displaced medially in relation to the proximal fragment, despite the fact that the pelvic ring is divided in only one place, is important to understanding the osteotomy. The displacement occurs as the distal fragment rotates on the symphysis pubis. This is the reason that the direction of the osteotomy is important in obtaining the "displacement." Proceeding laterally to medially **(A)**, the osteotomy should incline cephalad about 10 degrees. This permits the inferior fragment **(B)** containing the hip joint to displace medially.

These two crucial points, the location of the acetabular roof and the direction of the osteotomy, can be verified by drilling a small guide wire or driving an osteotome from lateral to medial in the estimated direction of the osteotomy at the proposed site of the osteotomy and viewing this with a radiograph or image intensifier. The osteotomy should incline cephalad 10 to 15 degrees from lateral to medial to facilitate the displacement (or more correctly, the *rotation*).

The osteotomy, as originally described by Chiari, was straight from anterior to posterior. Most commonly today, this cut is modified to produce a dome-shaped osteotomy that more closely conforms to the hip capsule after displacement. This is easily accomplished **(C)** in the anterior and midportion of the osteotomy but cannot be achieved posteriorly.

The lateral cortex **(D)** is cut first and then the medial cortex **(E)**. This allows the surgeon excellent orientation. These cuts are not extended into the sciatic notch because splintering of this posterior cortex may impinge on the sciatic nerve. The cuts in the lateral and medial cortex are then connected, leaving only the posterior cortex of the sciatic notch intact.


A
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B

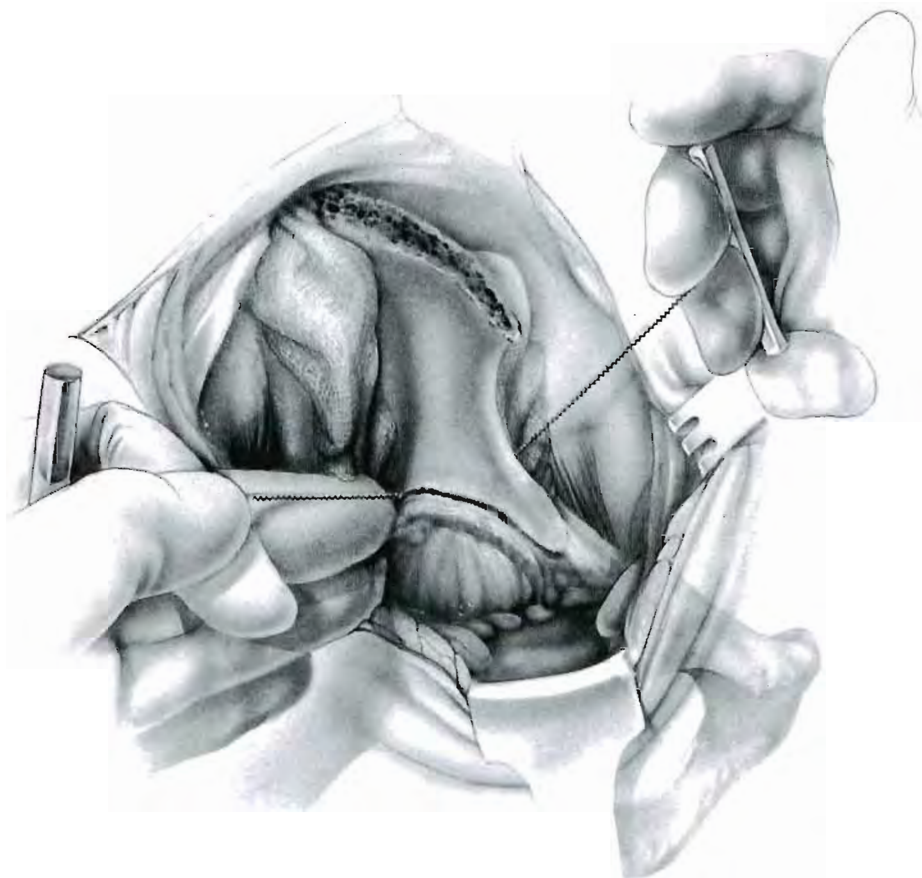

FIGURE 3-54. A Gigli saw is passed through the sciatic notch, as described for the Salter osteotomy. This is used to complete the osteotomy. Some surgeons prefer to make this cut first for a short distance to avoid having the bone splinter as the osteotomes approach the sciatic notch.

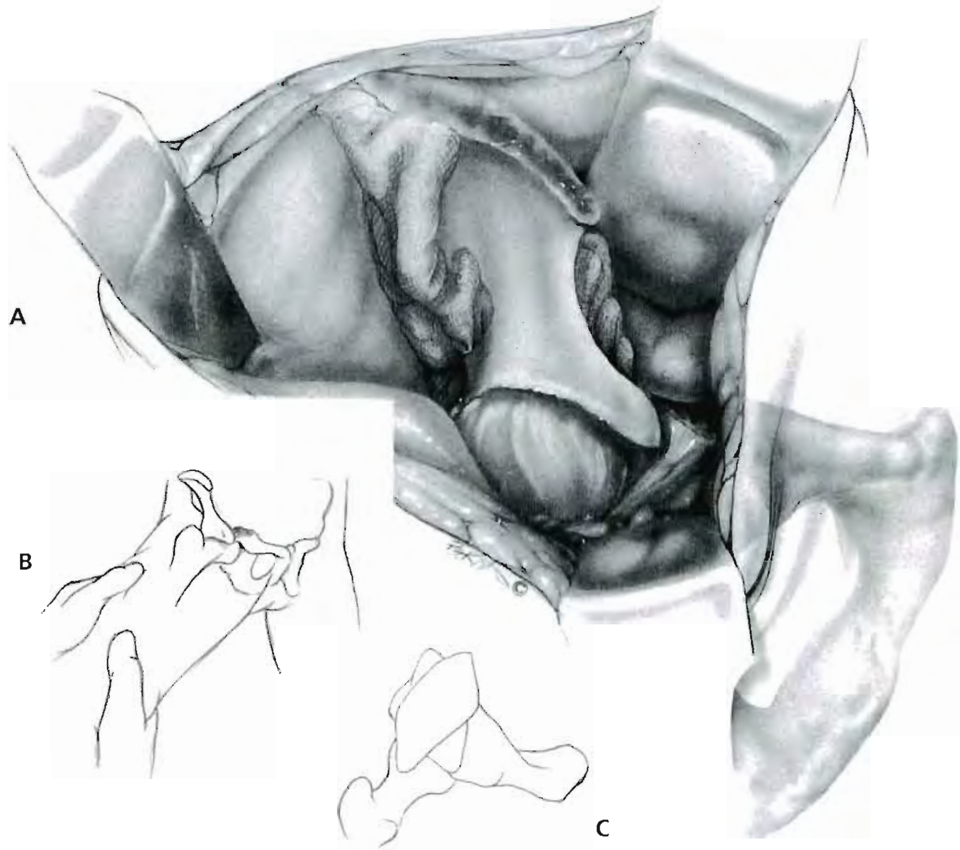

FIGURE 3-55. With the osteotomy complete **(A)**, the distal fragment is displaced medially. A common error at this point is to hinge the osteotomy on a posterior tether. This results in only the anterior aspect displacing. Without careful inspection of the posterior aspect of the osteotomy, this may go unnoticed, and it will not be reflected on postoperative radiographs.

The osteotomy **(B)** is usually displaced by abducting the leg. If the osteotomy has been performed properly, it should move easily by this maneuver. Further displacement can be achieved with direct pressure over the greater trochanter. There is a tendency for the inferior fragment with the hip joint to displace posteriorly. This probably should be avoided because it may increase the pressure on the sciatic nerve. Posterior displacement **(C)**, however, increases the amount of coverage because the ilium is wider in its posterior aspect than in its anterior aspect.

How much displacement is advisable is a matter of debate, with some authorities saying that there should be no more than 50% displacement. Such admonitions do not account for the variable width of the ilium, which is very thin in cross-section anteriorly and wide posteriorly. It is possible and often advisable to achieve nearly 100% displacement at the midportion of the osteotomy over the dome of the hip joint. If this much displacement is achieved, it should be secured with strong fixation to prevent further displacement and supplemented with bone graft to avoid delayed union or nonunion.

Healing may be slow, especially if the patient is older and the displacement greater. In these circumstances, it is best to fix the osteotomy with two or three strong screws, which can be left in place for several months without bothering the patient. In cases in which more rapid healing is anticipated, heavy threaded pins can be used and left subcutaneously for easy removal.

FIGURE 3-56. As has been mentioned, it often is necessary to augment the coverage obtained with the Chiari osteotomy. This is especially true anteriorly where the ilium is thin. An excellent method for accomplishing this coverage has been described (1,2). An appropriately sized piece of corticocancellous bone is removed from the inner table of the ilium. This is placed in the osteotomy site before fixation. The screws or pins used for fixation then transfix this graft. Additional cancellous bone graft is added over this graft and held in place by the periosteum and muscles when the wound is closed.

A
B
C

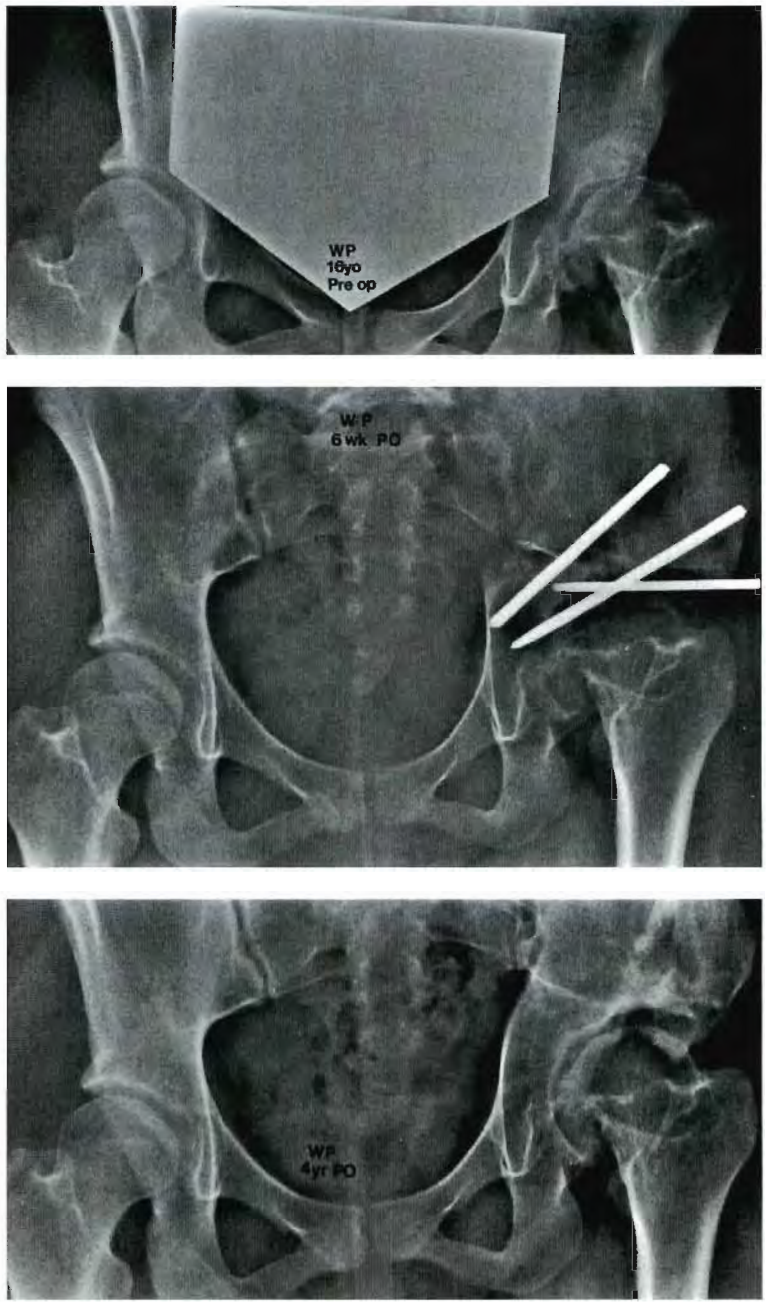

FIGURE 3-57. A: Radiograph of a 16-year-old girl with severe and painful dysplasia as a result of a congenitally dislocated hip. The anteroposterior radiograph demonstrates the coverage postoperatively. **B:** This can be misleading, however, on the true anteroposterior view because the posterior aspect of the ilium is rotated outward. **C:** Four years after the surgery, the hip is well contained and the patient symptom free. (Courtesy of Michael Millis, M.D., Children's Hospital Medical Center, Boston, MA.)

POSTOPERATIVE CARE

It is not necessary to place the older reliable patient in a cast. The osteotomy has a high degree of intrinsic stability that, if supplemented with strong internal fixation, permits a partial weight-bearing crutch gait. Crutches should be continued until radiographic evidence of healing is seen and the patient has rehabilitated the abductor muscles. If a spica cast is used in the younger child, it should be continued until radiographic evidence of union is present and the pins are removed. This usually is 8 to 12 weeks.

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3.12 STAHELI SHELF PROCEDURE

Procedures for creating a shelf of bone to augment a deficient acetabulum were first performed early in the 20th century. In its various forms, it remained the main method of treating the dysplastic acetabulum until procedures that redirected or displaced the acetabulum became popular. Since the 1980s, the popularity of the shelf procedures waned because of the popularity of the newer osteotomies and the poor technical performance of the shelf procedures (1).

The primary goal in the creation of an acetabular shelf, as in any of the acetabular procedures, is to increase the load-bearing area between the femoral head and the acetabulum, or to increase the stability of the hip. The shelf procedures, like the Chiari osteotomy, are salvage procedures because they use bone over capsule rather than articular cartilage and subchondral bone for the increased area. Although this may seem less than ideal at first, there are certain circumstances in which a salvage procedure is the only choice.

The indications for the slotted acetabular augmentation are the same as for any shelf procedure: hips with asymmetric incongruity. The operation should not be done in a hip with congruity in which acetabular redirection is more appropriate. The operation is not ideal when the capsule must be opened, although like the Chiari, it can be performed.

The slotted acetabular augmentation developed by Staheli is a shelf procedure in which a slot in the ilium is created for the bone graft. This aids in the correct and secure placement of the graft (2). The amount of coverage can be calculated by determining the length of the graft that is necessary to create the desired center-edge angle.

The exposure for the operation is the same as for the anterior approach for the open reduction of congenital hip dislocation. Larger teenage children can be placed on a fracture table, if the surgeon chooses. The outer table of the ilium and the entire superior capsule must be visible. The inner table of the ilium does not have to be exposed (Figs. 3-58 to 3-62).

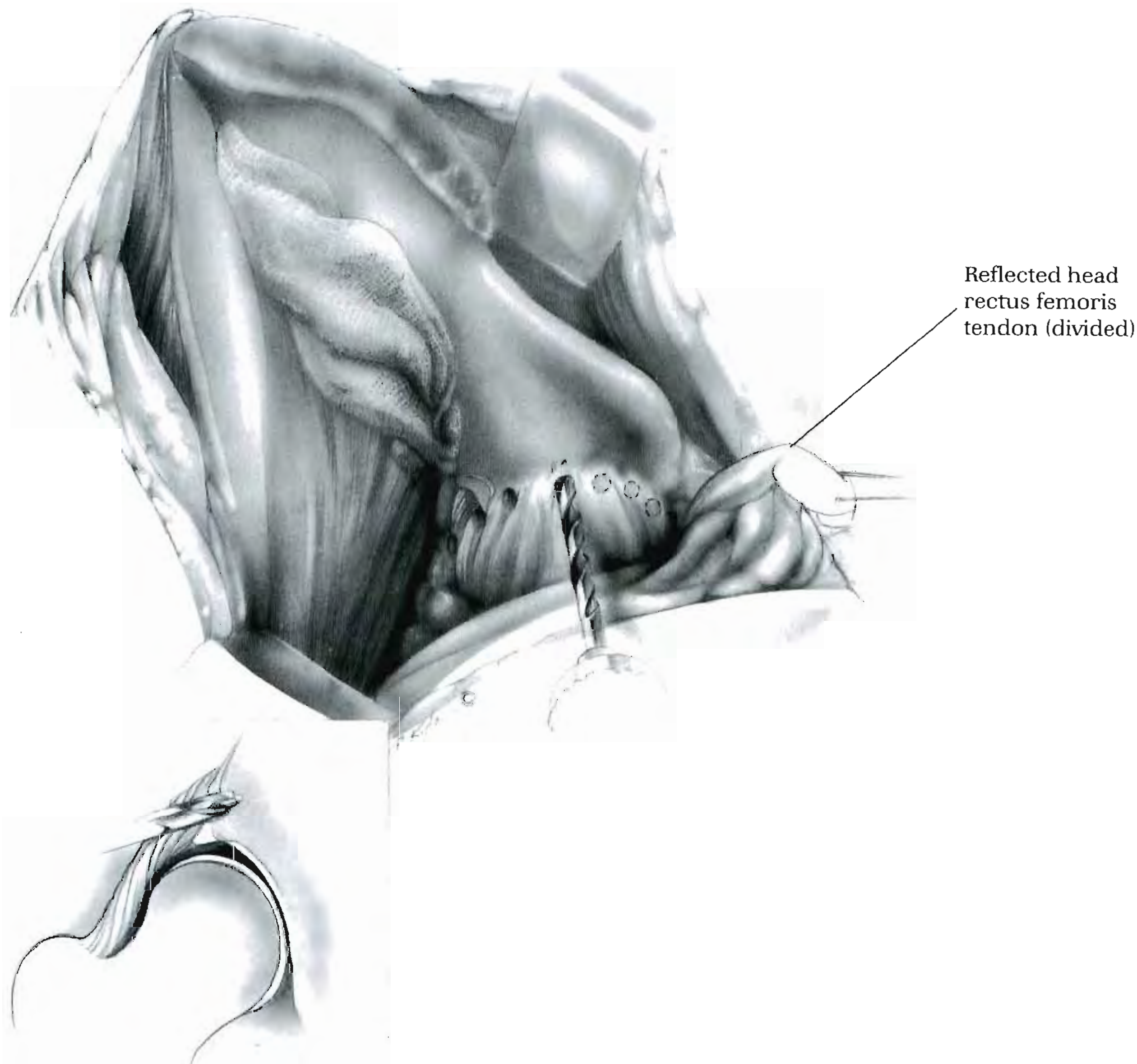


FIGURE 3-58. During the exposure, the reflected head of the rectus tendon should be identified, dissected free from the capsule, and divided somewhere between its mid-portion and its junction to the conjoined tendon. This is used to secure the grafts in place. If it is not present, flaps can be created from the thickened capsule, which serves the same purpose.

The most important part of the surgery is to identify the correct location for the slot. It should be placed at the exact acetabular edge. The surgeon must determine whether this is the true or false acetabulum based on which affords the greatest stability and congruity. The acetabulum is identified by a small incision in the capsule or by inserting a probe. In the subluxated and dysplastic hip, the capsule is usually thickened and adherent to the ilium, causing the surgeon to place the slot and therefore the graft too high. The correct location should be verified radiographically by placing a guide pin into the ilium at the presumed acetabular edge. In some cases, it may be necessary to thin the capsule to permit the graft to be placed in the proper location.

After the correct location is verified, a 5/32-inch drill is used to make a series of holes at the edge of the acetabulum. These holes should be drilled to a depth of about 1 cm and should incline about 20 degrees, as illustrated. They should extend far enough anteriorly and posteriorly to provide the necessary coverage.

FIGURE 3-59. A narrow rongeur is used to connect these holes and produce the slot. This slot may also be more easily created with the use of a power bur. The floor of this slot should be the subchondral bone of the acetabulum, and it should be level with the capsule.

The bone graft is obtained from the outer table of the ilium. Starting at the iliac crest, corticocancellous and then cancellous strips of bone are removed. In the region above the slot, the decortication should be shallow, to aid the incorporation of the graft without disrupting the integrity of the slot. It may be necessary in some neuromuscular patients to use bank bone.

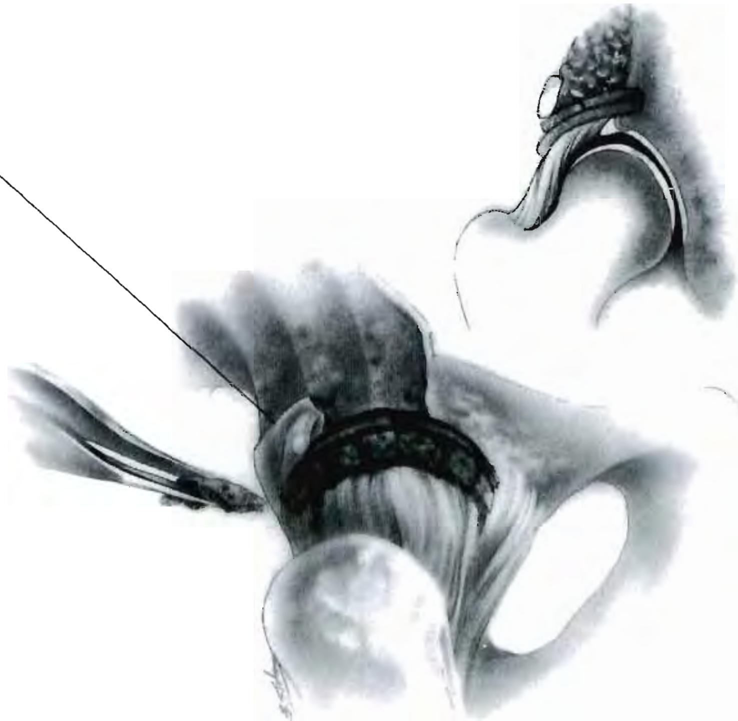


FIGURE 3-60. The cancellous grafts are cut in strips 1 cm wide and of appropriate length to provide the desired amount of lateral coverage. These are placed in the slot extending out over the capsule. A second layer of cancellous strips is placed at 90 degrees to the first strips of graft. The grafts must not extend too far laterally or anteriorly in the quest for spectacular radiographic coverage of the hip because this could result in a loss of motion secondary to impingement.

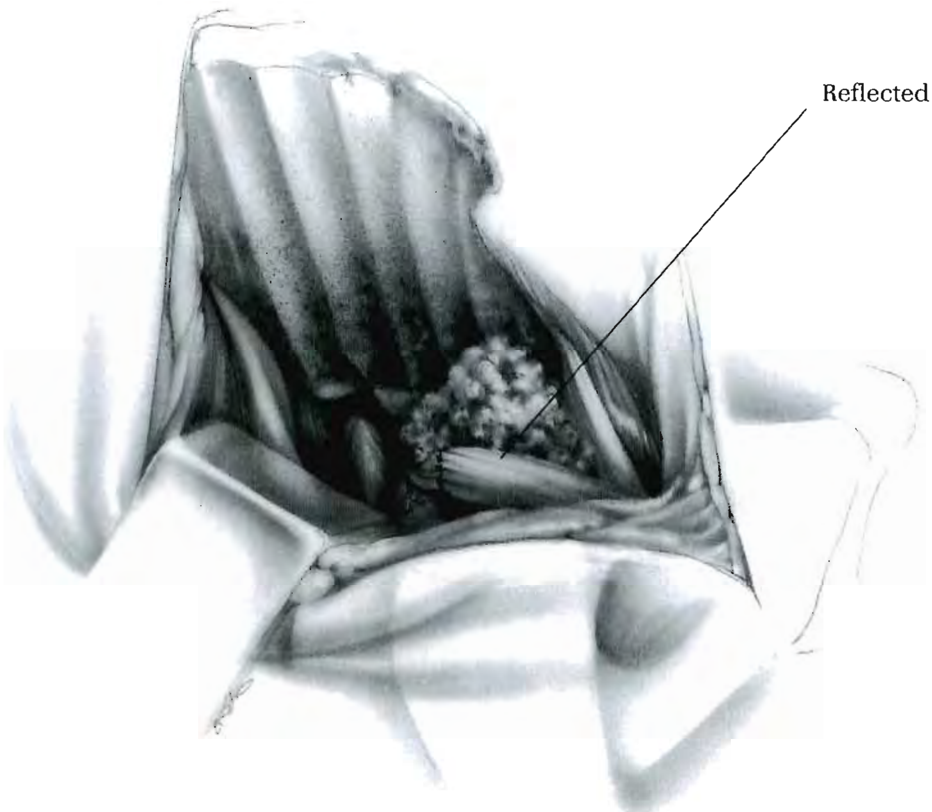
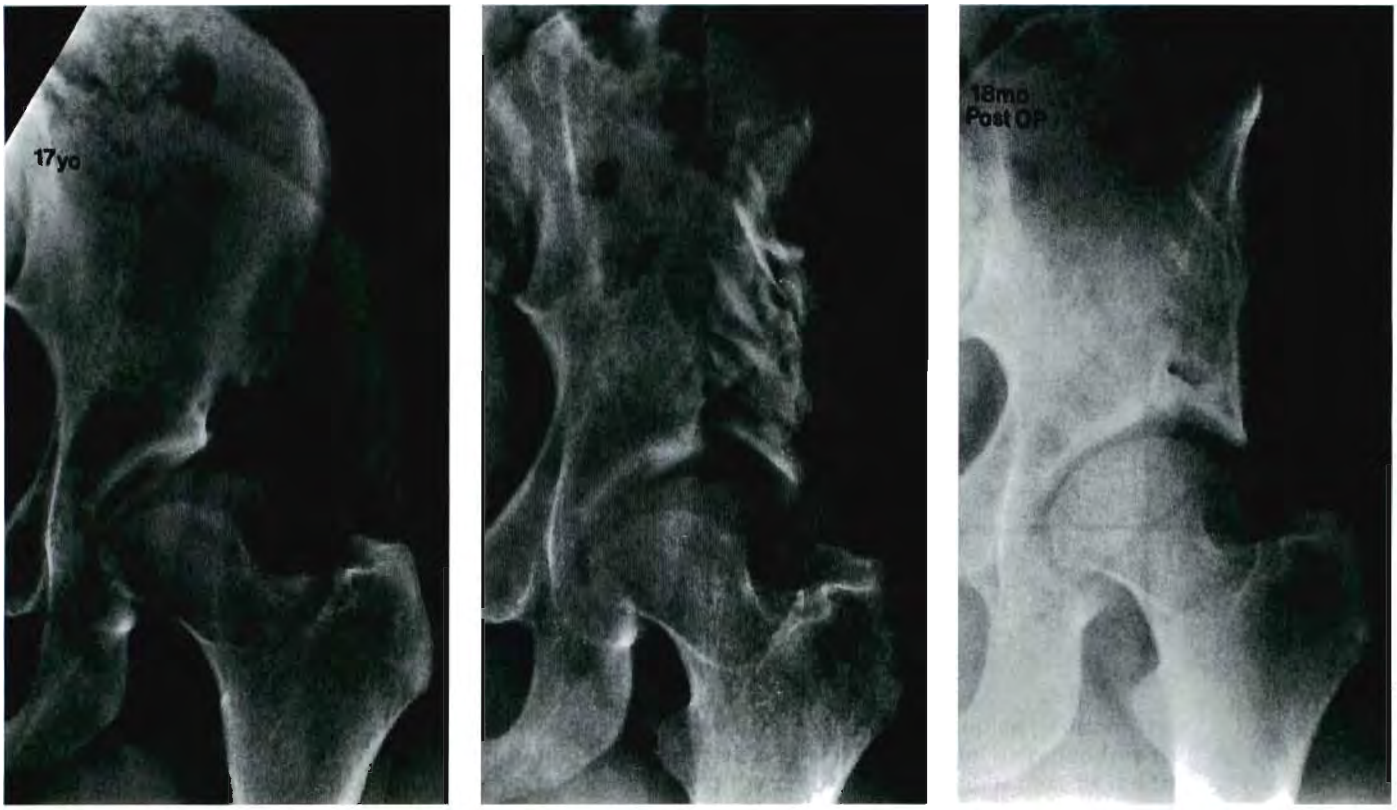


FIGURE 3-61. The reflected head of the rectus tendon is sutured, holding the grafts in place. The remaining bone is cut into small pieces and placed over the previously placed graft. This is held in place by the abductor muscles when the wound is closed.



A B C

FIGURE 3-62. A: Acetabular dysplasia in a 17-year-old woman that resulted from treatment of congenital dislocation of the hip with subsequent type II avascular necrosis of the femoral head. **B:** The radiograph taken 6 weeks after a slotted acetabular augmentation demonstrates the large amount of graft that is used. **C:** Eighteen months after surgery, good incorporation of the graft with a strong shelf is demonstrated. Note the remaining hole in the graft where the reflected head of the rectus tendon was repaired. (Courtesy of Lynn T. Staheli, M.D., Children's Hospital, Seattle, WA.)

POSTOPERATIVE CARE

The patient is placed in a single-leg spica cast with the hip in the position of 15 degrees abduction, 20 degrees flexion, and neutral rotation. The cast can be removed in 6 weeks, and radiographic assessment of graft incorporation can be made. Reliable patients can begin partial weight bearing. In less reliable patients, weight bearing can be permitted in a walking spica. It usually takes 4 months for complete graft incorporation.

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3.13 ARTHRODESIS OF THE HIP JOINT

Despite advances in total joint arthroplasty, arthrodesis of the hip joint remains the best option for the adolescent or young adult with destruction of the joint and pain. Despite the limitations imposed by hip arthrodesis, this probably remains true until technologic advances have solved the problem of loosening in total joint arthroplasty, especially in young active patients.

Most long-term studies have demonstrated that most patients are satisfied with the results of hip joint arthrodesis and lead active lives without hip pain (1,2). From such studies, however, it is also apparent that a significant number of patients develop back pain and knee pain, with radiographic signs of osteoarthritis decades after the arthrodesis. These problems are being solved with conversion to total hip arthroplasty (3,4). This does not necessarily negate the value of hip arthrodesis because at the time of conversion, patients are more suitable candidates for total joint arthroplasty and are able to take advantage of several decades of technologic improvement.

The relevant message from these studies for the surgeon performing a hip arthrodesis on a young patient is twofold. First, as much of the normal architecture of the hip as possible should be preserved so that total joint arthroplasty can be accomplished. This rules out the use of the cobra plate or other methods that alter the normal anatomy. Second, the position of the leg in relation to the pelvis is important in the development of late back and knee symptoms. Specifically, any abduction of the hip should be avoided.

A technique that has proved successful is that described by Thompson (5) and evaluated by Price and Lovell (6). It uses an intertrochanteric osteotomy to relieve the effect of the long lever arm of the leg on the arthrodesis and to allow accurate positioning of the leg after the drapes are removed (Figs. 3-63 to 3-70).

FIGURE 3-63. The hip is approached as for the Salter osteotomy. It is important that the hip capsule be exposed widely because dislocation of the diseased hip is difficult and requires an extensive capsulectomy. Both the inner and outer table of the ilium should be exposed subperiosteally.

FIGURE 3-64. The femoral head is dislocated by adducting, externally rotating, and extending the leg. This dislocates the femoral head anteriorly into the wound. Because of the amount of flattening of the femoral head, especially in cases of avascular necrosis, it is usually not possible to use a reaming cup to recreate the ideal rounded shape of the femoral head that is often seen in diagrams of hip arthrodesis. Rather, curved osteotomes or gouges should be used to remove the remaining articular cartilage and dead avascular bone, accepting the more flattened surface that results. The surface, regardless of its shape, should be bleeding bone.

FIGURE 3-65. Flexion and internal rotation of the leg displaces the femoral head posterior to the acetabulum. Because access to the acetabulum is restricted and the acetabulum is not deformed, a reaming tool is ideal to remove the cartilage and subchondral bone. It is usually not necessary to alter the resulting shape of the acetabulum because the femoral head can be moved into the most congruous position. Typically, this is abduction.

FIGURE 3-66. After the femoral head is placed in the desired position, one or two large, long, and strong screws with washers can be directed from the inner side of the ilium, through the acetabulum, and into the femoral head and neck (7). This provides fixation of the femoral head to the acetabulum. This fixation, however, will prove insufficient unless a proximal osteotomy is performed.

FIGURE 3-67. Using osteotomes or an oscillating saw, a trough is cut into the superior aspect of the ilium, just above the acetabulum and lateral to the iliopubic eminence, extending down onto the femoral neck. This should be as wide as the anterior portion of the iliac crest and about 1.5 cm deep to accommodate a tricortical piece of graft that was taken from the anterior iliac crest. This graft is wedged into place and can be secured by two screws. Cancellous bone can be removed from the exposed surface of the iliac crest with a curette and packed into the acetabulum around the femoral head.

FIGURE 3-68. An osteotomy of the femur is performed just above the lesser trochanter. The surgeon may prefer to perform this step before fixing the femoral head to the ilium. If this is done, a large Steinmann pin should be drilled into the femoral head fragment so that it can be controlled. Performing the osteotomy at this stage ensures that sufficient but not excessive mobility is achieved at the osteotomy site to allow proper positioning of the leg in the cast.

The osteotomy can be performed through a small anterolateral incision that splits the fibers of the tensor fascia muscle to reach the proximal femur. The periosteum is cut in the direction of the bone and elevated with a curved Crego periosteal elevator. The less periosteal disruption that is created, the more stable the osteotomy. Multiple drill holes are made, and the osteotomy is completed with an osteotome. In our experience, this results in quicker union than the use of the oscillating power saw, an important factor because rigid internal fixation is not used. The limb is moved to ensure that sufficient mobility is present at the osteotomy site.

With time, the distal fragment, the femoral shaft, tends to displace posteriorly. This presents a difficult situation regarding stem placement if revision to total joint arthroplasty is needed in the future. The situation can be avoided by placing a drill hole through the anterior cortex on each side of the osteotomy and passing a heavy strong suture through the holes. This is tied loosely enough to permit flexion and some extension as well as abduction and adduction at the osteotomy site while preventing any significant posterior displacement. The use of the anterolateral incision gives the surgeon a better exposure for this step than the traditional lateral incision.

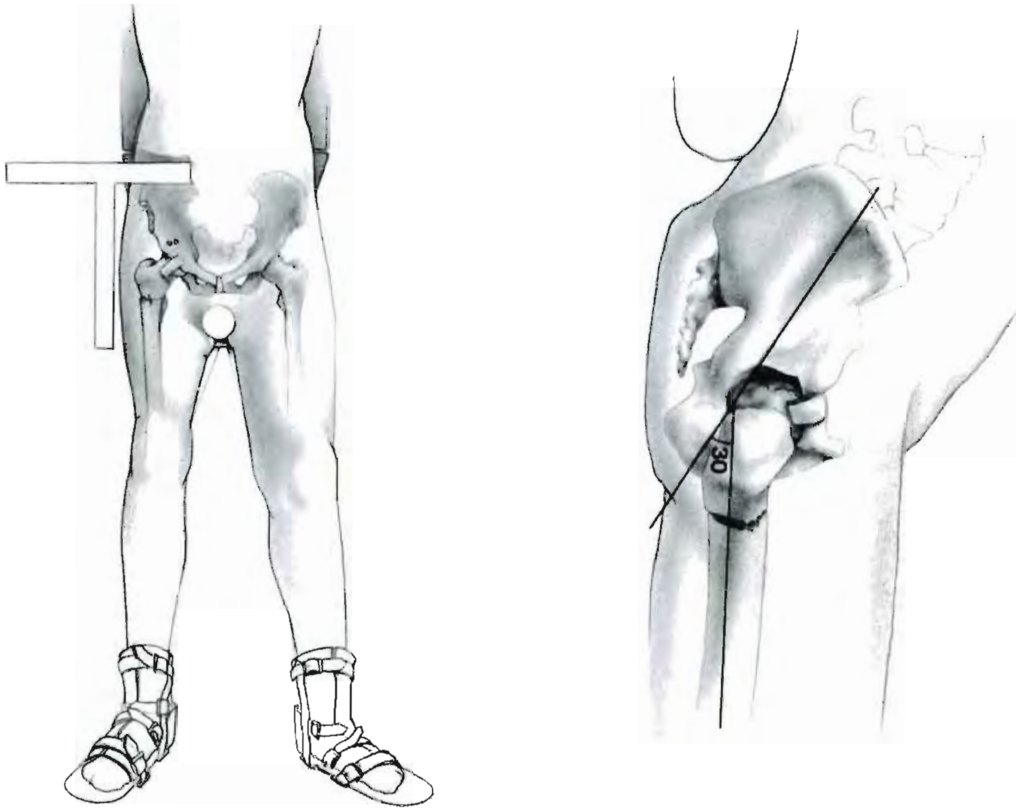
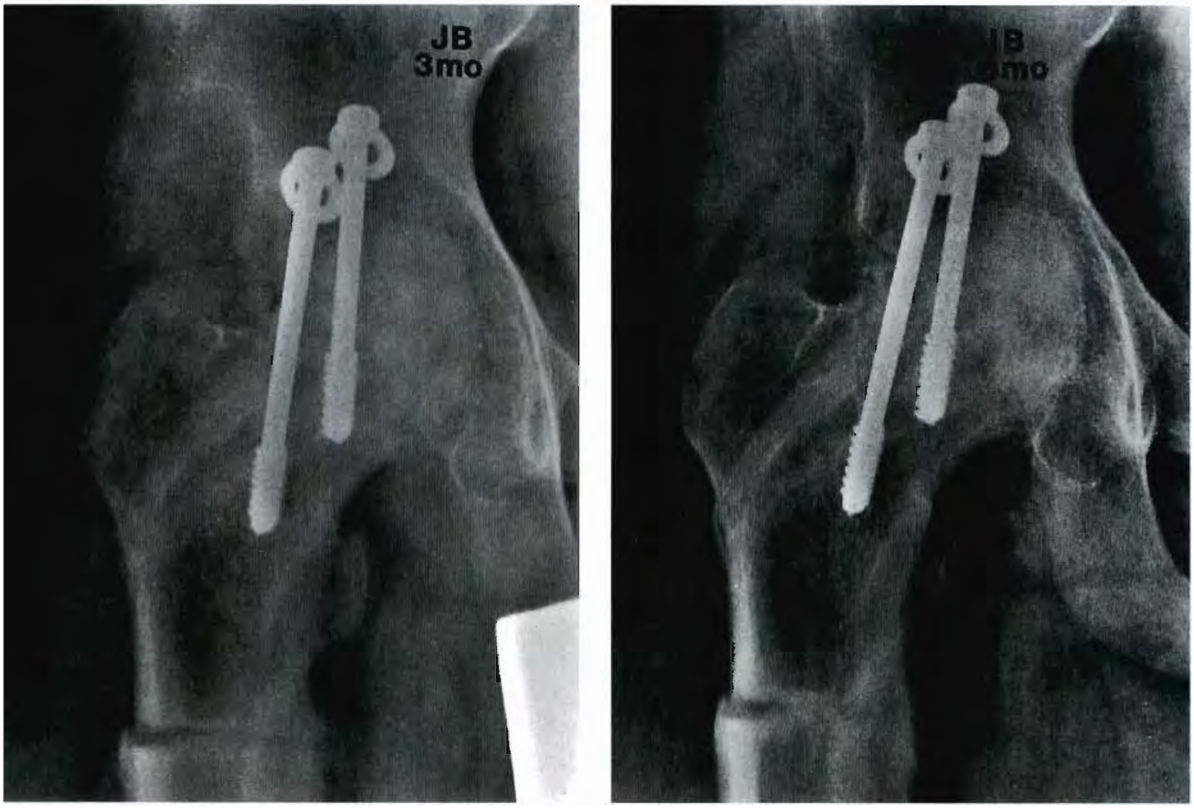


FIGURE 3-69. After the wounds are closed, the patient is moved to a fracture table for application of a spica cast. This is a critical stage in the operation because it determines the position of the leg relative to the pelvis, the importance of which has already been discussed. The best position for the leg is 30 degrees of flexion, 0 degrees of abduction, and 0 to 5 degrees of external rotation. In most situations, the correct amount of flexion is achieved by keeping the unoperated leg parallel to the floor and elevating the operated leg about 10 degrees. The resulting pelvic tilt, as evidenced by the lumbar lordosis, results in about 30 degrees of hip flexion. Because of the dressings and the absence of the anterosuperior iliac spine on the operated side, it is difficult to be sure of the degree of abduction. Because of its importance, the degree of abduction should be verified by radiographic control. This is made easier by the use of a large metal T square and an image intensifier.

The initial spica cast should include the entire leg and the foot if the knee is not bent, so that rotation of the osteotomy site is controlled. It is wise to verify the position of the limb radiographically again after cast placement.

An alternative method of intraoperative positioning using prepositioning on bean bags has been described (8). This requires careful attention to detail before beginning surgery and is well suited to techniques that accomplish arthrodesis of the hip without a femoral osteotomy. Such techniques require that the leg be positioned correctly as the fixation is applied. No adjustment is possible after the drapes are removed.



A B

FIGURE 3-70. Radiographs of a hip arthrodesis 3 months **(A)** and 6 months **(B)** after surgery for avascular necrosis secondary to slipped capital femoral epiphysis illustrate the delayed healing that can occur at the osteotomy site when it is created with a power saw. In this case, the graft was wedged tightly into place, and screws were not used to secure it.

POSTOPERATIVE CARE

Depending on the surgeon's confidence in the internal fixation of the hip, the spica cast's immobilization of the femoral osteotomy, and the patient's ability to follow instructions, the patient can be mobilized on crutches or kept at bed rest. Bed rest is the usual result. When early radiographic signs of healing are observed at the osteotomy site, usually by 6 weeks, the cast can be altered to allow knee motion, and the patient is mobilized on crutches. This is important to avoid permanent knee stiffness in these patients, who depend on full motion of adjacent joints for full function. The cast is discontinued when there is radiographic evidence of union between the femoral head and the ilium. This usually takes 12 weeks.

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3.14 PERCUTANEOUS IN SITU CANNULATED SCREW FIXATION OF SLIPPED CAPITAL FEMORAL EPIPHYSIS

Since the 1950s, the most common method of treatment for slipped capital femoral epiphysis (SCFE) has been in situ fixation with threaded pins of one type or another. Since the 1980s, the treatment of SCFE has undergone several changes as a result of that experience (1). Chondrolysis may be related to persistent pin penetration of the joint that goes unrecognized on the radiographs, and avascular necrosis may be caused by disruption of the lateral epiphyseal arteries within the femoral head by the pins or a drill that enters the superior aspect of the femoral head (2). The surgeon must know where the tip of the fixation device is within the femoral head. It becomes apparent that in situ fixation of an SCFE is a radiographic technique because no incision, no matter where placed or how large, can show the surgeon where the tip of the fixation device is within the femoral head. This technique of percutaneous screw fixation has been described (2) (Figs. 3-71 to 3-78).

FIGURE 3-71. The availability of several types of strong cannulated screws has allowed significant improvement in the safety and ease of in situ fixation for slipped capital femoral epiphysis (SCFE). It is preferable to use one of the 7-mm cannulated screws shown on the left to the earlier devices, which contained the pin in a drill sleeve. The latter are more difficult to use, leave larger holes if not filled with a screw (you may not get it right the first time) and generate more heat and potential bone necrosis than a sharp drill.

Because the strength of one screw appears sufficient for the treatment of a SCFE, with some surgeons preferring two screws for an acute unstable SCFE, it is almost always possible to keep the fixation within the central axis of the femoral head, where it does not interfere with the blood supply and where the radiographs are the most accurate (3). In addition, the cannulated aspect allows the screws to be inserted percutaneously, thus decreasing the postoperative morbidity.

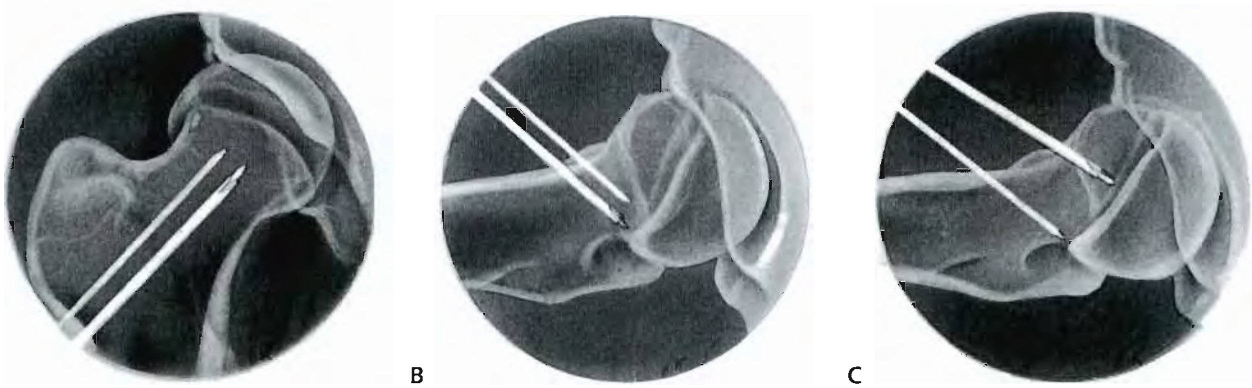
FIGURE 3-72. The patient is placed on a fracture table with the image intensifier placed between the legs. It is important to verify that the subchondral bone of the femoral head, as well as the physeal plate, can be seen in the anteroposterior lateral plane. The operation should not begin until this is achieved.

Some surgeons prefer to use a translucent operating table and frog the leg for the lateral view. Although this may work well, it is difficult to get a true lateral view in some children, and the guide pin will be bent during the maneuver.

The most difficult problem is the lateral view. In many cases, this is due to the angle of the x-ray beam relative to the femoral head. This is not solved by abducting or adducting the leg because the femoral head and neck remain in almost the same position. Rather, the base of the image intensifier and its angle to the hip have to be varied. In cases of obese patients and when using older, less powerful image intensifiers, there may not be adequate power to obtain a good image. In such cases, the image intensifier is positioned for the anteroposterior view on the opposite side of the patient, and a portable radiographic machine is positioned between the legs for lateral radiographs taken on conventional radiographic film.

The x-ray tube can be positioned below the table, which is not the way in which it is illustrated here. This has several advantages: the scatter of the x-rays is reduced for the personnel, the recording tube can be brought close to the wound, and the smaller x-ray tube is further from the supports of the table.

FIGURE 3-73. The exact location and angle of the femoral neck are identified by laying a guide pin over the femoral neck on the anterior thigh under radiographic control. This permits more accurate placement of the percutaneous guide wire. At this point, the percutaneous guide wire is inserted through a stab wound in the skin down to the bone of the femoral neck and is drilled into the bone for a short distance under radiographic control. Now the surgeon is certain that the guide pin and the screw are heading in the correct direction as they enter the femoral head in the anteroposterior projection. The surgeon does not know, however, whether the guide pin is headed too far anteriorly or posteriorly. This determination is best left to the next step because this guide wire is not fixed in the bone and tends to move. After a little experience and a better understanding of the anatomy of a slipped capital femoral epiphysis, it becomes surprisingly easy to judge this posterior inclination of the percutaneous guide pin and the screw correctly.



A B C

FIGURE 3-74. The guide pin is fixed in the bone and does not move. The image intensifier is switched to the lateral projection to see how the pin is directed in the anteroposterior plane. If the direction is incorrect, a second pin parallel to the first pin on the anteroposterior projection is inserted, this time with the correct anteroposterior inclination. It is imperative that the direction of this second pin be verified on both projections, and the surgeon must not assume that he or she placed the pin perfectly parallel on the anteroposterior projection. A few degrees of change at the starting point results in the tip of the pin being in a different location by the time it is in the femoral head.

A: The guide pin is parallel and just inferior to the guide pin on the skin surface. It is well placed in this projection. **B:** Two different pins are shown that are not correct on the lateral projection. They are correct in that the inclination places them perpendicular to the surface of the physis of the femoral head, but they are starting too far laterally on the femoral neck. **C:** One of the pins is redirected in the correct direction.

After the pin is in the bone, its progress should be monitored on the lateral view because this view shows the correct depth of penetration. The guide pin should advance easily until cortical bone or the epiphyseal plate is encountered. As the guide pin reaches the physeal plate, drilling becomes more difficult. Before the surgeon drills the guide pin across the physeal plate and into the femoral head, he or she must be confident that the pin is headed for the center of the femoral neck, to avoid damaging the lateral epiphyseal vessels in the superior quadrant of the femoral head.

FIGURE 3-75. When the proper placement and direction of the guide pin are achieved, it is drilled across the physeal plate. This should be monitored on the lateral view. The anteroposterior view does not portray accurately the true depth of the guide pin and screw because they are not perpendicular to the x-ray beam. When the tip of the guide pin is in the desired location (the center of the femoral head and 5 mm from the subchondral bone), its length can be measured.

Now the pin should be advanced about 5 mm so that the threads engage in the subchondral bone. The cannulated drill is then used to drill over the pin. The drill should stop short of the end of the pin so that it does not loosen in the bone and come out with the drill. As the drill is removed (still turning in the same direction used for its insertion), check the image intensifier to be sure the guide pin remains in place. If it does not, insert a second guide pin through the drill to push it back into the femoral head.

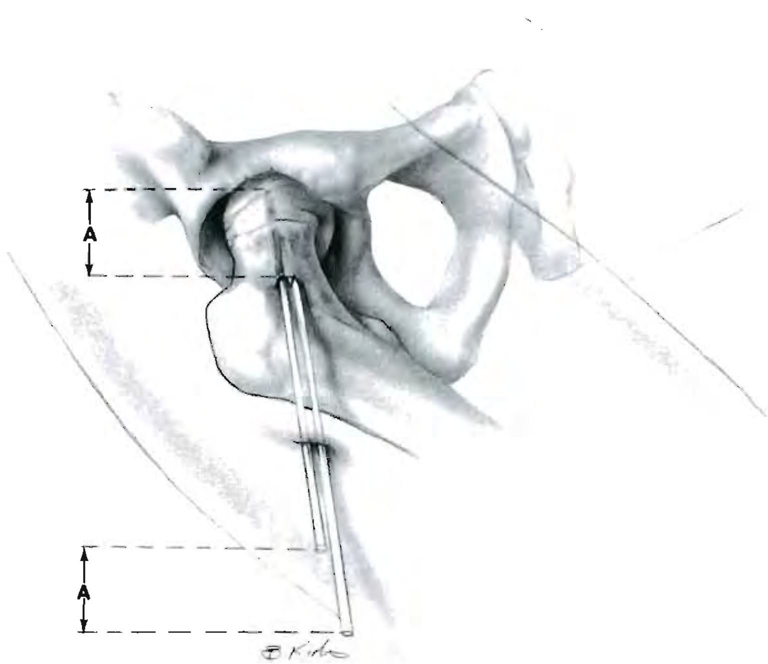


FIGURE 3-76. Although the length of the guide pin (and therefore the desired length of the screw) can be measured with the device that is provided, it is sometimes difficult with this percutaneous approach to ensure that this device is in close contact with the bone, a condition that is required for accurate measurement. If such a device is used, its contact with the bone should be verified radiographically.

FIGURE 3-77. The correct length of screw is inserted over the guide wire, and its position is monitored on the lateral view. It is comforting to check for screw penetration before leaving the operating room.

The leg is removed from traction and put through a range of motion to confirm under the image intensifier that the screw does not penetrate the joint. It is important to recognize that this method of seeking screw penetration has a significant limitation. Unless the screw can be aligned perpendicular to the plane of the x-ray beam, it will not be completely accurate. This can be difficult to achieve because of the lack of internal rotation in the hip with an SCFE.

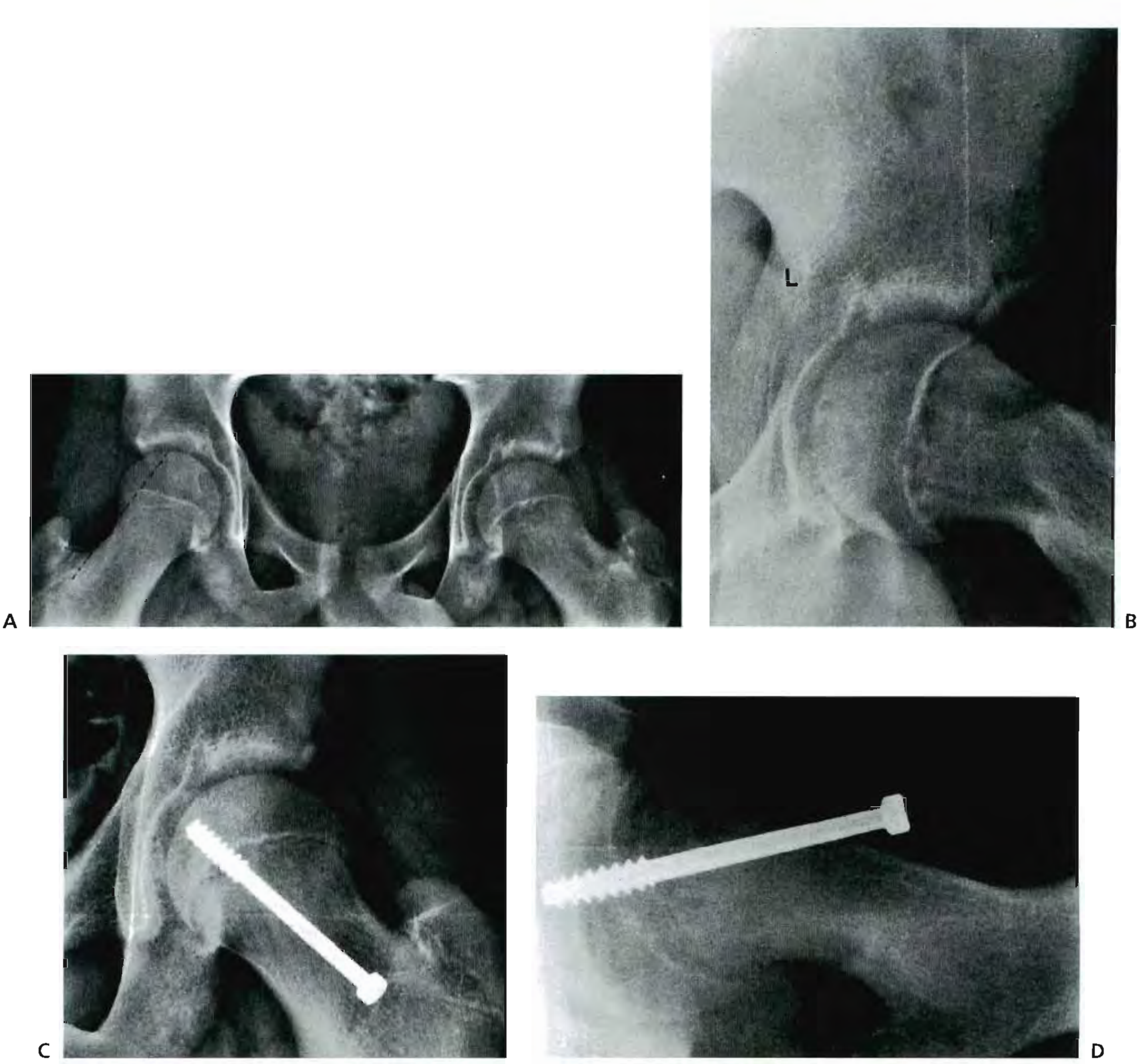


FIGURE 3-78. A, B: Radiographs of a 13-year-old boy whose complaints are a limp and pain in the knee for 3 months. The Klein line, drawn on the right hip, does not appear abnormal on the left hip. The frog lateral radiograph **(B)**, however, demonstrates slight irregularity and widening of the physis and no overlap of the epiphysis on the metaphysis typical in a mild chronic slipped capital femoral epiphysis. **C, D:** Anteroposterior and lateral radiographs, respectively, were obtained 1 day after percutaneous in situ fixation with a single screw. Notice on the true lateral radiograph **(D)** how far posterior the femoral head is actually displaced. The screw is almost perfectly located in the central axis of the femoral head. On the anteroposterior radiograph **(C)**, the screw is slightly below the central axis of the femoral head. Notice the position on the anterior femoral neck where the screw must start to remain in the central axis of the displaced femoral head.

POSTOPERATIVE CARE

Patients are started on a three-point partial weight-bearing crutch gait as soon as their recovery from anesthesia permits, which is usually the next morning, although some patients have been treated as outpatients. Crutches are discontinued as soon as the patient can walk comfortably. In cases of chronic slip, this is usually 1 week. In patients with a severe acute unstable slip that is reduced, it may be best to continue crutches for a longer time. In such cases, we recommend 6 weeks, but without discomfort, compliance is difficult to gain.

The patients are given instructions about the same symptoms, particularly anterior thigh or knee pain, developing in the opposite hip and the need for prompt return. They are seen routinely, every 3 months until fusion of physis, and progress is monitored with anteroposterior radiographs and an examination for range of motion and synovitis.

If screw removal is indicated for any reason, it is performed on an outpatient basis under general anesthesia. A guide wire is passed down the center of the screw, under radiographic control, and the screwdriver is inserted over the wire into the screw head. The screw backs out easily. Occasionally, the head of the screw is covered by bone, which can be cleared with a small periosteal elevator that is passed percutaneously to the screw.

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3.15 OPEN BONE GRAFT EPIPHYSIODESIS FOR TREATMENT OF SLIPPED CAPITAL FEMORAL EPIPHYSIS

The original description of open bone graft epiphysiodesis for the treatment of slipped capital femoral epiphysis (SCFE) was originally described by Ferguson and Howorth (1). Subsequent experience with this procedure has been limited, but it is characterized by a striking absence of the complications of avascular necrosis and chondrolysis (2–4). The possible reasons for this low complication rate in contrast to the historical rate of complications for in situ pin fixation have been discussed (5). There have been reports documenting unsatisfactory results with this technique, which reflect many of the problems that have prevented wide use of this procedure (6,7). It appears that the use of this procedure is rapidly disappearing from the scene.

The philosophy underlying this procedure is that closure of the growth plate is the best way to prevent further slipping. This is accomplished by open reaming and curettage of the growth plate and femoral head followed by the insertion of corticocancellous bone grafts. The technique for this procedure has been discussed (8,9) (Figs. 3-79 to 3-83).

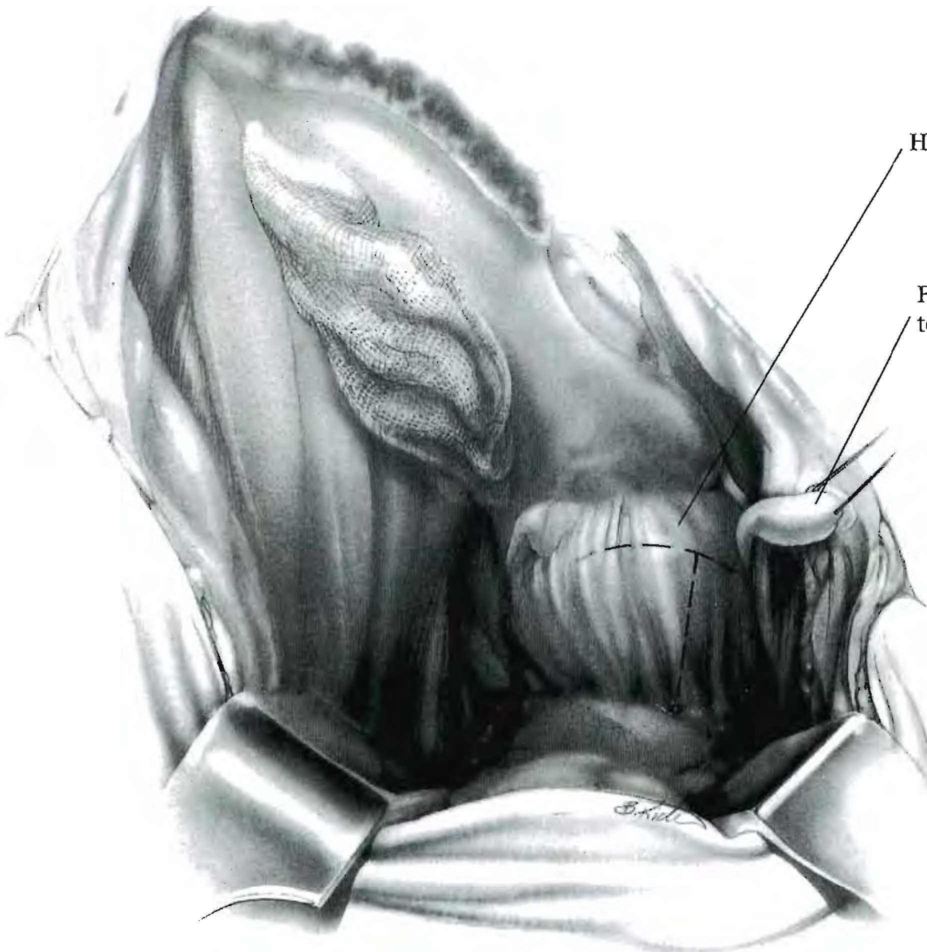

FIGURE 3-79. The capsule of the hip joint and the outer table of the ilium are exposed as for a Salter osteotomy or an anterior open reduction of the hip. It is not necessary to expose the inner table of the ilium, but it is important to obtain good exposure of the hip capsule. The anterior capsule is opened with an incision parallel to and 1 cm from the acetabular margin. The second incision extends at right angles from this incision over the anterior femoral neck.

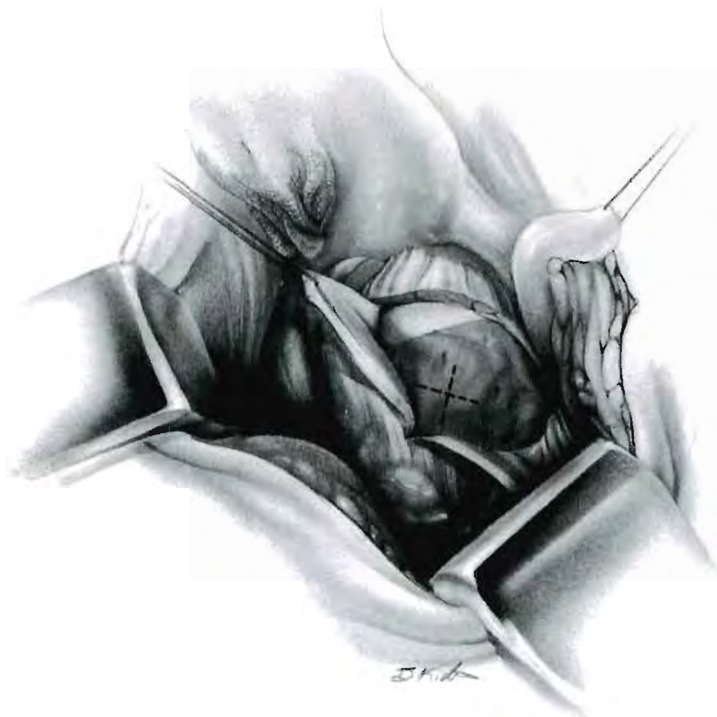

FIGURE 3-80. The hip joint is now exposed. Inspection shows the articular surface of the femoral head to be displaced posteriorly, with the amount of displacement depending on the severity of the slip. The capsule can be slightly adherent to the anterior femoral neck as a result of the healing callus and inflammation. The surgeon should see an adequate amount of the femoral neck and the articular surface of the femoral head to ensure that he or she is properly oriented to the anatomy.

The periosteum over the anterior neck is incised in a cruciate fashion and elevated, exposing the bone. This should be placed in a location that allows the hollow mill drill to cross perpendicular to the epiphyseal plate.

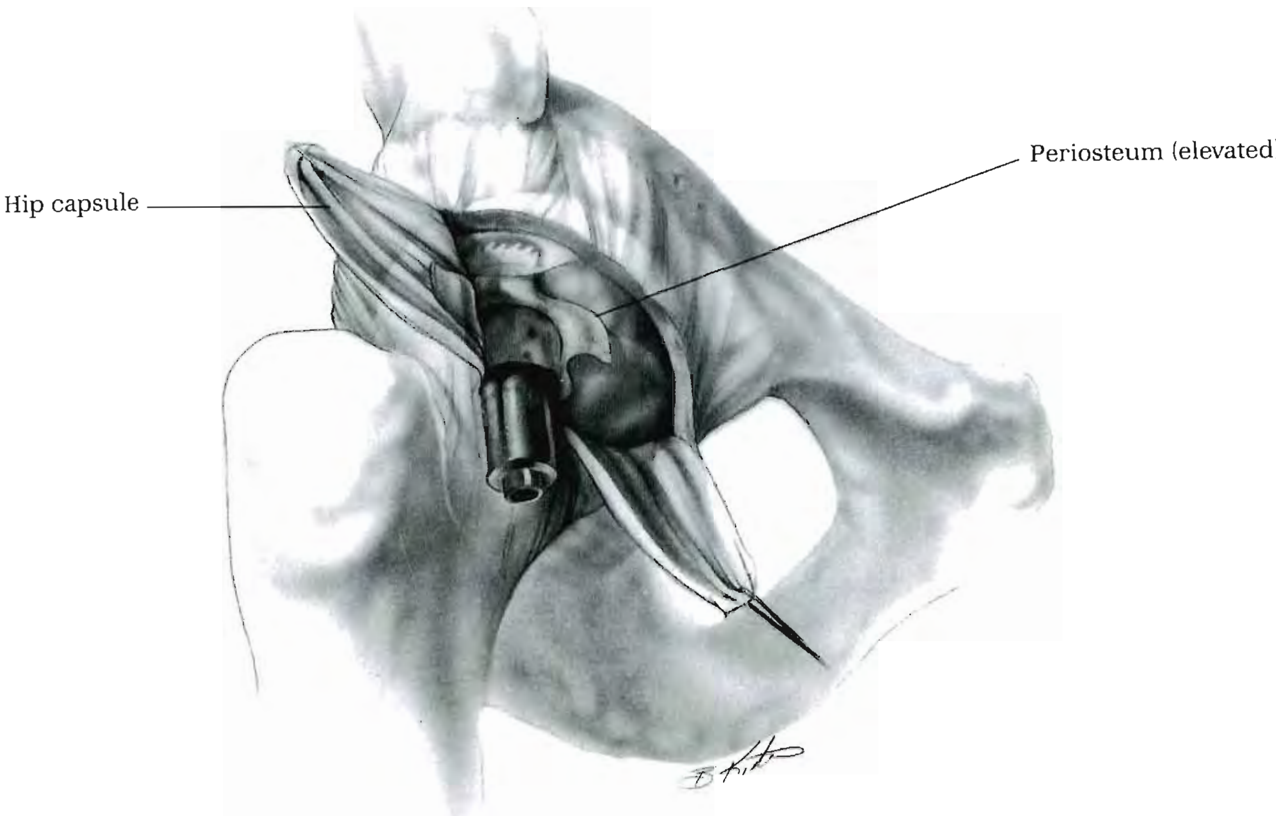

FIGURE 3-81. A guide wire is inserted, and its proper placement in the center of the femoral head and at a safe distance from the articular surface is verified by an anteroposterior and frog lateral view on the image intensifier. When the proper direction is verified, the hollow mill is drilled through the anterior cortex of the femoral neck, across the physeal plate, and into the femoral head.

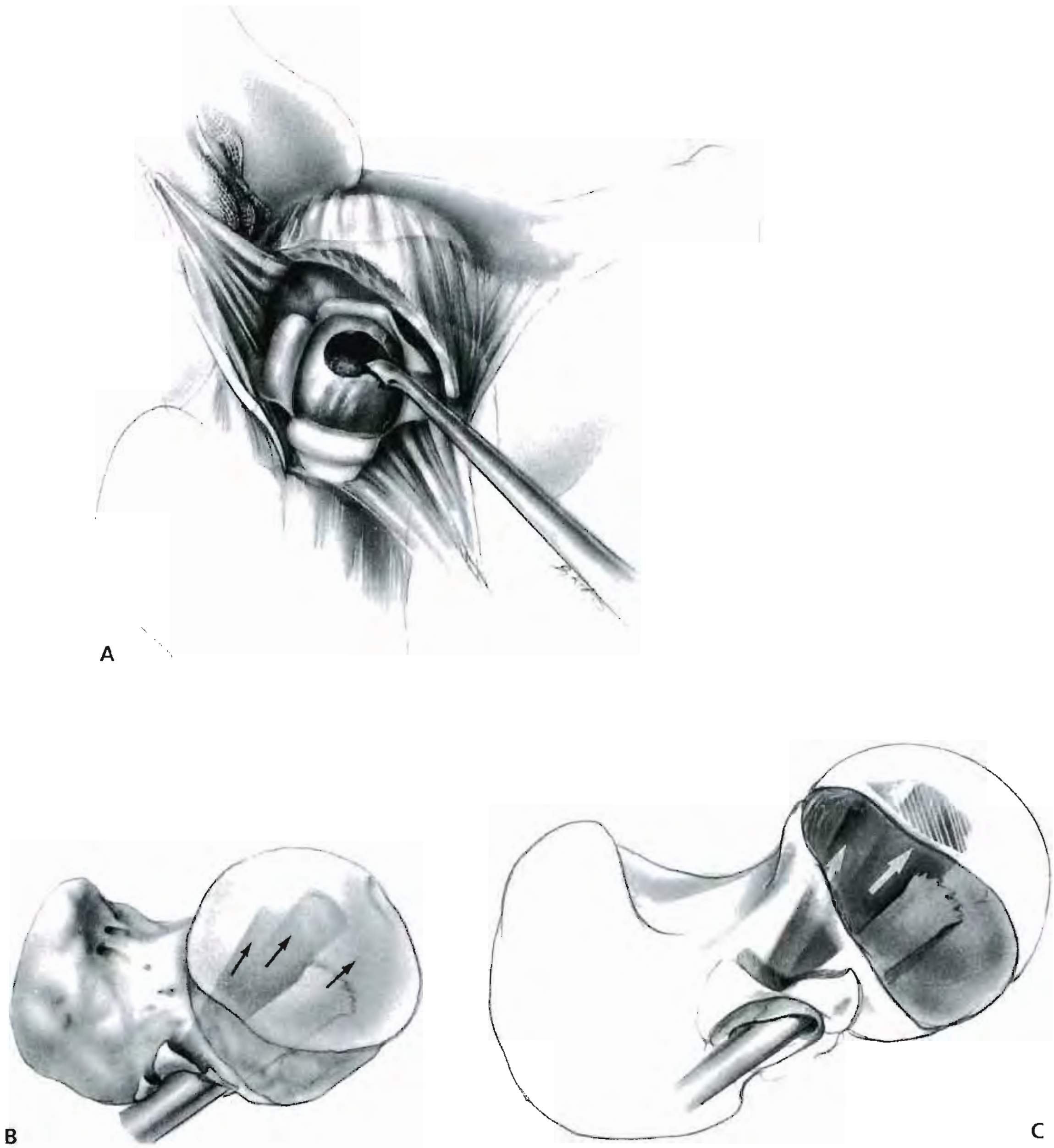

FIGURE 3-82. The hole in the cortex can be enlarged with a curette, which also can be used to remove additional physeal plate **(A)**. The hollow mill is angled in multiple directions to enlarge the hole **(B, C)**. This allows the placement of grafts sufficient strength to provide temporary stability to the epiphysis.

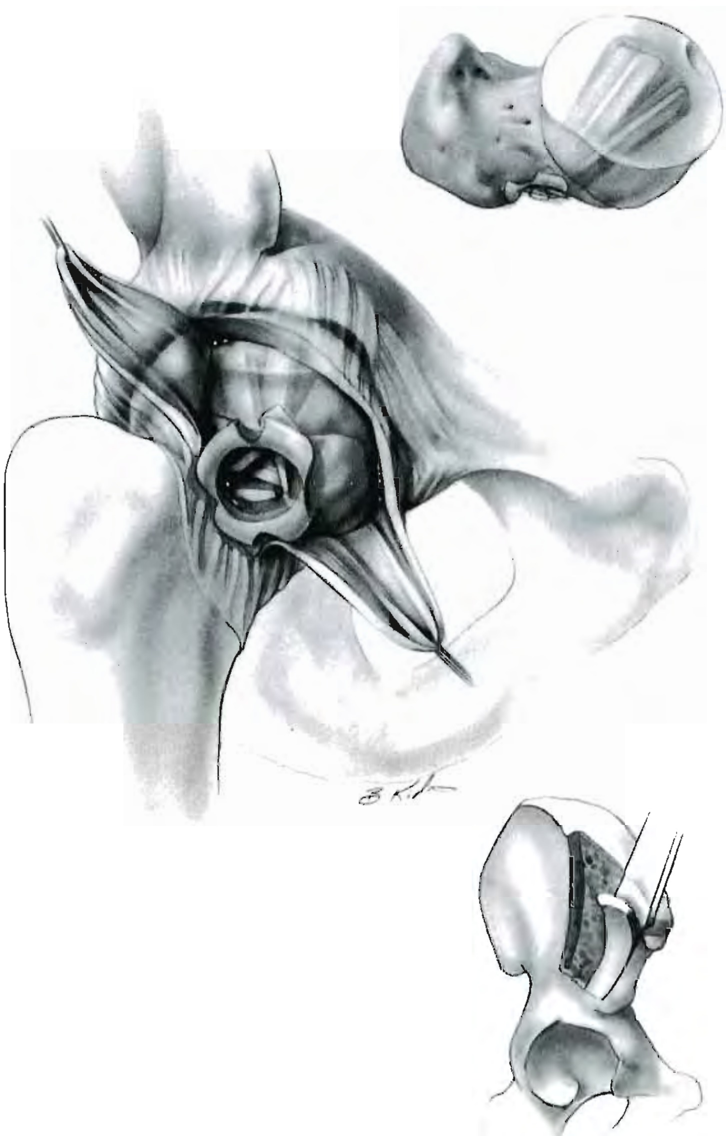

FIGURE 3-83. Three or four corticocancellous strips of bone are removed from the outer table of the ilium. This is preferable to several small matchstick-sized pieces because the larger grafts possess more strength. These grafts are driven into the hole, and their location is verified on the image intensifier. The periosteum, the capsule, and the wound are closed.

POSTOPERATIVE CARE

A drain can be used at the discretion of the surgeon, but there should be no dead space and little bleeding at the conclusion of the procedure. Those series reporting no further slipping after grafting used a spica cast for immobilization until healing was complete, in 8 to 12 weeks. There have been reports of using only crutch protection, not a cast, with an incidence of further slipping in some patients (10).

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3.16 RESECTION OF THE PROXIMAL FEMUR FOR PAINFUL DISLOCATION OF THE HIP IN CEREBRAL PALSY

Dislocation of the hip is common in cerebral palsy patients, particularly in patients with spastic quadriparesis or total-body involvement. Although many of these dislocated hips cause no pain or interference with the patients' activities and care, some do. In many of these patients, reduction of the dislocation by proximal femoral shortening, rotation, and varus osteotomy combined with acetabular osteotomy is not possible because of destruction of the articular surface of the femoral head.

To address this problem, many solutions have been proposed: arthrodesis, total-joint replacement, various abduction osteotomies, and Girdlestone resection. None of these has proved to be the ideal solution. Sharrard (1) pointed out the common experience with Girdlestone resection by observing that the stump of the femoral neck often continues to move proximally, becoming prominent under the skin. In addition, ectopic bone formation leading to stiffness has been a problem. A report by Kalen and Gamble (2) showed that two thirds of patients achieved pain relief, but 89% had ectopic ossification, and 28% were ankylosed.

In 1978, Castle and Schneider (3) proposed an operation that differed from the Girdlestone operation by resecting a larger portion of the proximal femur and interposing tissue over the acetabulum and the resected end of the femur. In subsequent reports by McCarthy and colleagues (4) and Baxter and D'Astous (5), generally favorable outcomes with this procedure are documented. McHale and colleagues (6) recommended combining a femoral head resection with an abduction osteotomy to place the lesser trochanter into the acetabulum to minimize proximal migration (Figs. 3-84 to 3-88).

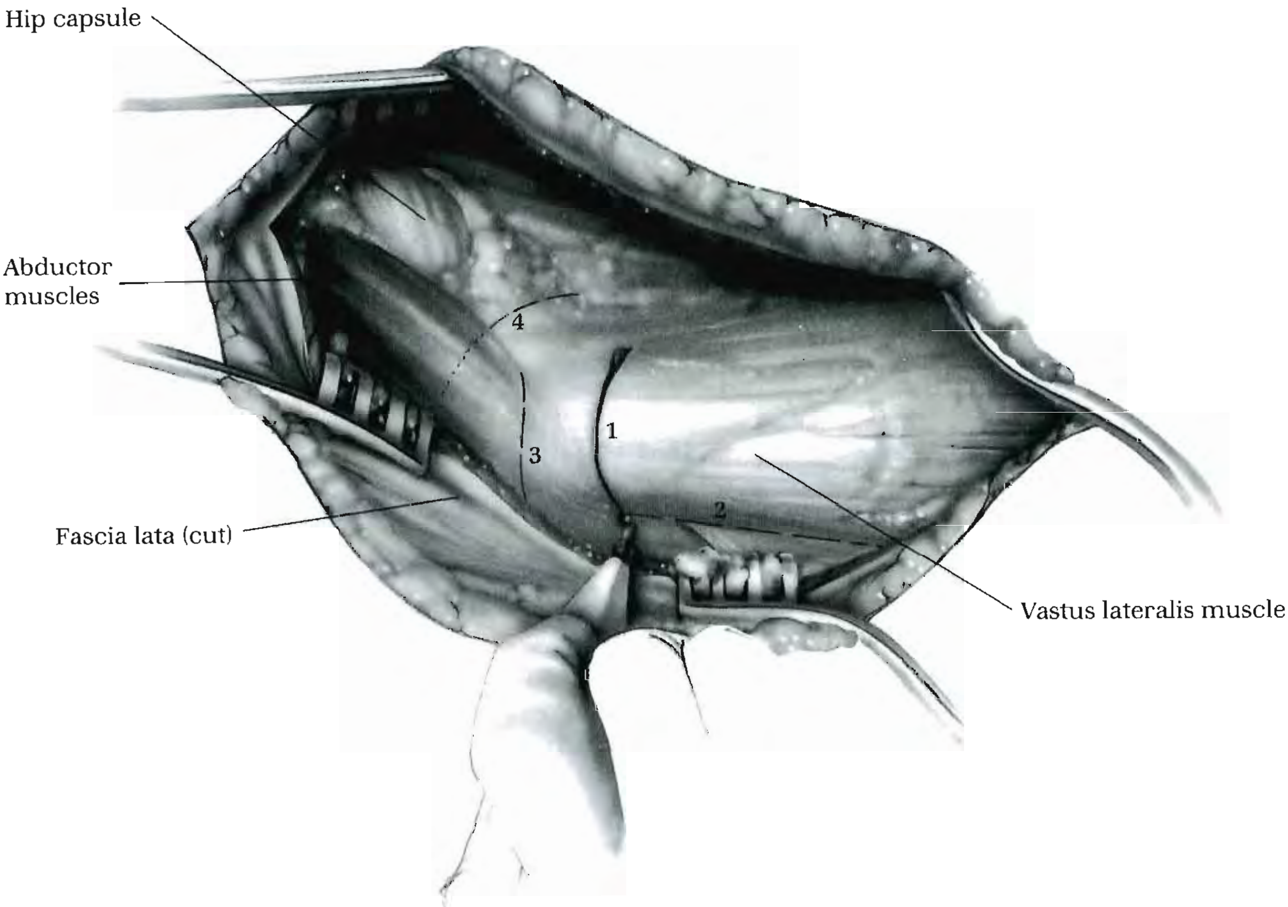

FIGURE 3-84. The patient is placed on a regular operating table with a bolster under the affected pelvis. Although reports describe a straight lateral approach beginning 10 cm proximal to the greater trochanter, a variety of approaches to the hip can be used. The often-forgotten Watson-Jones approach (see Chapter 4, Procedure 4.8) makes the exposure of the medial structures easier without increasing the difficulty in reaching the posterior structures.

This approach, which was designed to provide access to the hip joint and the femoral neck and proximal shaft, should be extended more distally than usual to allow resection of the femur. A good guideline to the amount of femur that needs to be resected is to draw a line across the bottom of the ischia on an anteroposterior radiograph. The femur proximal to this line is resected. This is usually 4 to 5 cm of femoral shaft distal to the lesser trochanter.

The exposure provides an excellent view of all the structures that must be divided. The vastus lateralis muscle **(1)** is detached from the vastus ridge. The posterior aspect of the vastus lateralis muscle **(2)** is divided close to the linea aspera. The abductor muscles **(3)** are detached from the greater trochanter. The hip capsule **(4)** is opened.

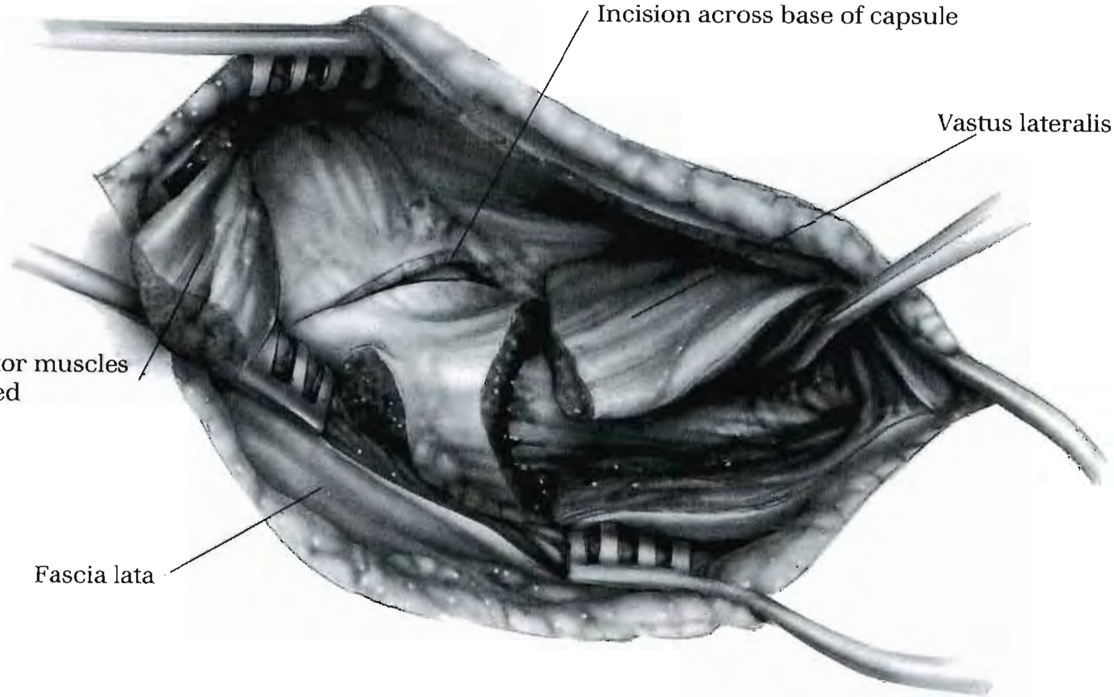

FIGURE 3-85. This resection is extraperiosteal to minimize any bone formation after the resection.

First, the surgeon divides the vastus lateralis muscle along the vastus ridge and splits it longitudinally, taking care not to enter the periosteum. The fascia can be split with the electrocautery, and a periosteal elevator is used to tear the muscle in the direction of its fibers. At the same time, this muscle can be stripped from the periosteum posteriorly to the linea aspera and anteriorly and as far medially as is convenient. This aids the removal of the bone after the osteotomy is performed.

Next, the abductor muscles are released from the greater trochanter using electrocautery. They can be tagged with a suture for later ease in identification.

Finally, the capsule is incised along its insertion into the femoral neck rather than close to the acetabulum. The incision in the capsule is in the shape of an inverted T. All but the most medial and posterior capsule can be divided at this time. This facilitates mobility of the proximal fragment, an important adjunct to the next step.

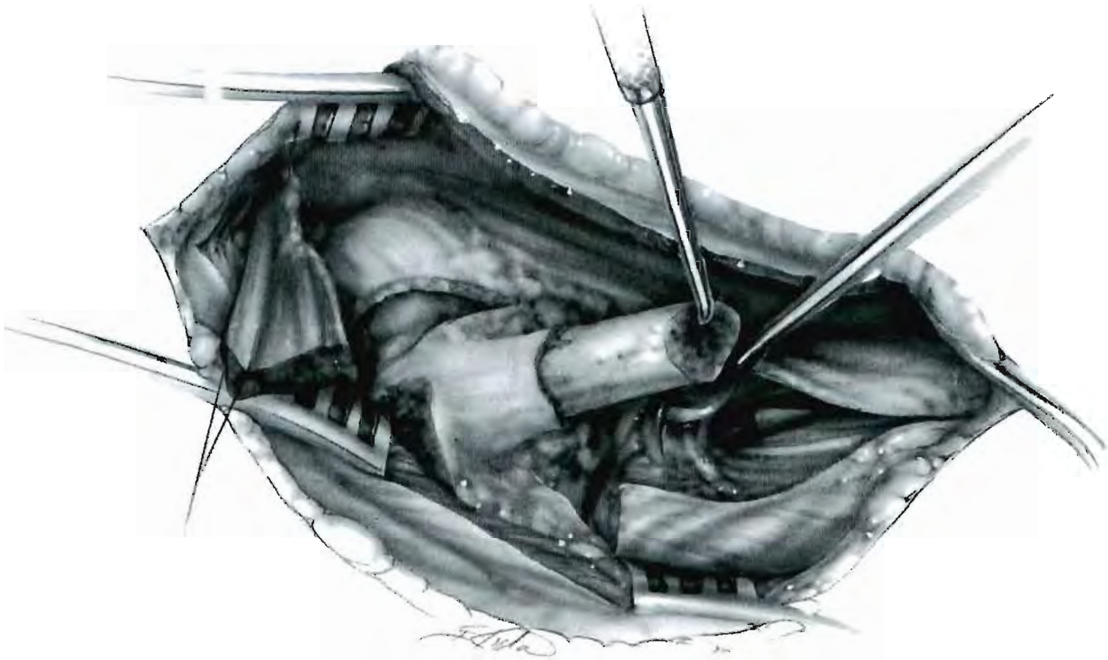

FIGURE 3-86. At the previously determined level of resection (usually at the level of the ishium), the femur is exposed circumferentially without entering the periosteum. The osteotomy is performed. A large bone hook is placed in the medullary canal, and the proximal fragment is pulled laterally, anteriorly, and posteriorly while the remaining muscle is stripped off the periosteum, and the linea aspera is divided with the elevator and the electrocautery until the tendon of the iliopsoas is encountered.

The tendon of the iliopsoas is exposed and divided. The periosteal elevator is used to expose the remaining capsule back to the short external rotators. This capsule is divided, and the short external rotators are then divided. Care must be taken to identify and coagulate the large vessels in this area. The final step in the removal of the bone is division of the ligamentum flavum.

If sufficient mobility of this fragment cannot be obtained, it is necessary to divide the adductor muscles, the iliopsoas tendon, and the medial capsule through an incision in the groin. This is usually not necessary.

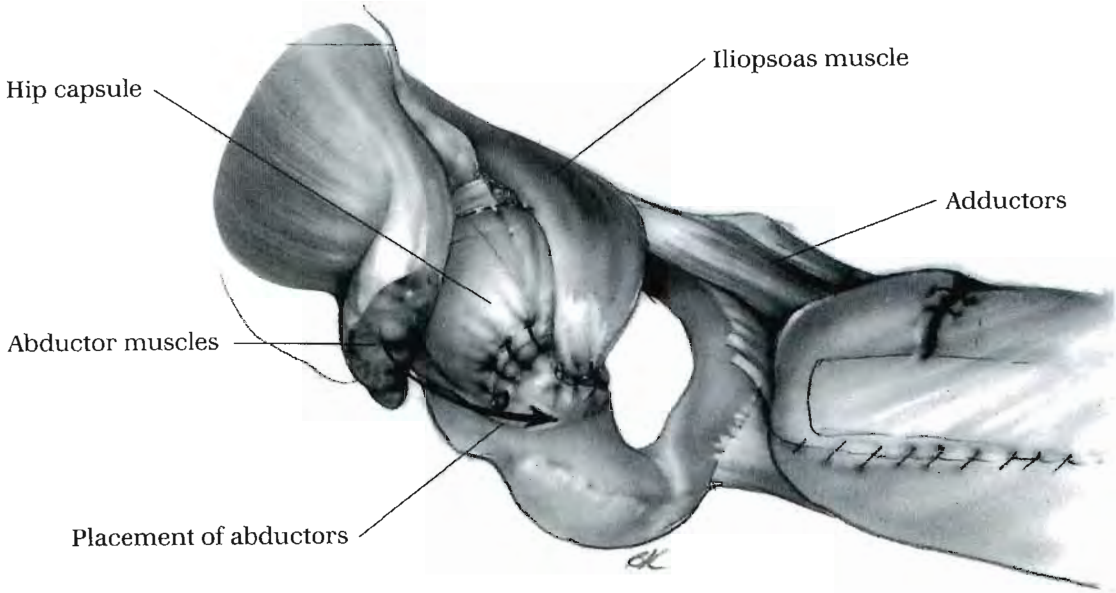

FIGURE 3-87. Careful inspection for any bleeding is performed, and the wound is irrigated. The repair of the soft tissues for interposition between the acetabulum and the femur follows.

First, as much of the remaining capsule as possible is brought together. Second, the tendon of the iliopsoas is brought down to the most distal and posterior part of the capsule and sutured into place. Third, the abductor muscles are brought distally, overlapping the iliopsoas tendon and capsule, and sutured into place.

Finally, the vastus lateralis muscle is brought over the distal end of the femur. This is done by closing the lateral longitudinal incision in the muscle, bringing it over the femur from lateral to medial, and then suturing it back onto itself.

Drains are placed deep, and the wound is closed.

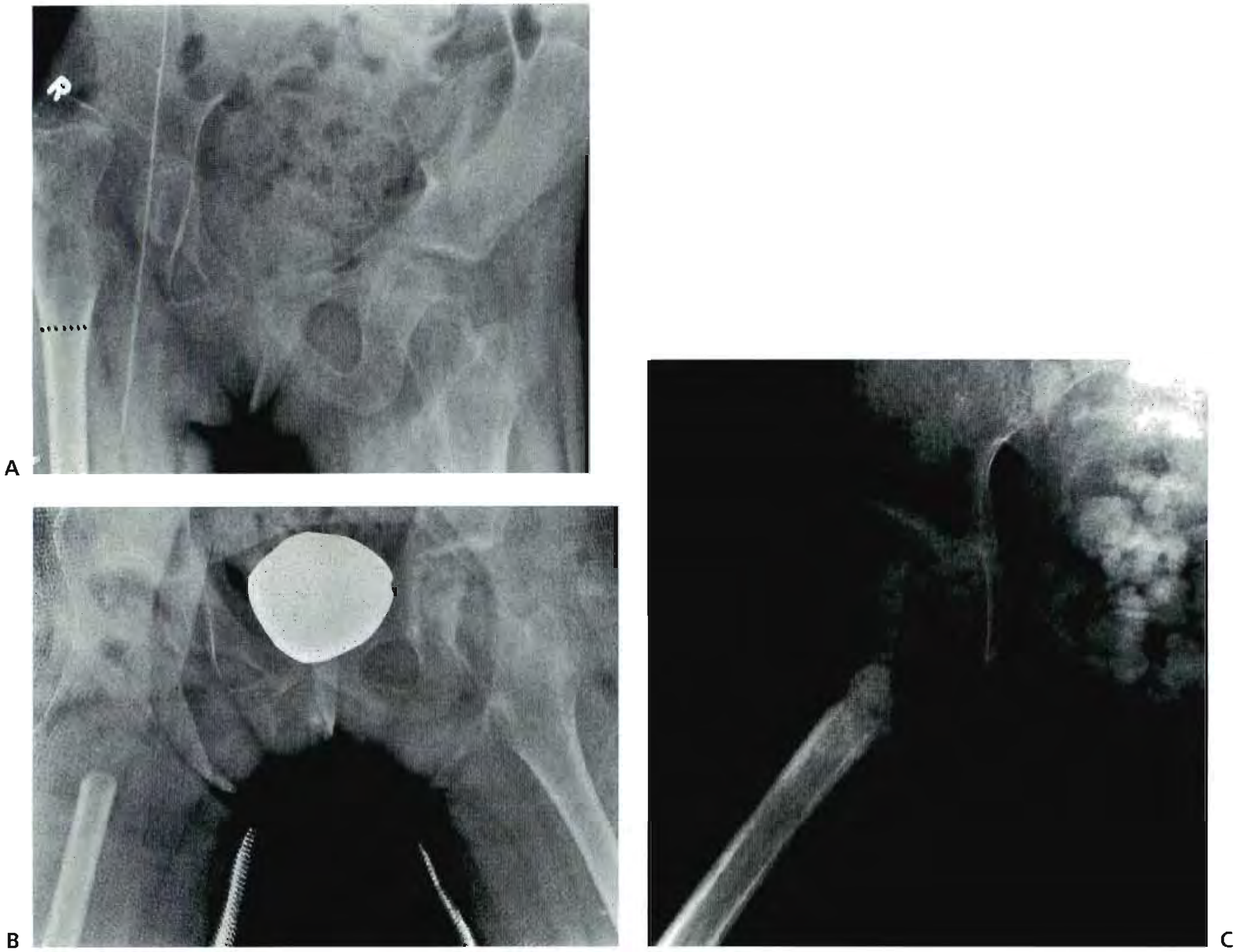

FIGURE 3-88. A: The right hip of a 12-year-old girl with spastic quadriplegia and painful subluxation of the femoral head. The operative plan was to attempt reduction with a femoral and pelvic osteotomy. The possibility of the articular cartilage being destroyed was correctly anticipated preoperatively, however, and a back-up plan for femoral resection was discussed with the parents preoperatively. **B:** The position of the femur in the cast after resection. **C:** The result 6 months after surgery. Note the formation of heterotopic bone. This did not interfere with the hip motion, and the patient had no pain. Some surgeons use indomethacin (Indocin) postoperatively to help prevent ectopic ossification.

POSTOPERATIVE CARE

Postoperative management has included everything from 6 weeks of skeletal traction to hinged external fixators. The goal is to permit soft tissue healing and provide some degree of immobilization for comfort. If traction is the method of choice, arrangements should be made for care at a step-down facility or if possible at home. Immobilization in a single-leg spica cast for 4 to 5 weeks provides excellent results without undue hospitalization, parent inconvenience, and expense. After the cast is removed, gentle range-of-motion exercises are instituted until 90 degrees of flexion is obtained and the patient can sit.

References

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2. Kalen V, Gamble JG. Resection arthroplasty of the hip in paralytic dislocations. Dev Med Child Neurol 1984;26:341.
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3.17 ADDUCTOR AND ILIOPSOAS RELEASE

Adductor myotomy is one of the oldest and most commonly performed operations in children with spastic cerebral palsy. Here, the operation is described in conjunction with iliopsoas tenotomy because the two procedures are often indicated in the same patient and can be performed through the same incision. The indications for these procedures are discussed in Chapter 15 of **Lovell and Winter's Pediatric Orthopaedics, Fifth Edition** (1). It is important to recognize that simply because these operations are described together does not mean that all of them need to be performed in every patient. For many ambulatory children with spastic diplegia, release of the adductor longus and gracilis muscles is all that is necessary, whereas in a dependent sitter, all of the components described, including iliopsoas tenotomy and proximal hamstring release, may be necessary (2).

Although anterior branch obturator neurectomy was a routine part of this procedure in the past, its value is questionable, and it is usually not considered necessary. If the adductor brevis muscle is not sectioned, anterior branch obturator neurectomy should not be done because it denervates this muscle. If all of the muscles supplied by this nerve are cut and retract sufficiently, what is the value in cutting the nerve? The posterior branch of the obturator nerve should not be cut because it denervates the adductor magnus, removing all of the adductors and resulting in unopposed abduction (Figs. 3-89 to 3-94).

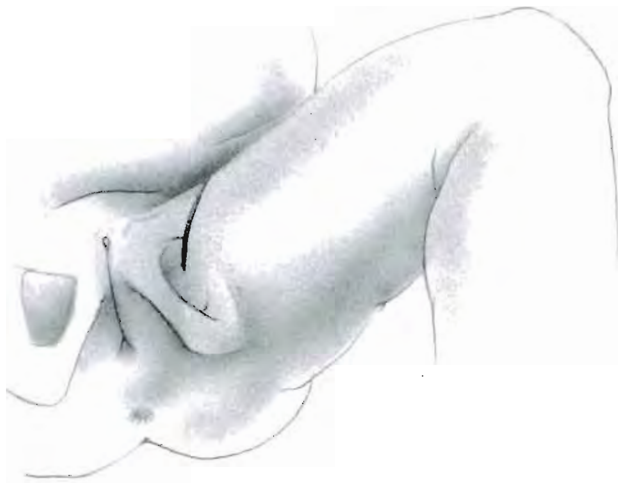


FIGURE 3-89. The patient is draped so that the perineum is isolated and both legs are free. The incision can be longitudinal over the tight tendinous portion of the adductor longus muscle or transverse, centered over the adductor longus tendon about one finger breadth distal to the groin crease. This transverse incision is opened down to the deep fascia.

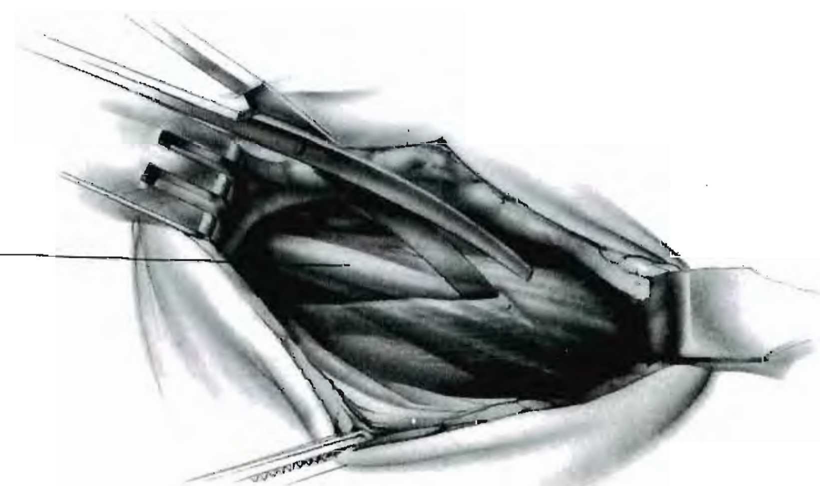


FIGURE 3-90. A sponge is placed over the index finger and pulled proximally and distally along the adductor longus tendon, exposing the deep fascia overlying it. This fascia is, in turn, opened longitudinally, exposing the adductor longus muscle and the tendon. This permits the deep fascia to be closed in a direction 90 degrees to the superficial fascia and the skin, providing tighter wound closure.

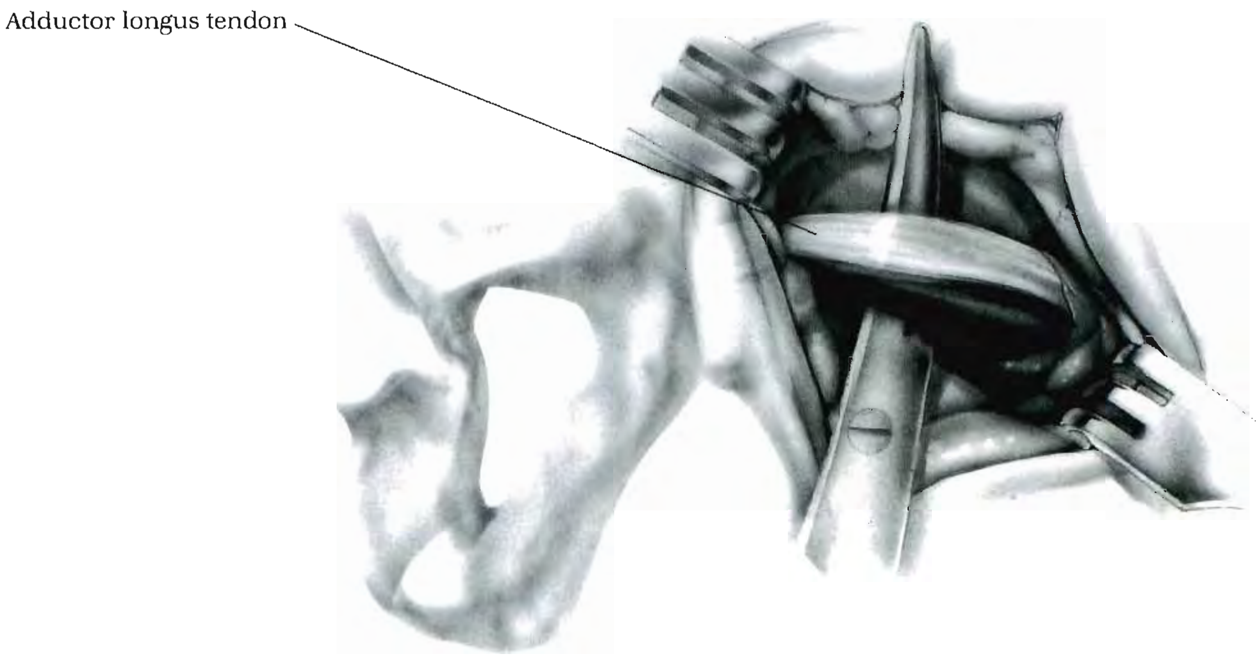


FIGURE 3-91. The tendon of the adductor longus is isolated easily in the proximal part of the wound and can be cut close to its attachment to the pelvis. If the surgeon wishes to perform an anterior branch obturator neurectomy, this common trunk can be found deep to the adductor longus between the pectineus muscle superiorly and the adductor brevis muscle inferiorly.

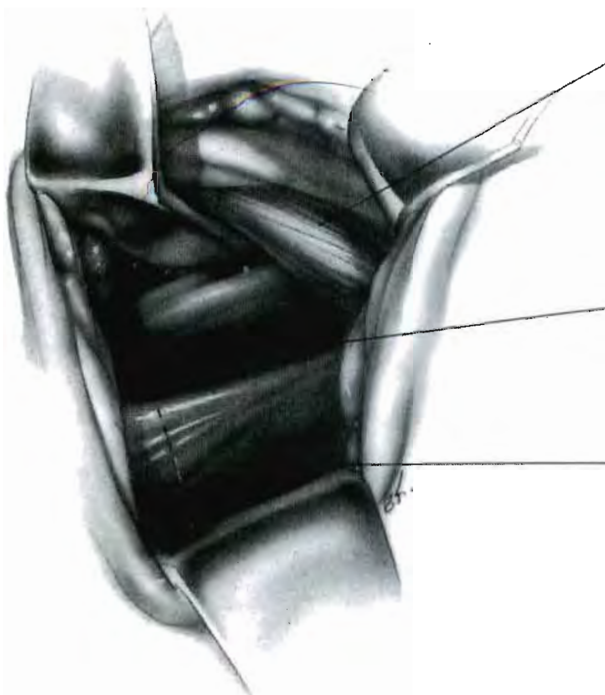


FIGURE 3-92. Lying below the adductor longus tendon is the adductor brevis. A retractor pulling the pectineus superiorly helps in visualizing the full extent of this large muscle. Some branches of the anterior obturator nerve usually can be seen coursing over the upper portion or side of this muscle. If desired, each of these branches to the adductor longus, the adductor brevis, and the gracilis muscles can be identified by stimulating and then dividing them. It is easiest at this point to leave the adductor brevis muscle and divide the gracilis muscle *(dotted line)*.

The gracilis muscle is, as its name implies, a long thin muscle that is found medial to the adductor brevis muscle. It is easily isolated by dissecting posteriorly between it and the deep crural fascia by spreading with a scissors. The inner aspect of the muscle is identified and separated from the adductor brevis muscle in the same manner. Abducting the leg and straightening the knee help identify the entire extent of this muscle. Two long retractors are placed, one on either side of the muscle, and it is divided close to its attachment to the pelvis.

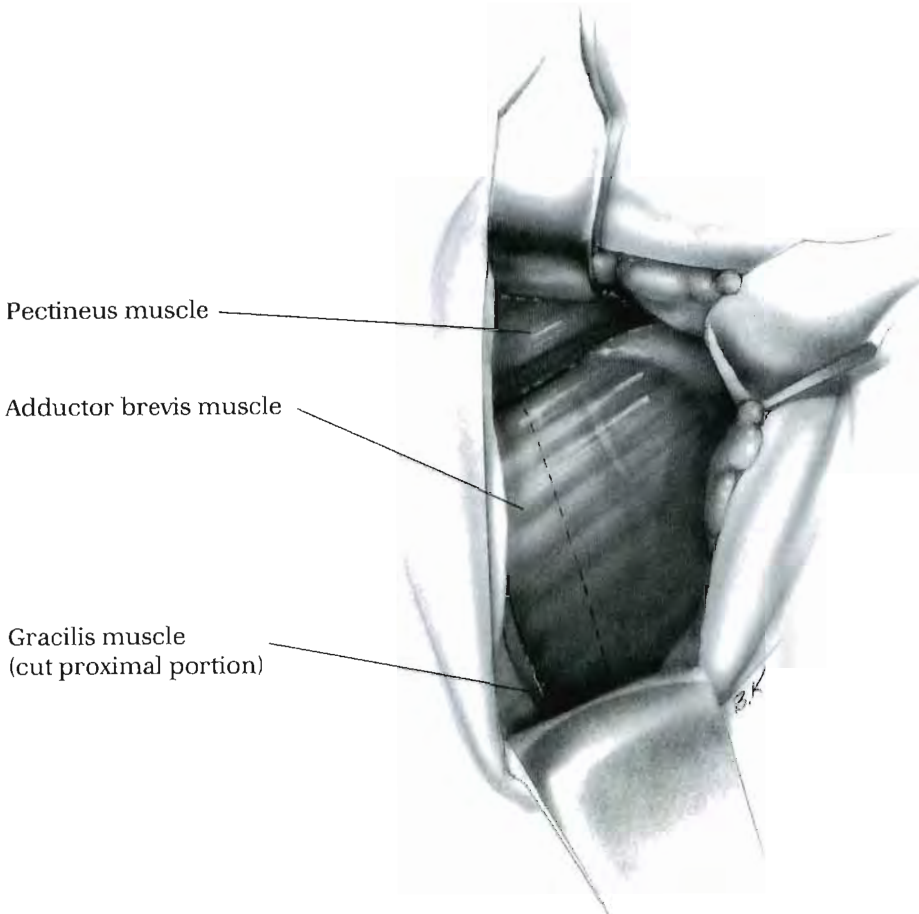
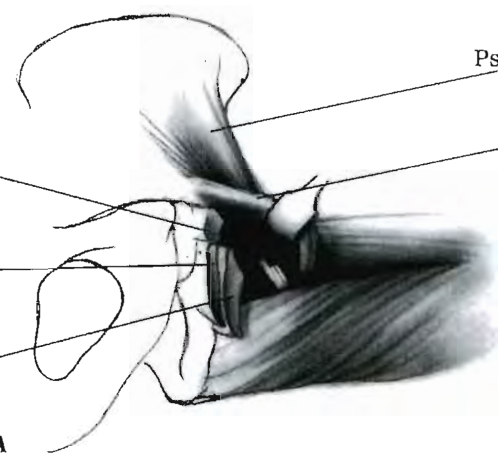
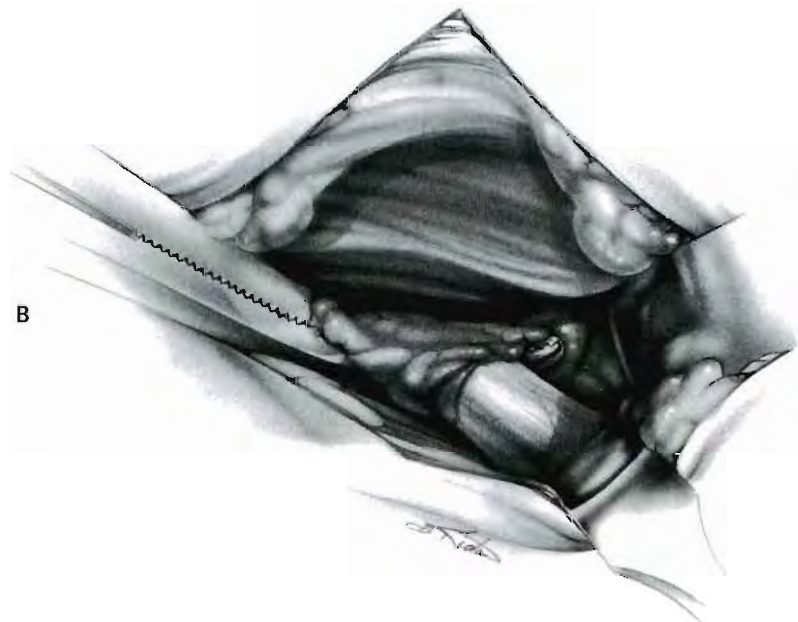


FIGURE 3-93. It is now relatively easy to divide the adductor brevis if this is the operative plan. Although many surgeons routinely pass an instrument behind this muscle before beginning to divide it, this can be difficult and cause unnecessary trauma if the muscle is large. Much of this muscle can be divided with the cautery current, leaving a much smaller posterior part that is easier to isolate and divide. Behind this muscle lies the adductor magnus muscle. It is covered by a layer of fascia, beneath which the posterior branch of the obturator nerve that supplies this muscle can be seen. It is important that this nerve not be injured or else all adduction will be lost.



A



B

FIGURE 3-94. If it is desired to divide the iliopsoas tendon, it can be done at this time. The surgeon should constantly consider **(A)** the orientation of the pelvis and the femur and the direction of the psoas tendon because it is easy to become confused at this stage. The leg should be held in about 70 degrees of flexion, 20 to 30 degrees of abduction, and slight internal rotation to make the exposure easier.

A long right-angled retractor is placed under the pectineus muscle **(A)**, which is retracted superiorly, while blunt dissection with the index finger identifies the lesser trochanter. A common error here is to go too far proximally and mistake the bulge of the inferior portion of the femoral head for the lesser trochanter. When the lesser trochanter is identified, it should also be possible to palpate the psoas tendon coming off of the lesser trochanter if the surgeon is properly oriented.

To expose the tendon, it is necessary to open the sheath that surrounds it by sharp dissection with a knife or scissors. This usually provides a glimpse of the tendon **(B, C)**, which can be pulled into better view with a right-angled clamp. Then, it can be sharply divided with a knife.

Note the cut ends of the adductor longus, the adductor brevis, and the gracilis **(A)**. The large posterior muscle remaining intact is the adductor magnus. Just posterior to this are the proximal insertions of the hamstrings.

The wound should be inspected for bleeding, and any bleeding that is found should be controlled. It is much easier, however, to accomplish hemostasis at each step. It is important to minimize hematoma formation in the dead space that is inevitably created. The deep fascia is closed with a running suture, and the deep crural fascia is closed with an interrupted suture. This provides a tight wound closure without puckering of the skin. This skin can be closed with a running subcuticular suture and the dressing applied. (*continued*)

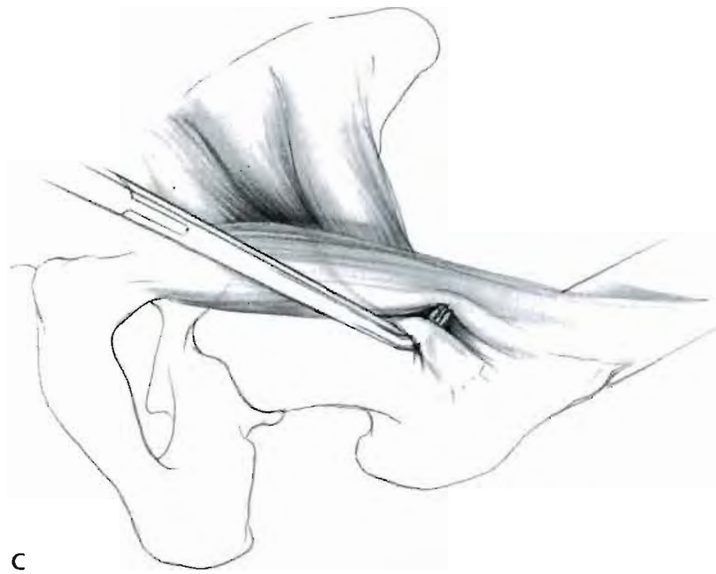

C

FIGURE 3-94. *(Continued)*

POSTOPERATIVE CARE

There are multiple choices for postoperative immobilization. Some authorities prefer little and may use temporary soft splints for the first week or two and then start physical therapy. Other surgeons prefer bilateral long leg casts with an abduction bay for 4 to 6 weeks. After removal of the casts, a short course of physical therapy is started.

In the first 24 to 36 hours after surgery, patients experience episodes of severe spasm and pain as they jerk awake from sleep. This has been impossible to eliminate completely with narcotics or other medication. The parents should be forewarned of this and the fact that it will pass. It is possible that continuous epidural anesthesia alleviates this, but its effectiveness and safety have not yet been proved.

References

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2. Bleck E. Orthopaedic management in cerebral palsy. Philadelphia: JB Lippincott, 1978:289.

3.18 ADDUCTOR TRANSFER

Transfer of the hip adductor origins posterior to the ischium was first reported by Stephenson and Donovan (1). The design of the operation resulted from their belief that the function of this group of adductor muscles (adductor longus, adductor brevis, and gracilis) was hip flexion, internal rotation, and adduction, which together created the troublesome problems seen in the hip in spastic cerebral palsy, and that their transfer would eliminate them as a source of the trouble. In the 31 patients presented, they observed no negative effects and thought that gait improved in many. Root and Spero also have commented on the beneficial effect on gait (2). They did not, however, use quantitative assessment of preoperative and postoperative gait; presumably, the adductor brevis was released along with the adductor longus and the gracilis muscles.

Because it is recognized that some degree of adduction is necessary for efficiency in gait, the real comparison of the effect on gait should be between transfer of the adductor origins and the release of the adductor longus and gracilis muscles only, leaving the brevis intact (3). Studies that have compared adductor release with transfer are not any different in preventing or correcting subluxation of the hip when radiographic criteria are used to show the effectiveness of these procedures (4,5).

The approach to the adductors is the same as described for adductor myotomy, with the following exceptions: the origins of the muscles must be isolated at their attachment to the bone, and the area of the ischium posterior to the gracilis muscle must be exposed (Figs. 3-95 to 3-97).

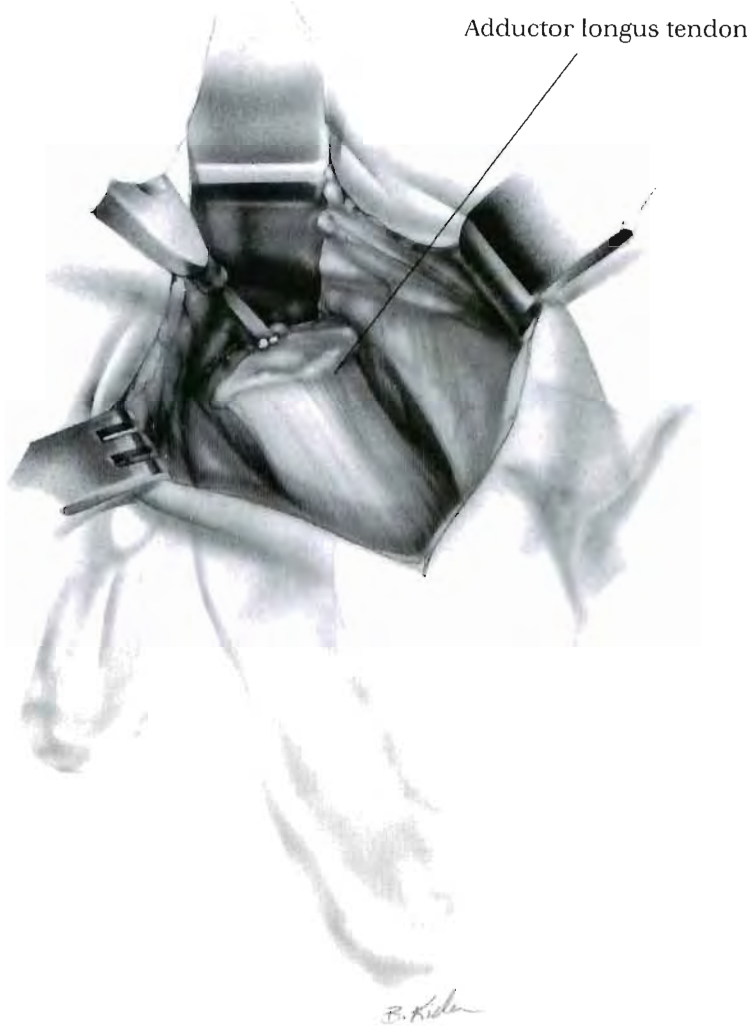

FIGURE 3-95. The origin of the adductor longus muscle is separated from its attachment using the cautery current. The anterior branch of the obturator nerve is then identified between the adductor brevis and pectineus muscle so that it can be protected. Next, the entire origin of the adductor brevis is removed from the bone. It is necessary to cut the muscle directly off the bone to preserve some strong tissue that will hold a suture.

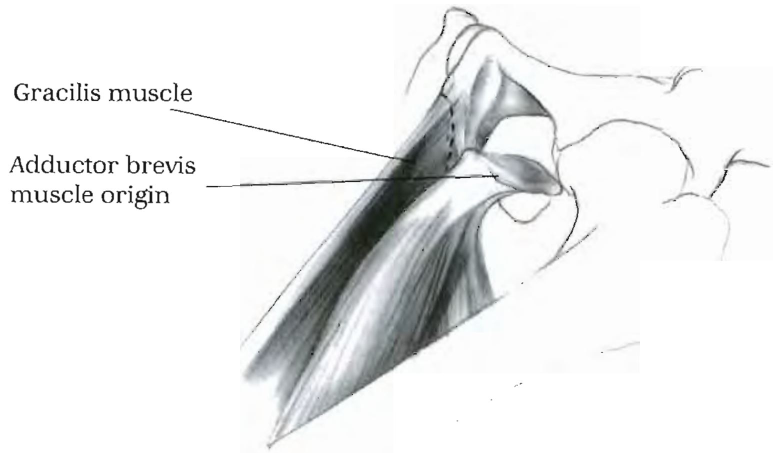

FIGURE 3-96. The gracilis is easy to identify and can be cut close to the bone with the cautery current, preserving its tendinous origin. Blunt finger dissection exposes the ischium posteriorly, just lateral to the insertion of the adductor magnus muscle.

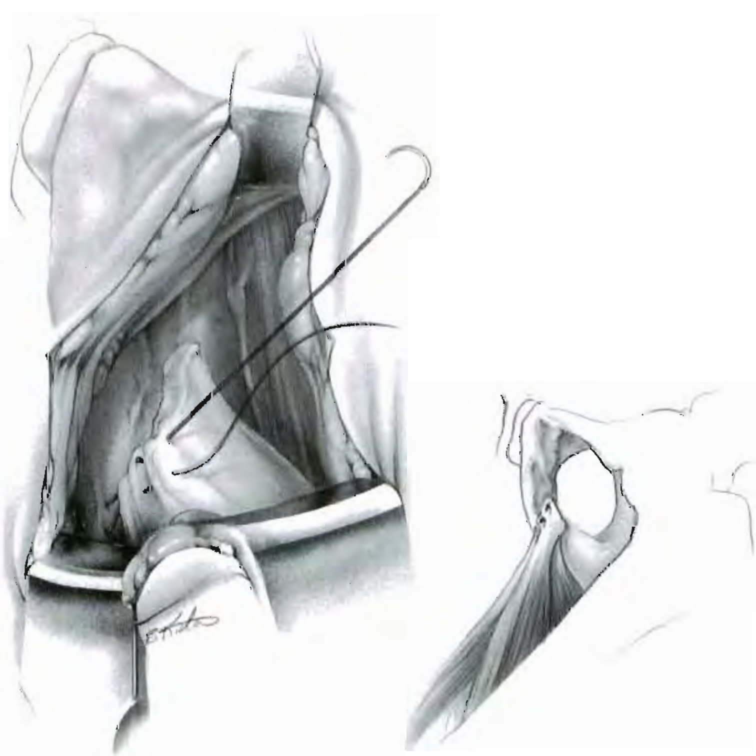

FIGURE 3-97. The three muscles, the adductor longus, the adductor brevis, and the gracilis, are pulled together by two strong absorbable sutures, which are then passed through the periosteum of the ischium and tied. The wound is then closed as in adductor myotomy.

POSTOPERATIVE CARE

The patient is held in a double spica cast for 6 weeks. After this procedure, the amount of abduction is less than that for adductor release to avoid tension on the repair; 25 degrees of abduction in each hip is sufficient.

References

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2. Root L, Spero CR. Hip adductor transfer compared with adductor tenotomy in cerebral palsy. J Bone Joint Surg [Am] 1981;63:767.
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3.19 PROXIMAL HAMSTRING TENOTOMY

Seymour and Sharrard (1) were the first to describe a proximal release of the hamstring tendons in patients with cerebral palsy. They and other authors who have found this a suitable technique have described performing this operation with the patient prone and the incision placed laterally to the ischial tuberosity or in the natal crease (2,3). Bell (4) reported performing this operation through an anterior approach, which has several advantages. Release of the adductor muscles and iliopsoas can be performed at the same time, and straight leg raising can be tested to be certain that the preoperative goals are achieved.

The proximal lengthening is mainly indicated in the patient with total-body involvement in conjunction with adductor myotomy and iliopsoas tenotomy for subluxating hip or in those patients with difficulty sitting because of tight hamstrings. It may also be the operation of choice for patients with a short stride length. Release of the proximal hamstrings can result in forward tilt of the pelvis with subsequent lordosis of the spine. This complication can be avoided by correction of hip flexion contracture before release of the hamstrings (Figs. 3-98 to 3-100).

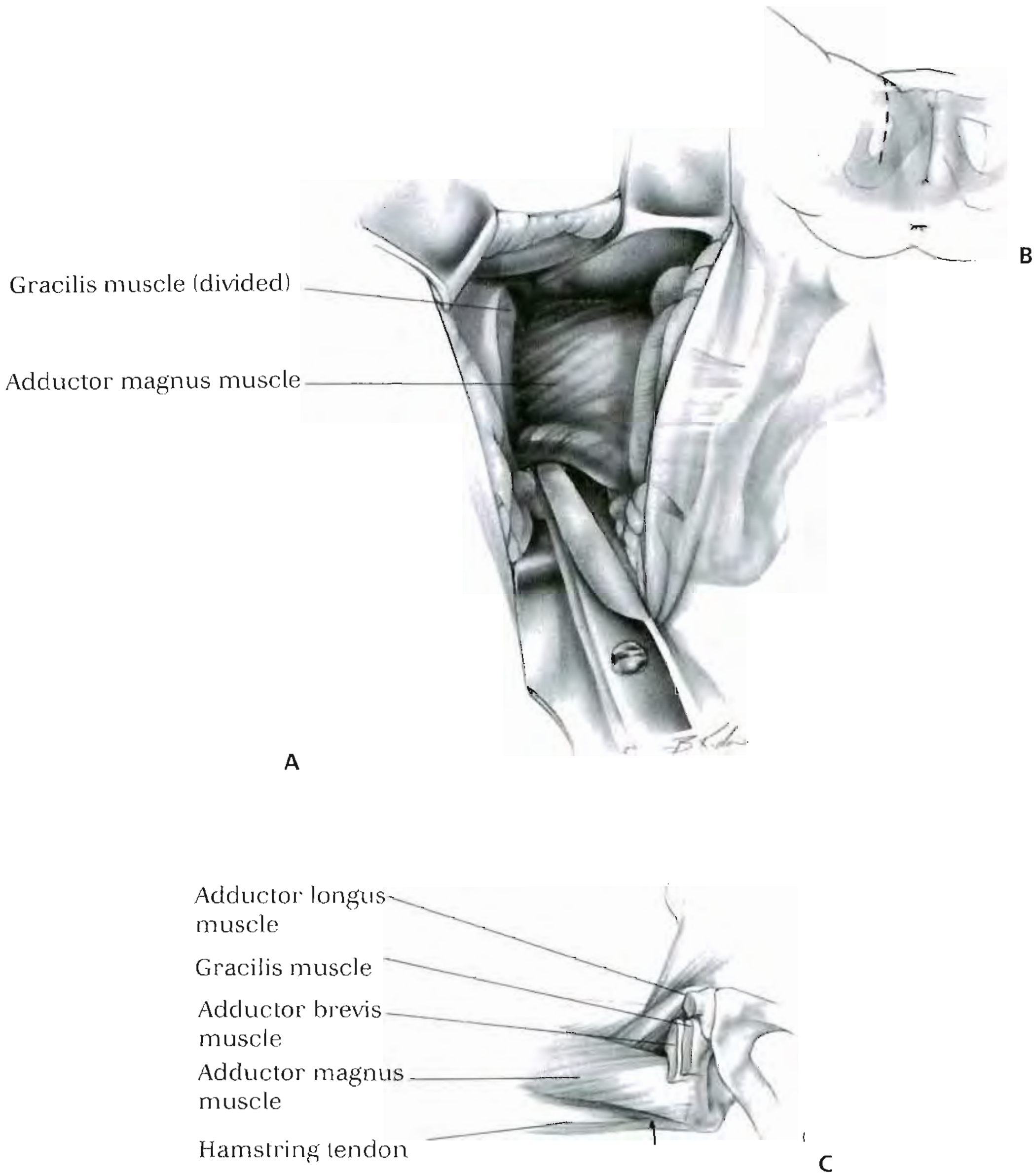

FIGURE 3-98. The patient is placed supine with a small folded towel or sand bag under the sacrum. The legs are draped free so that they can be moved through a full range of motion. The incision used is the same as for adductor tenotomy. A transverse incision is placed 1 cm distal to the groin crease starting at the adductor longus tendon and extending posteriorly **(A)**. The incision does not have to be excessively long because the skin is mobile in this region, and the incision can be shifted anteriorly and posteriorly without unduly stretching the skin. It is often easier to stand opposite the leg being operated on. In these illustrations, the surgeon stands on the left side of the patient and operates on the right leg with the head toward the right.

The gracilis muscle is divided, exposing the adductor magnus muscle that lies deep to it. The posterior border of the adductor magnus is identified, and the fascia along its posterior border is opened **(B, C)**. This fascial compartment should be opened sharply for an adequate distance so that the surgeon does not find himself or herself operating in a deep dark hole.

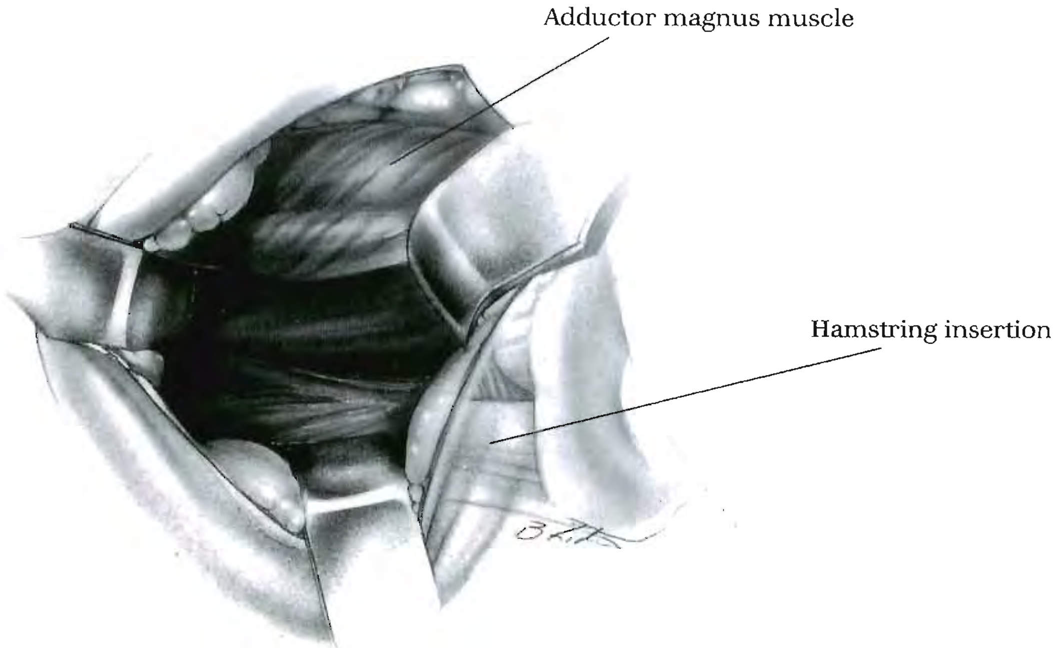

FIGURE 3-99. Retractors are placed to pull the adductor magnus anteriorly and laterally and open the interval on its posterior surface. At this point, the origins of the hamstring tendons can be palpated. Straight-leg raising demonstrates their tightness. The most medial tendon of origin is that of the semitendinosus muscle followed by the semimembranosus muscle and the biceps femoris muscle. These muscles need not be identified separately because they seem to have a common tendinous origin from the ischial tuberosity. The sciatic nerve lies anterior and slightly lateral to these muscles. Palpation should be used to ensure correct identification of the sciatic nerve. It does not become as tight as the hamstrings when straight-leg raising is performed, and unlike the hamstring tendons, it extends proximal to the ischial tuberosity.

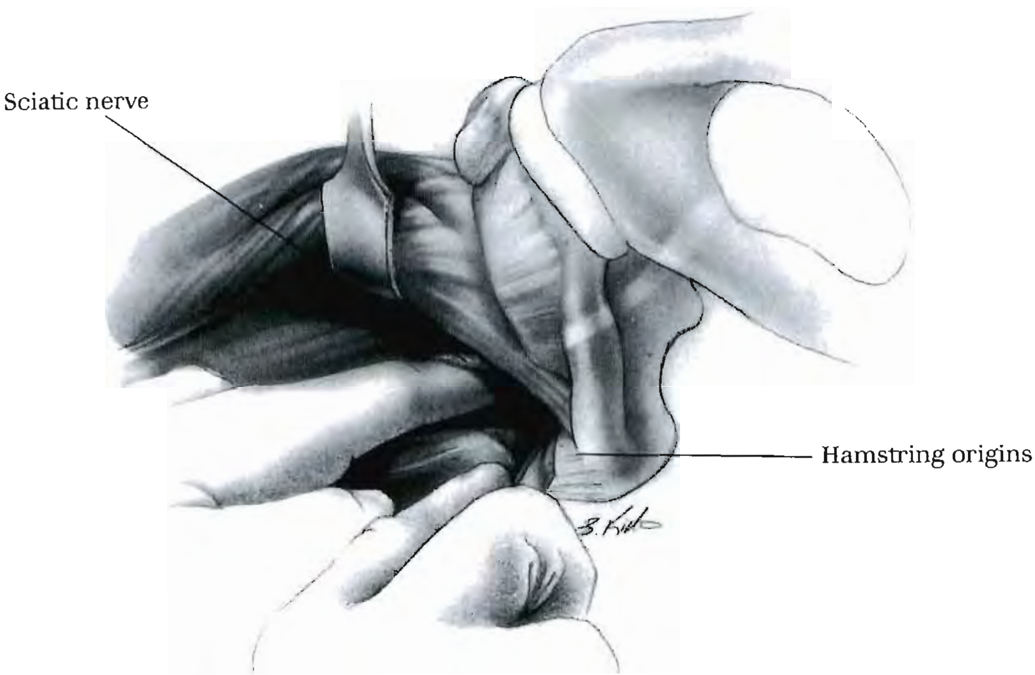

FIGURE 3-100. With the adductor magnus retracted anteriorly and laterally, a finger is inserted to palpate the sciatic nerve, elevate it, and push it laterally. An assistant performs straight-leg raising to place the tendons of origin of the hamstrings under tension, and the surgeon divides them by directing the knife posteriorly. The degree of correction and adequacy of the release can be assessed by the straight-leg-raising test.

POSTOPERATIVE CARE

The legs are immobilized in long leg casts with the knees straight but not hyperextended and a bar between the legs to maintain the desired degree of abduction. Therapy should be instituted as soon as the acute pain and spasm of the surgery subside. It consists simply of having the child begin sitting. If the iliopsoas tendon has been sectioned because of associated hip flexion contractures, sitting should be alternated with prone lying. Six weeks of immobilization is sufficient, and at that time, the casts are removed and therapy is continued.

References

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4

THE FEMUR

4.1 PLANNING AN INTERTROCHANTERIC OSTEOTOMY

MECHANICAL CONSIDERATIONS

Intertrochanteric osteotomy is probably the most common operation performed around the child's hip. It is used for a variety of conditions: congenital dislocation of the hip, acetabular dysplasia, Perthes' disease, congenital coxa vara, posttraumatic problems, and so forth. In addition, it is a deceptively easy operation to perform. Consequently, surgeons give little attention to the details of the osteotomy and often even less attention to the preoperative planning that is essential.

An intertrochanteric osteotomy can have one or several components. Among these are varus, valgus, extension, flexion, rotation, shortening, medialization, lateralization, and transfer of the trochanter. The indications for each of these components are found in a careful analysis of the physical examination and the preoperative radiographs. Altering the varus inclination of the femoral neck will have profound effects on the abductor lever arm as well as on the forces across the knee joint. Thus, in a particular circumstance, a varus osteotomy may require both greater trochanter transfer, to restore the articulotrochanteric distance, and medialization of the femoral shaft, to maintain an equal weight distribution through the medial and lateral compartments of the knee. An analysis of the permutations of intertrochanteric femoral osteotomy is beyond the scope of this discussion but can be found elsewhere (1–4).

For most of the intertrochanteric osteotomies in children in which the remainder of the limb is in normal alignment, it is usually sufficient to account for the following relationships in planning:

- Varus osteotomy results in genu varum and requires medial displacement of the femoral shaft to restore normal alignment to the leg.
- Valgus osteotomy results in genu valgum and requires lateral displacement of the femoral shaft to restore normal alignment to the leg.

A varus intertrochanteric osteotomy in the normal hip of greater than 25 degrees may need trochanteric transfer to maintain normal abductor muscle function. If a varus intertrochanteric osteotomy is performed in a hip with an already decreased articulotrochanteric distance, with a proximal physeal growth arrest as frequently seen in Perthes' disease, or in conjunction with a medial displacement pelvic osteotomy (e.g., a Chiari osteotomy), the need for transfer of the greater trochanter is increased.

A valgus intertrochanteric osteotomy lengthens the leg and increases the pressure on the femoral head (just as a varus osteotomy shortens the leg). Release of tight muscles or shortening of the bone should be considered.

PREOPERATIVE PLANNING

Preoperative planning in the detail described here is not usually necessary for an intertrochanteric varus osteotomy in a 2-year-old child undergoing reduction of a congenitally dislocated hip. It is essential for intertrochanteric osteotomies in the older child, however, because the mechanical effects are greater, the potential for remodeling is less, and derangements are more complex.

After clinical considerations, planning begins with a preoperative anteroposterior view of the pelvis and both hips. The normal hip should be taken in internal rotation to see the normal neck shaft angle. If there are other mechanical alterations in the alignment of the limb, a full-length radiograph from the hips to the ankles with the patient standing should be obtained on a 36-inch cassette. This permits the surgeon to examine the effect of the intertrochanteric osteotomy on the alignment of the limb and the need for additional osteotomies. Depending on the circumstances, additional radiographs with the limb in various positions can be obtained to determine the range of motion of the femoral head in the acetabulum and the best position for congruity. In some difficult cases, this is best done with an arthrogram. In our opinion, the degree of anteversion is best determined functionally by the rotation of the hip in extension rather than by radiographic means because the surgeon may be misled into correcting the radiographically determined amount of rotation only to find that the hip will not have sufficient internal rotation postoperatively.

The actual process of planning the osteotomy has been well described by Muller (5). This can be done on transparent paper or radiographic film. Two drawings are made on two separate sheets of paper or film (Figs. 4-1 to 4-6).

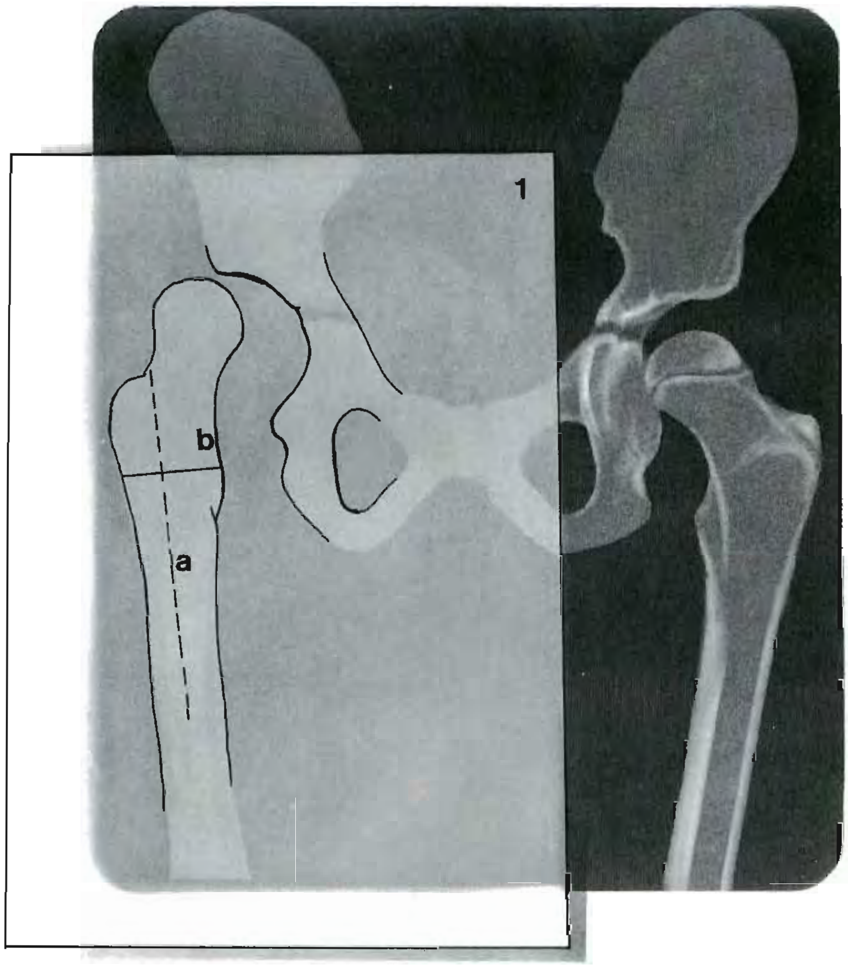

FIGURE 4-1. The first drawing traces the exact outline of the femoral head and the proximal shaft and the acetabulum. A dotted line (a) is drawn down the axis of the femoral shaft, and a second solid line (b) is drawn perpendicular to the dotted line just above the lesser trochanter. This is the line of the osteotomy.

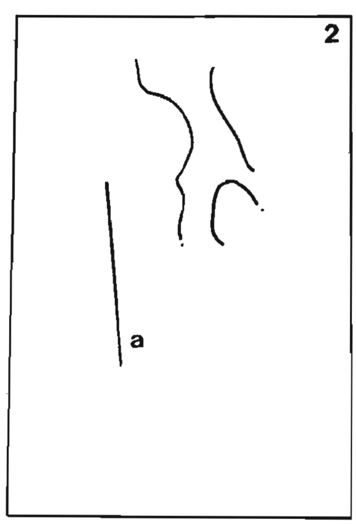

FIGURE 4-2. The second drawing, on a separate sheet of paper, traces the outline of the acetabulum. Again, draw in a line down the axis of the femoral shaft (a).

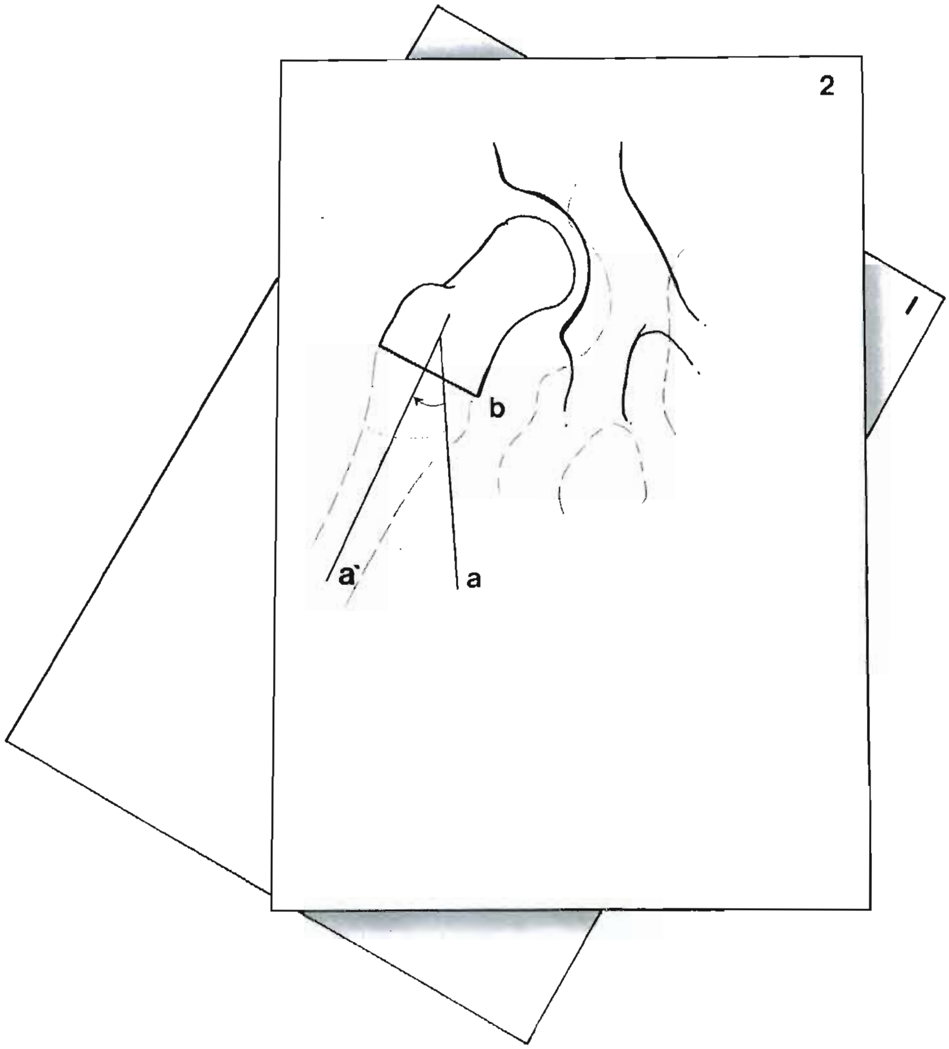

FIGURE 4-3. Superimpose the second drawing on the first one. Turn the drawings until the femoral head on the first drawing is in the desired relationship to the acetabulum of the second one. Draw in the proximal femur down to the osteotomy line (b) along with the new femoral axis (a') and the line of the osteotomy (b). The amount of varus that is needed to produce the desired result is found by measuring the angle between the original femoral axis (a) and the new femoral axis (a').

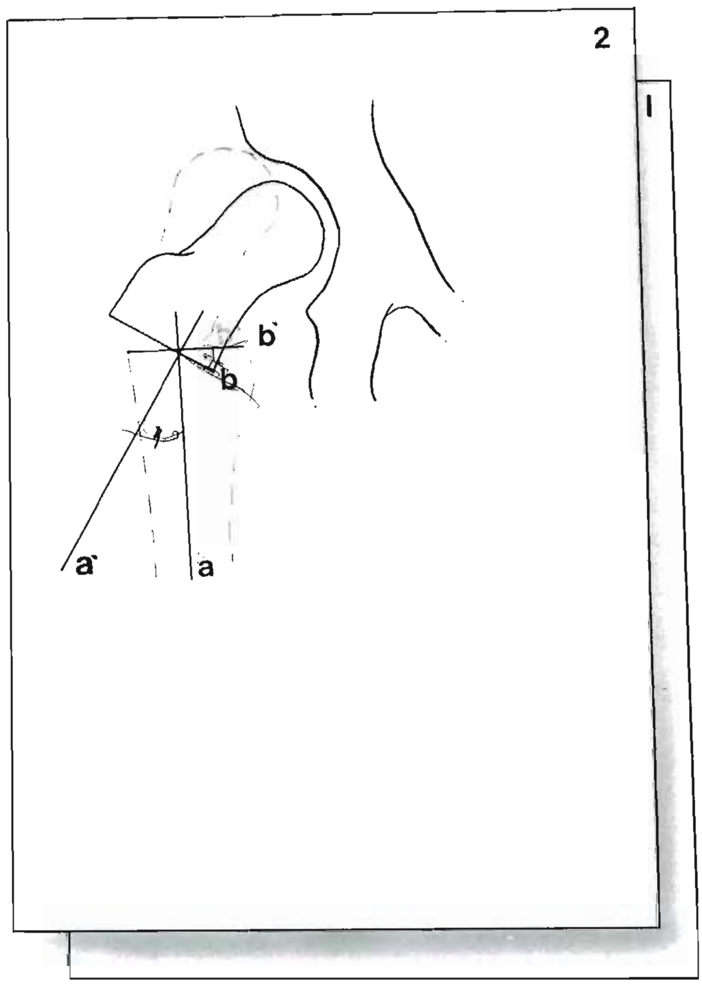

FIGURE 4-4. Superimpose the two drawings, aligning the femoral axis (a) of each. Slide the second drawing up and down until the intersection of a* and b of the second drawing intersects with line b on the first drawing. At this point, draw line b* perpendicular to the axis of the femoral shaft (a). This is the definitive osteotomy line. The wedge that lies below the definitive osteotomy line (b*) is the wedge that will be resected. Because the femoral axis remained superimposed, the correct amount of medial displacement is accounted for, and there is no change in the alignment of the leg.

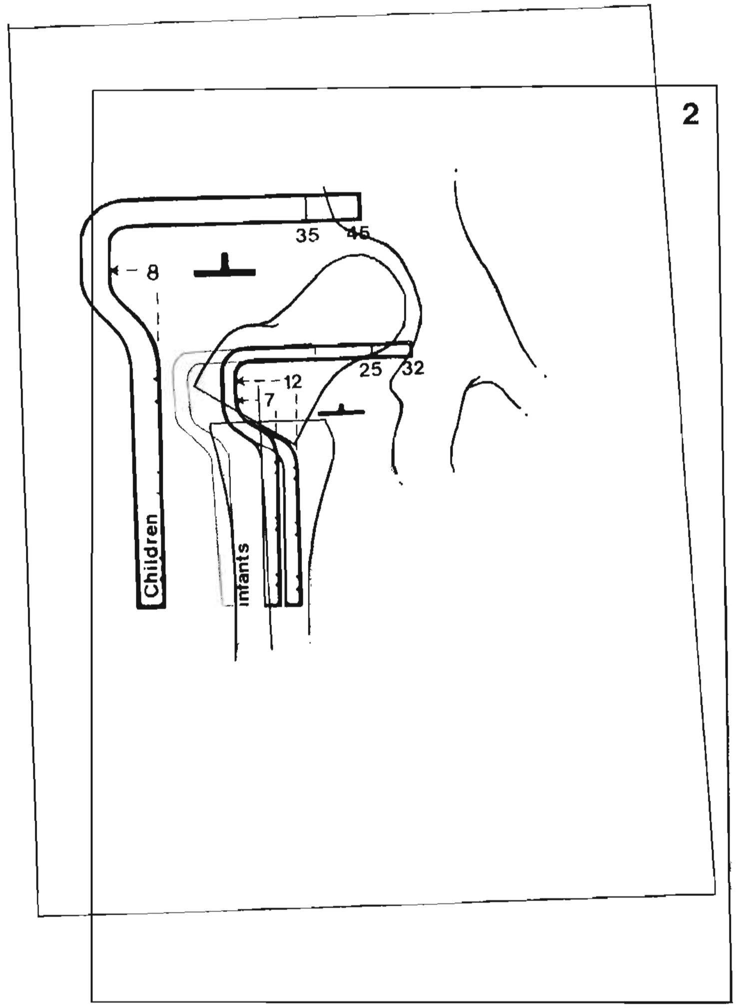

FIGURE 4-5. Draw in the distal part of the femur below the osteotomy line. If blade plates are used as a means of internal fixation, the insertion point of the chisel can be determined. For the adult-sized plate, this is about 12 to 15 mm proximal to the osteotomy site. For the juvenile and adolescent plates, this distance is less and can be determined from transparent templates or measurement from the desired size of plate. On this same drawing, the correct amount of displacement can also be measured and the correct plate selected. Finally, the desired length of the blade can be measured and the blade plate drawn in. This should represent what the postoperative radiograph will look like.

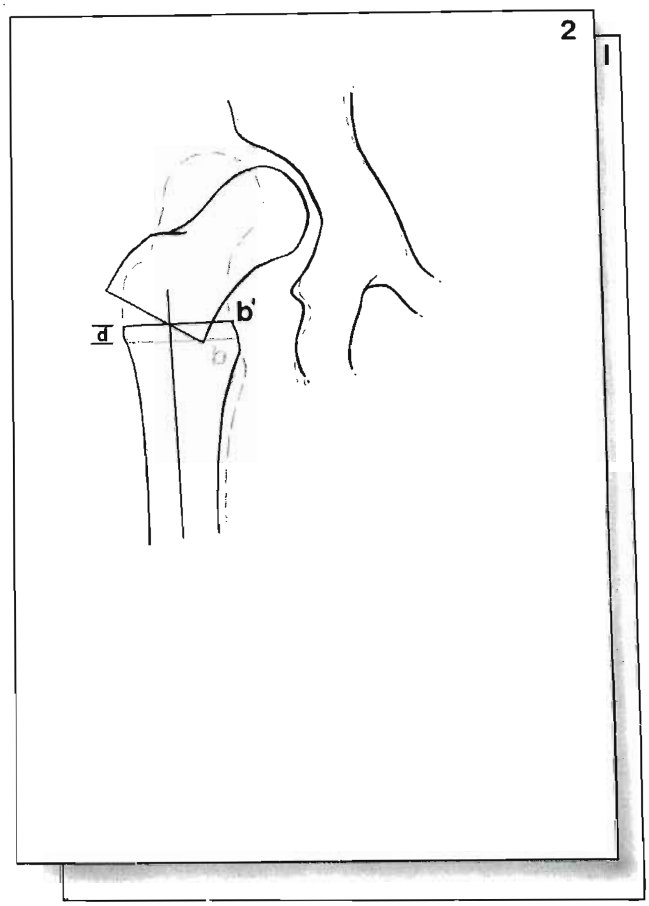

FIGURE 4-6. The amount of shortening that the osteotomy produces can be determined directly from the drawings. Align the femoral axis (a) of both drawings and superimpose the acetabular joint line of each. The amount of shortening produced (d) is the distance between the osteotomy line (b) of the first drawing and the definitive osteotomy line (b*) of the second drawing.

References

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2. Pauwels F. Biomechanics of the normal and diseased hip. Berlin: Springer-Verlag, 1976.
3. Schatzker J. The intertrochanteric osteotomy. Berlin: Springer-Verlag, 1984.
4. Oest O. Special diagnostic and preoperative planning of corrective osteotomies. In: Hierholzer G, Muller KH, eds. Corrective osteotomies of the lower extremity after trauma. Berlin: Springer-Verlag, 1985:29.
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4.2 PROXIMAL FEMORAL VARUS OSTEOTOMY IN CHILDREN USING A 90-DEGREE BLADE PLATE

As the child becomes older or larger, there is a need for both increased precision in the performance of the osteotomy and increased strength or rigidity of the fixation. Although accomplishing this may seem difficult to the novice, careful preoperative planning and a little experience gives the surgeon a degree of control and security that is not possible with most other methods of fixation (Figs. 4-7 to 4-16).

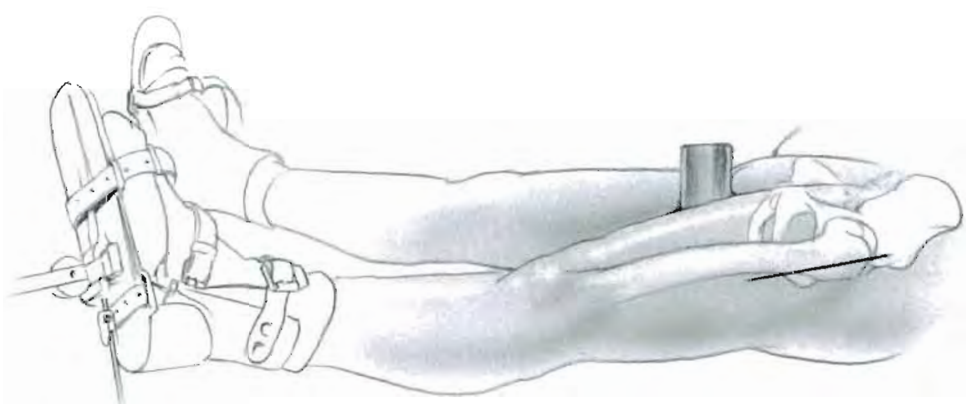


FIGURE 4-7. An intertrochanteric femoral osteotomy can be performed on a fracture table or a regular operating table with a translucent top, depending on the surgeon's preference. The surgeon without an assistant may find it easier to place the larger adolescent patient on a fracture table to control the leg more easily. Many fracture tables do not accommodate small children or permit bilateral hip surgery, making the choice obvious. To position children without a fracture table, it is useful to roll or fold a sheet with tape wrapped around it sticky side out. This prevents the child from shifting off of the bolster during the surgery.

The patient should be positioned so that anteroposterior and lateral views of the hip can be obtained on an image intensifier. This is necessary to confirm the correct placement of the osteotomy and blade of the fixation device. For the patient who is not on a fracture table, the hip may be placed in the "frog-leg" position.

The incision should extend from the tip of the greater trochanter as far distally as necessary. The distal extent of the incision depends on the fixation device used and the type of osteotomy; a shortening osteotomy requires a longer incision.

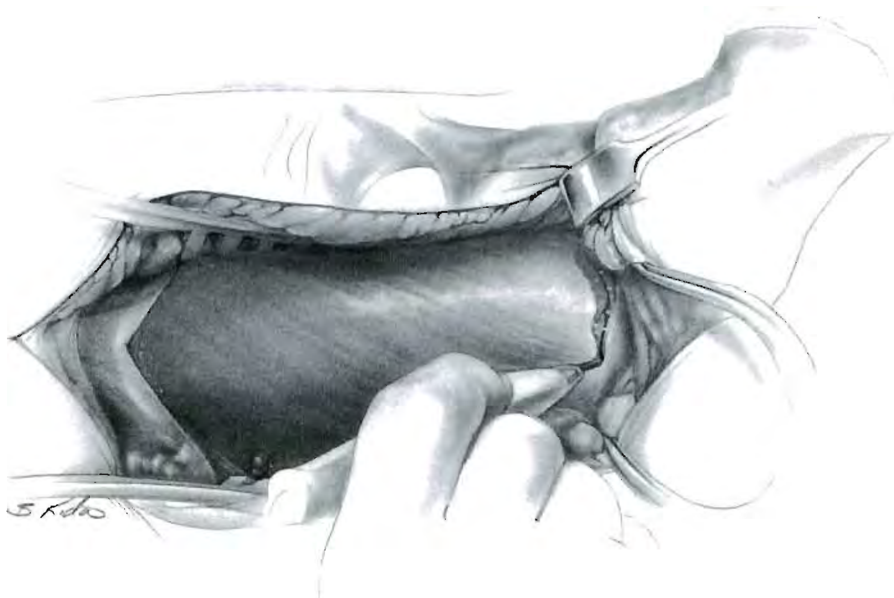


FIGURE 4-8. After the incision is deepened through the subcutaneous fat and fascia lata, two self-retaining retractors are placed beneath the fascia lata. The vastus ridge, where the vastus lateralis muscle inserts, is identified, and the cautery current is used to cut through this muscle. This cut in the vastus lateralis muscle should extend from the anterior femoral shaft posteriorly to the point where the insertion ends.

FIGURE 4-9. A sharp rake is used to pull up the belly of the vastus lateralis muscle, exposing its posterior attachment into the femur at the linea aspera. This muscle should be divided as close to this attachment as possible because all of the muscle posterior to the division will be denervated. It is not wise to cut the muscle at its attachment because two to three large vessels will be encountered coming around the posterior aspect of the femur to enter the muscle. Therefore, the muscle is divided about 1 cm anterior to its attachment. This can be done carefully, with the cautery current, or bluntly, by pulling a periosteal elevator from cephalad to caudad, tearing the muscle, and dividing the periosteum. With care and a bit of luck, these perforating vessels can be identified and cauterized before they are divided.

FIGURE 4-10. A periosteal elevator is used to elevate the entire quadriceps muscle group from the bone. In elevating the muscle from the medial side of the femur, care must be taken to stay in a subperiosteal location. A curved elevator (e.g., a curved Crego elevator) is helpful in this regard. The same is true in elevating the attachments off the linea aspera; a sharp elevator or osteotome should be kept in close contact with the bone, even elevating small fragments of bone. This reduces bleeding, which is greatest in this area. The amount of circumferential periosteal elevation that is done depends on the type of osteotomy performed. A varus osteotomy without rotation requires the least elevation, whereas a rotational osteotomy requires the most elevation, to allow the bones to rotate untethered by the linea aspera.

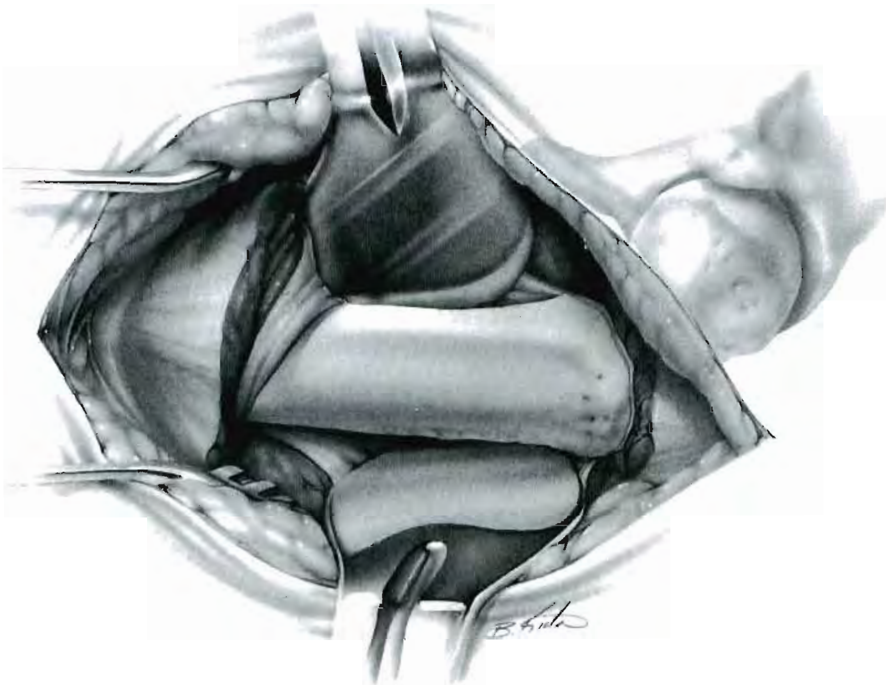


FIGURE 4-11. At the completion of the exposure, it should be possible to see the anterior femoral shaft as it curves medially, including the inferior curve of the femoral neck. It should be possible to palpate both the lesser trochanter and the anterior femoral neck with a finger. This exposure allows accurate placement of the blade plate and the osteotomy without the excessive use of radiographs.

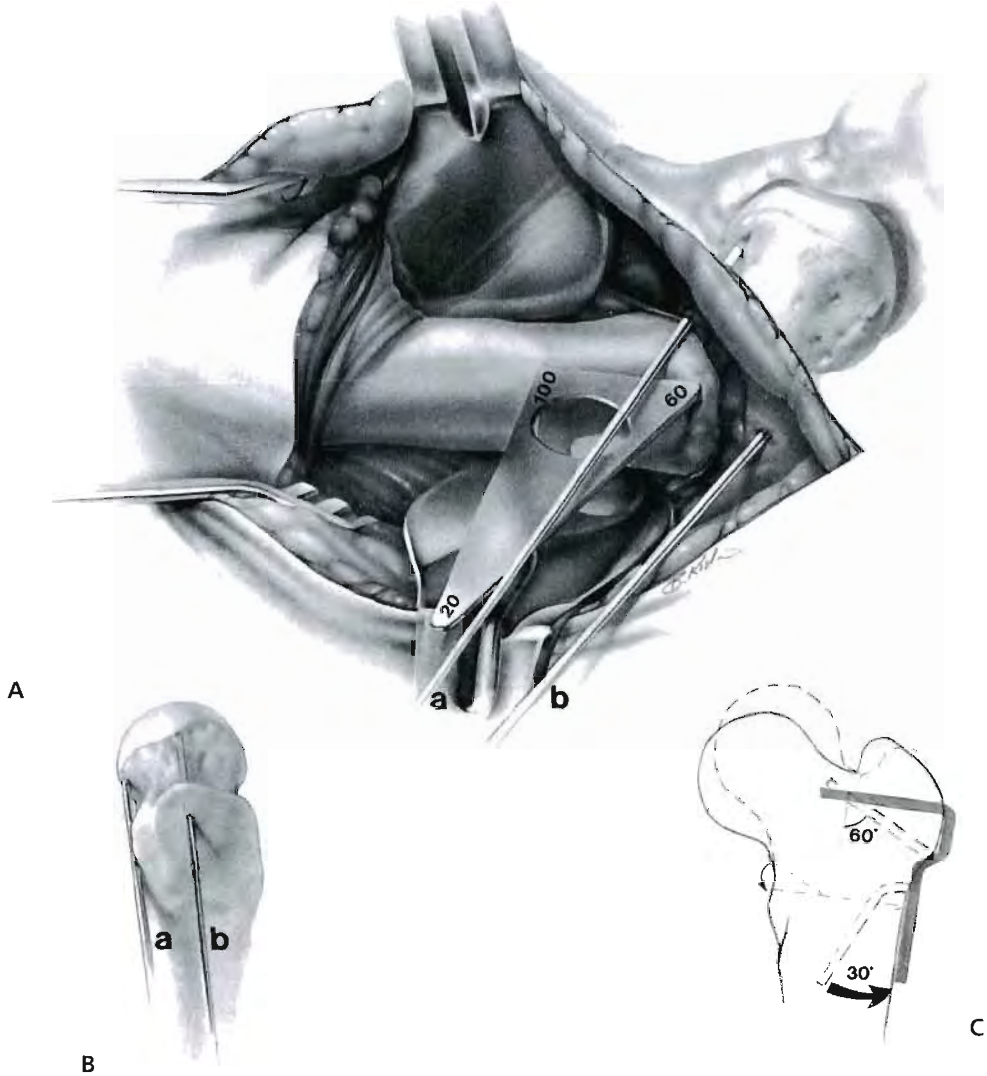


FIGURE 4-12. The first step after the exposure is to identify the correct placement of the osteotomy and determine the placement of the blade of the fixation device. First, a Kirschner wire (a) is passed on top of the femoral neck until it encounters the femoral head **(A, B)**. This determines the amount of anteversion of the femoral neck, which is important for the correct insertion of the blade.

The next step is to determine at which angle the blade should be inserted relative to the femoral shaft. The correct amount of angular correction is achieved when the blade is attached to the femoral shaft, and this in turn is determined by the angle at which the blade enters the femoral neck. If it is desired to create 30 degrees of varus with a 90-degree plate, then the blade should enter the femoral neck at a 60-degree angle to the femoral shaft. When the plate is attached to the femoral shaft, the amount of correction will be 30 degrees if the blade was inserted correctly **(C)**.

In this example, the template with the 60-degree angle is selected and placed on the femoral shaft. A second Kirschner wire (b) is drilled into the most cephalad portion of the femoral neck. The amount of anteversion in this wire is guided by the first wire that was placed along the anterior femoral neck (a) and the amount of varus and valgus is guided by the 60-degree angle on the template **(A, B)**. This wire serves as the guide for the direction of the seating chisel and the blade. The Kirschner wire on the anterior femoral neck (a) can now be removed.

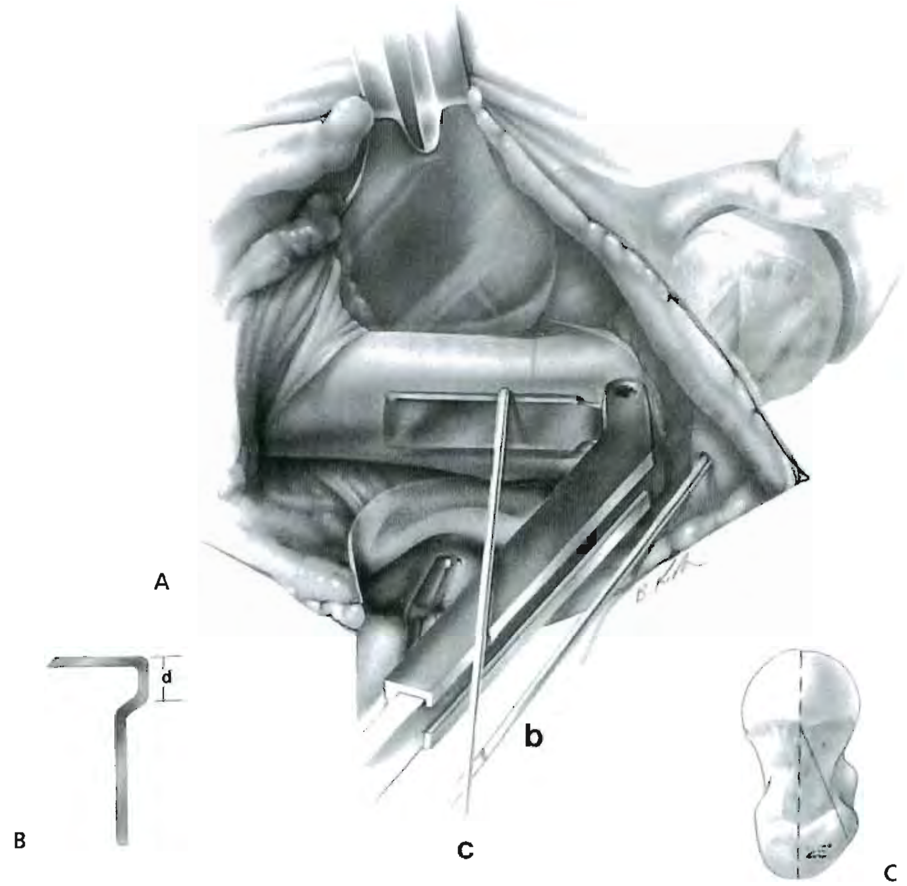


FIGURE 4-13. The next step is to mark the site of the osteotomy and insert the seating chisel. Palpate the lesser trochanter with a finger and drill a Kirschner wire (c) perpendicular to the femoral shaft into the center of the lesser trochanter. This should place the wire about 5 mm below the site for the osteotomy, which is just at the superior margin of the lesser trochanter. Keep this wire anterior so that it will not interfere with the seating chisel guide **(A)**.

In preparation for placement of the seating chisel, select the site where it will enter the bone. Its distance cephalad to the osteotomy is determined from the preoperative plan by the size of the blade plate to be used and can be confirmed by direct measurement of the plate. This distance is represented by d **(B)**.

It is important that the insertion point not be too far posterior, or the blade will cut out of the back of the femoral neck. Because the flat surface of the greater trochanter faces about 25 degrees more posteriorly than if it were perpendicular to the axis of the femoral neck and lies posterior to the femoral neck, it is easy to make this mistake **(C)**. The shape of the greater trochanter should be ignored and the chisel inserted in line with the femoral neck. To achieve this, it will seem that the chisel is starting far anteriorly on the greater trochanter.

When the correct insertion point is determined, the correct chisel for the plate being used is selected. If the large adult plate is used, it is best to open the cortex of the femur before driving the chisel in, but with the use of the adolescent and child plates, this is not necessary. The chisel guide is placed along the femoral shaft. This is essential to ensure that the plate will not lie anteriorly or posteriorly to the shaft after the plate is inserted. If flexion or extension is part of the osteotomy, the angle that this guide forms either anteriorly or posteriorly to the femoral shaft determines the amount of flexion or extension. If necessary, the rotation of the chisel can be controlled with the slotted hammer. The chisel is now driven into the femoral neck using both the chisel guide and the Kirschner wire (b) as guides. The depth of the chisel is read from the scale on the bottom side and correlated with the preoperative plan. At this point, an anteroposterior image can be obtained to check the placement of the seating chisel, and the osteotomy site is marked by the Kirschner wire (c). Here, we always place a pin directly up the center of the neck and take a frog-leg anteroposterior radiograph to be certain where the pin is. This takes away any chance of not being dead center.

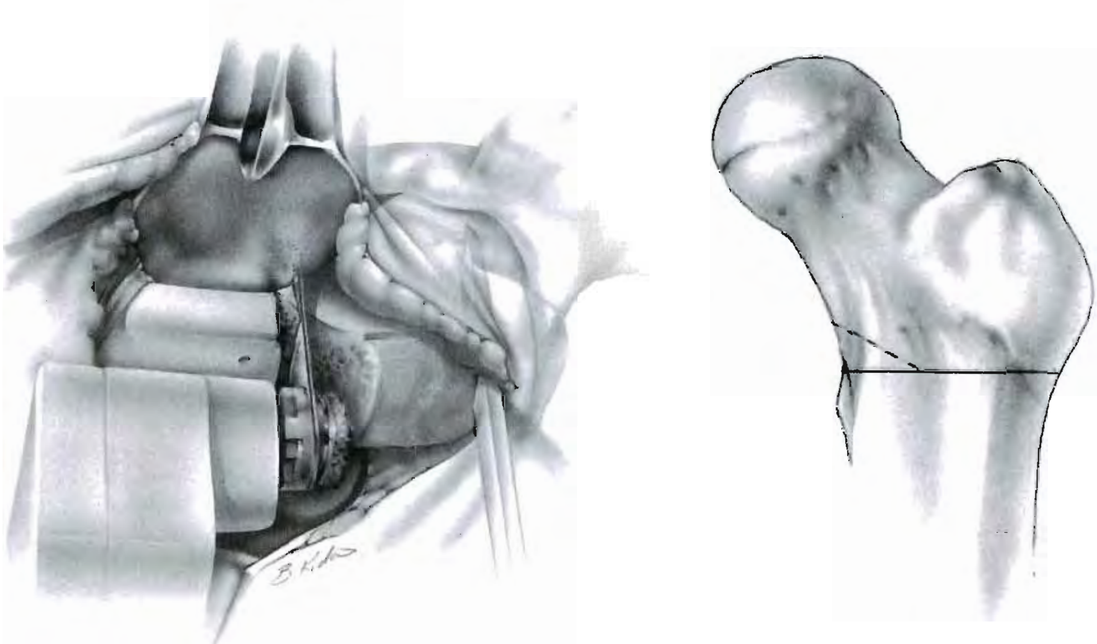


FIGURE 4-14. Before making the osteotomy cut, it is wise to score the anterior femoral shaft longitudinally with the saw to serve as a mark that will indicate whether any rotation has occurred. If rotation of the osteotomy is planned, pins can be placed as described for rotational osteotomy of the proximal femur. The osteotomy is performed by making the first cut perpendicular to the femoral shaft. This cut should be just cephalad to the lesser trochanter. The soft tissues are protected by placing two Bennett or similar retractors around the bone. An oscillating saw is used to cut the bone. Copious irrigation is used during the cutting to reduce heating of the bone.

After the first cut is completed, the seating chisel is used to tip the proximal fragment into varus. Beginning halfway across the bone, the desired wedge is removed from the medial side. This completes the osteotomy. How do you ensure that the wedge you cut off medially is exactly 30 degrees? We generally "eyeball" this cut.

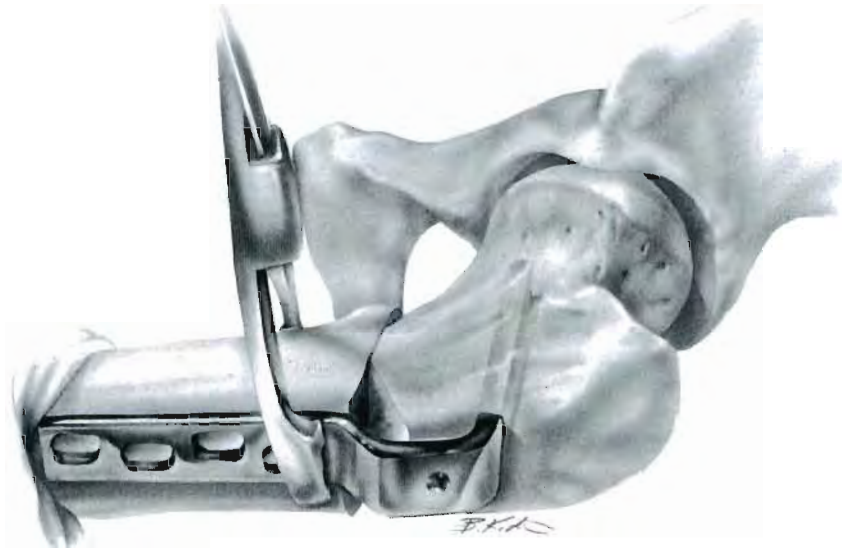


FIGURE 4-15. The seating chisel is removed, and the blade plate is inserted. The blade should be started by hand and then softly tapped with a mallet to avoid starting a false channel. After it is fully seated, it is held to the femoral shaft with a bone clamp. If rotation of the osteotomy is desired, it is accomplished at this point. The plate then is fixed to the femoral shaft with the appropriate screws. The wound is closed by reattaching the vastus lateralis to its origin at the base of the trochanter and closing its fascia posteriorly. A drain is placed deep to the fascia lata, and it and the remainder of the wound are closed in a routine manner.

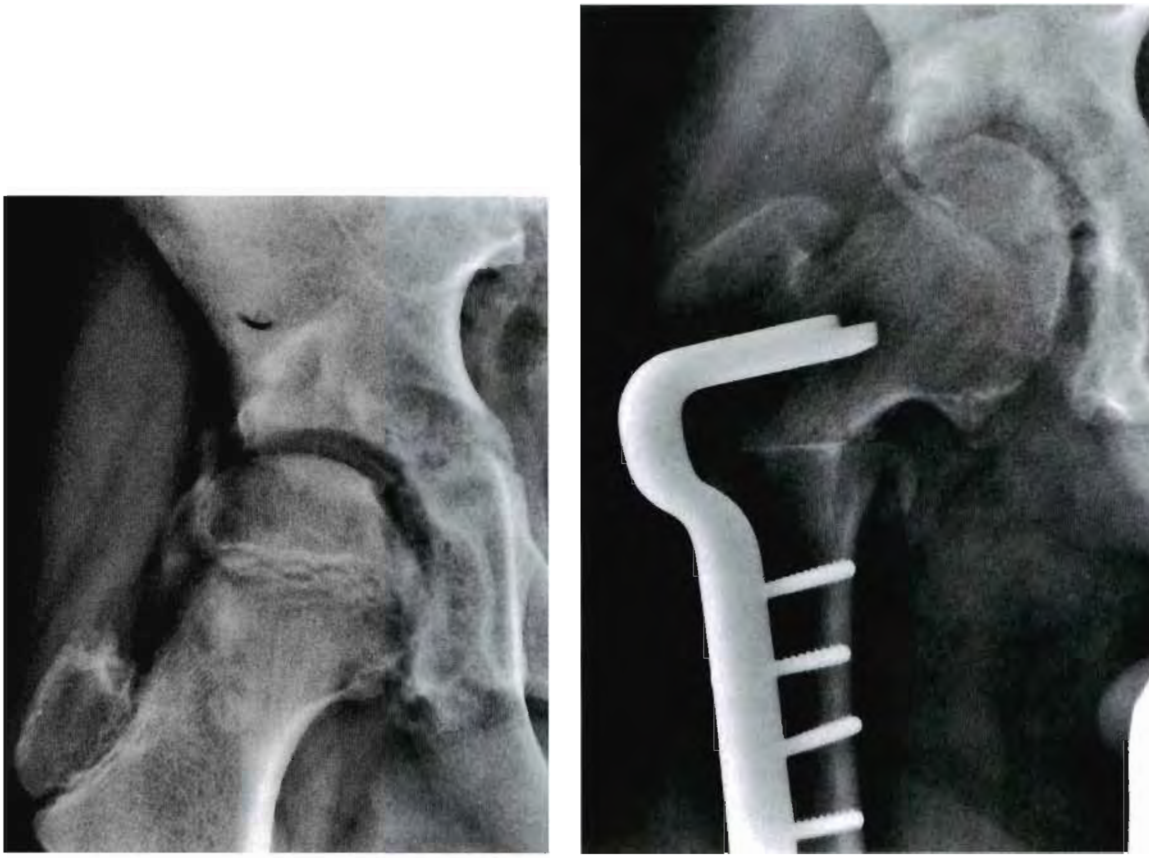

A B

FIGURE 4-16. CP is a 14-year-old boy who presented with a painful hip 1 year after a motor vehicle accident in which he sustained an unrecognized posterior dislocation of the hip with a posterior acetabular fracture **(A)**. He was treated successfully with a varus and rotational osteotomy of the proximal femur, which eliminated the posterior subluxation and consequent synovitis. The fixation is strong enough to permit immediate, protected weight bearing **(B)**.

POSTOPERATIVE CARE

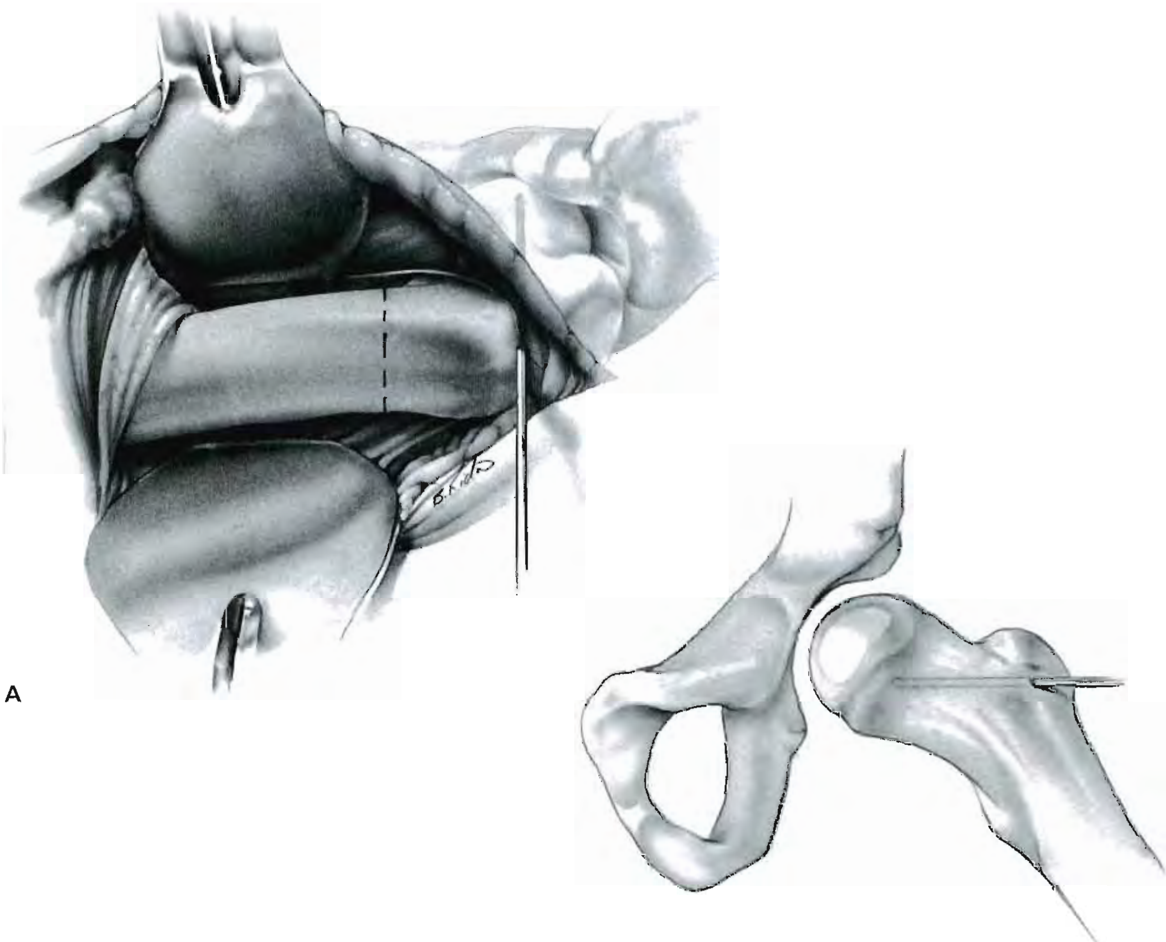
Subtrochanteric osteotomies usually take 6 to 8 weeks to heal. The degree of immobilization or bed rest during this period depends on many factors: the size of the child and hence the strength of the plate that was used, the strength of the bone, the stability of the osteotomy, and the ability of the patient to cooperate with partial weight bearing. We prefer to place small children in a one-leg spica cast at bed rest. Cooperative children between 8 and 12 years of age can usually be left out of a cast at bed rest or given the use of a wheelchair. In the adolescent group, the fixation is usually strong enough to permit a partial weight-bearing crutch gait if the patient is cooperative. Full weight bearing is permitted in all age groups when there is radiographic evidence of bony union.

4.3 PROXIMAL FEMORAL OSTEOTOMY IN INFANTS USING THE ALTDORF HIP CLAMP

The Altdorf hip clamp is a 130-degree angled malleable blade plate. Wagner (1) has described the technique for using the plate, which greatly simplifies an intertrochanteric osteotomy. Wagner does not use a cast with this plate unless other procedures dictate it.

This plate is most useful in children younger than 5 to 6 years of age who are undergoing a femoral osteotomy in conjunction with treatment of congenital dislocation of the hip. It can also be used in children up to 12 years of age (2). Although this plate is designed for varus osteotomies, the fact that it can be easily bent makes it ideal for the treatment (by valgus osteotomy) of developmental coxa vara in small children (Figs. 4-17 to 4-23).

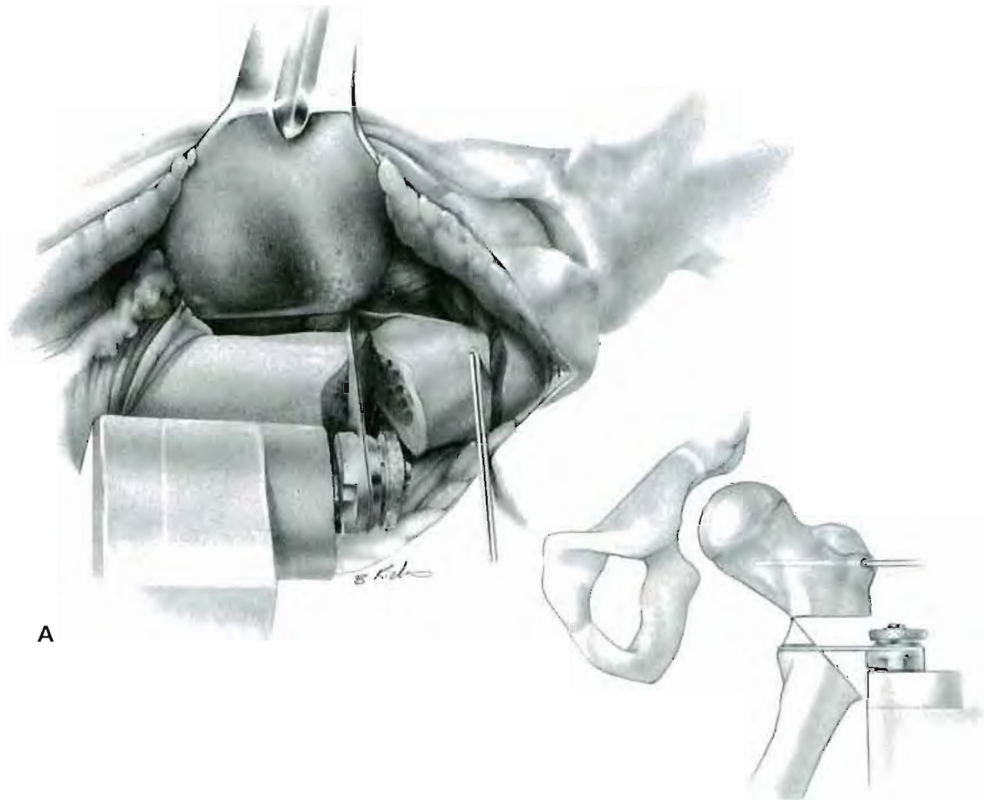
FIGURE 4-17. The Altdorf clamp is an angled blade plate of 130 degrees. The blade is bifurcated, and the entire plate is malleable. The plate comes in three sizes: 9-, 10.5-, and 12-mm wide, with different blade lengths. There are two oval holes on the side plate, which in the smaller two plates accommodate the 3.5-mm cortical screws and in the larger plate the 4.5-mm cortical screws. There is also a round hole at the cephalad end of the plate that is designed to accept a cancellous screw to hold the blade securely in the proximal fragment.



A

B

FIGURE 4-18. It is easiest to perform this operation on a regular flat radiolucent operating table. After the intertrochanteric region of the femur is exposed, the leg is manipulated to place the femoral head and neck in the desired position. This can be ascertained by an image intensifier. A Steinmann pin heavy enough to control the proximal fragment is then drilled into the proximal fragment. This pin should start just below the epiphysis of the greater trochanter and be parallel to the floor and perpendicular to the median plane of the body **(A, B)**. When this pin is returned to this position after the osteotomy, the femoral head is returned to the desired relationship with the acetabulum. Here in the abduction, internal rotation radiograph, we try to restore Shenton's line as a guide to where we want to wind up, just like your figure B and Figure 4-23.



A

B

FIGURE 4-19. The osteotomy cut is then made parallel to this pin and just above the lesser trochanter. The leg is then placed in a neutral position relative to the body, and a medial portion of the distal fragment is removed perpendicular to the femoral shaft (the drawing does not show the perpendicular cut) **(A, B)**. In small children who are younger than 3 to 4 years of age, a single osteotomy cut perpendicular to the femoral shaft and just proximal to the lesser trochanter can be made. As the proximal fragment is tipped back up into the desired position and displaced medially, the spike it forms tends to stabilize in the canal of the distal fragment **(A)**. Release of the iliopsoas is also particularly important.

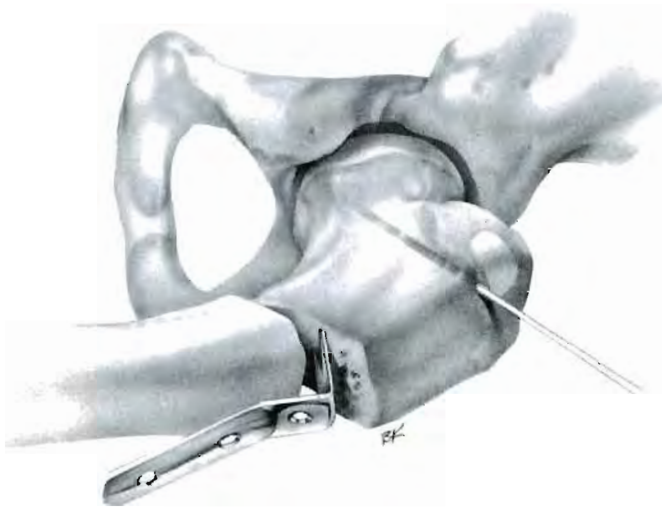


FIGURE 4-20. The angle of the Altdorf clamp is 130 degrees, but the clamp can be bent with pliers or plate benders to the required angle. In most cases of varus osteotomy, the 130-degree angle is ideal. The Altdorf clamp is designed to be pushed into the cut surface of the proximal fragment and not through the lateral cortex. To accomplish this, the proper size of clamp is grasped with the holding device.

Medial displacement is controlled by the point at which the splines of the clamp enter the proximal fragment. The more medially the splines enter the proximal fragment, the more medially the displacement achieved. The amount of varus achieved depends on the angle at which the blade enters the femoral neck. To judge the angle for insertion of the blade, the fragments are held in the desired position while the splines are first pushed into the cancellous bone of the femoral neck and then impacted with a mallet.

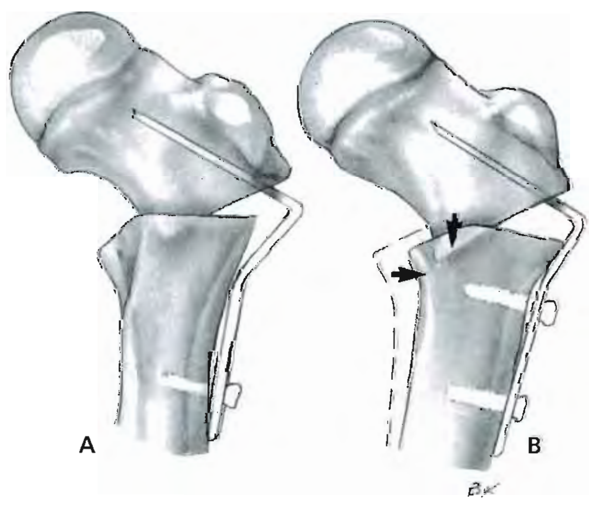


FIGURE 4-21. After the bifurcated blade is inserted, the osteotomy fragments are brought together in a position of slightly exaggerated medial displacement and slightly less varus than planned.

This should result in the distal tip of the plate touching the femoral shaft, but the proximal part of the plate will not be in contact with the shaft. The plate is first attached to the femoral shaft through the most distal screw hole **(A)**. Next, the screw is placed in the middle hole on the plate. As this is tightened, it pulls the shaft laterally and pushes the proximal fragment into more varus, producing interfragmentary compression **(B)**.

FIGURE 4-22. Finally, a 4-mm cancellous screw is inserted through the proximal round hole into the proximal fragment. This screw should not be longer than the bifurcated blade to avoid penetrating the physeal plate.

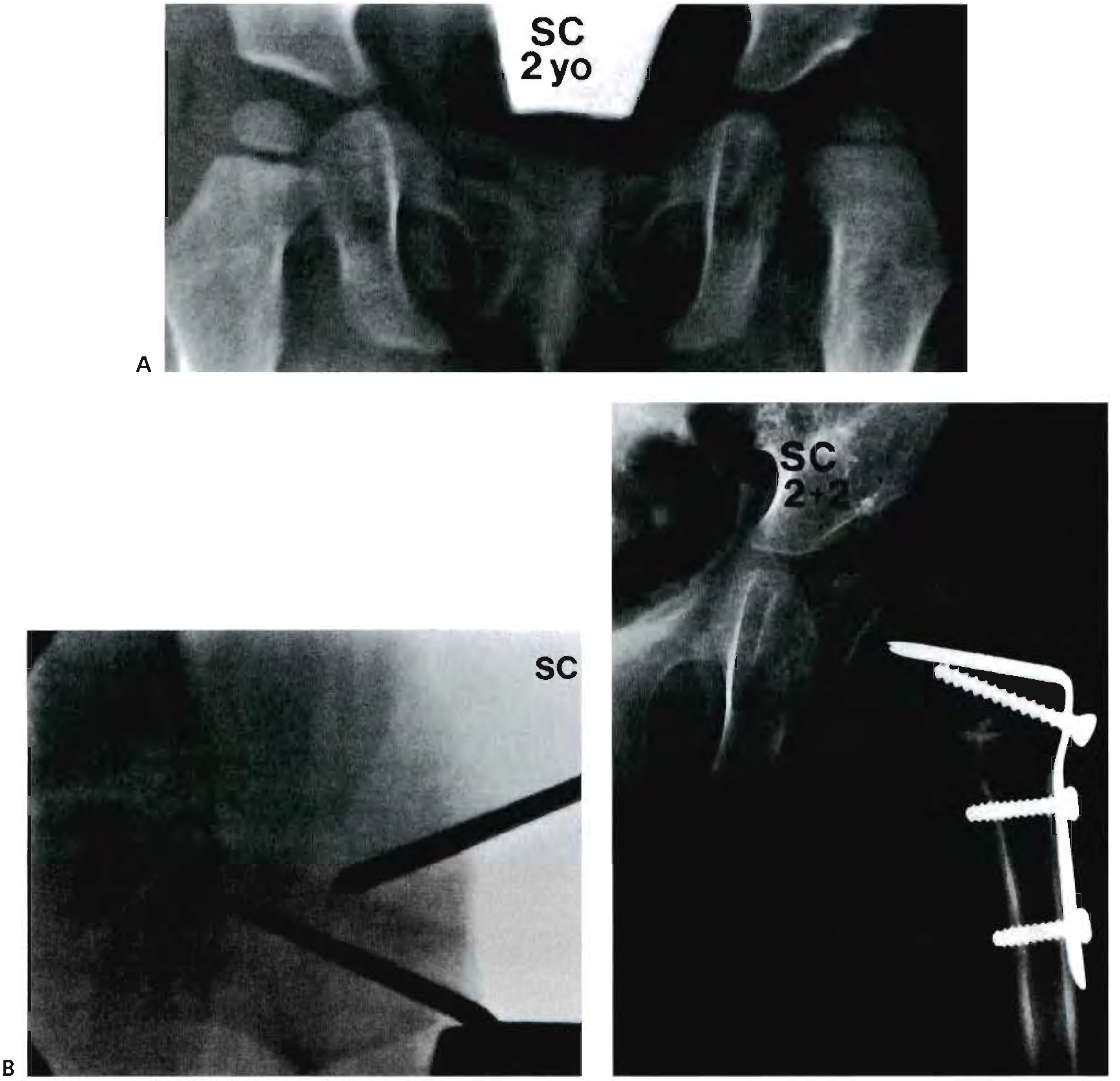


FIGURE 4-23. SC is a 2-year-old girl who underwent a closed reduction of the left hip at 3 months of age. Radiograph **(A)** showed persistent widening of the joint and failure of the acetabulum to remodel. A varus and rotational osteotomy was performed. The position of the femur was ascertained interoperatively by image intensifier **(B)**. The position of the femoral head in relation to the acetabulum and the healing osteotomy is shown 6 weeks after surgery **(C)**.

POSTOPERATIVE CARE

The fact that this method of fixation is used most often in young children in combination with other procedures for congenital dislocation of the hip means that a cast is usually required. In addition, the difficulty in executing this osteotomy to perfection, which is what produces the compression and stability (along with the malleable plate and only two screws for fixation), tends to make most surgeons uncomfortable treating children without cast immobilization.

References

1. Wagner H. Osteotomies for congenital hip dislocation. In: The hip: proceedings of the fourth open scientific meeting of The Hip Society. St. Louis: CV Mosby, 1976:45.
2. Alonso JE, Lovell WW, Lovejoy JF. The Altdorf hip clamp. J Pediatr Orthop 1986;6:399.

4.4 VALGUS OSTEOTOMY FOR DEVELOPMENTAL COXA VARA

Valgus osteotomy of the proximal femur is indicated in a variety of conditions over a wide range of childhood and adolescent disorders. Although the planning of a valgus osteotomy is done in the same way as for a varus osteotomy, the techniques are more varied and the successful execution more difficult. Among the technical difficulties encountered are the lack of appropriate internal fixation devices for children and the difficulty in lateralizing the distal fragment.

The many methods reported in the literature for correction of coxa vara in the smaller child, the paucity of published radiographs of actual osteotomies, and especially the lack of adequate correction in many reports speak to the difficulty of this procedure. This chapter illustrates several techniques for the correction of developmental coxa vara.

There is no one correct method, and several work well if executed correctly. There are more variations than can be illustrated here, but these techniques have proved useful to us. It is important to recognize the degree of correction that is necessary and to achieve that at the time of surgery. In addition, the retroversion that is usually present may need to be corrected by internal rotation of the distal fragment at the time of osteotomy.

The Pauwels Y-shaped osteotomy (1,2) is illustrated first because the planning involved in this osteotomy aids the surgeon in understanding the conversion of abnormal to normal mechanics (Figs. 4-24 to 4-32).

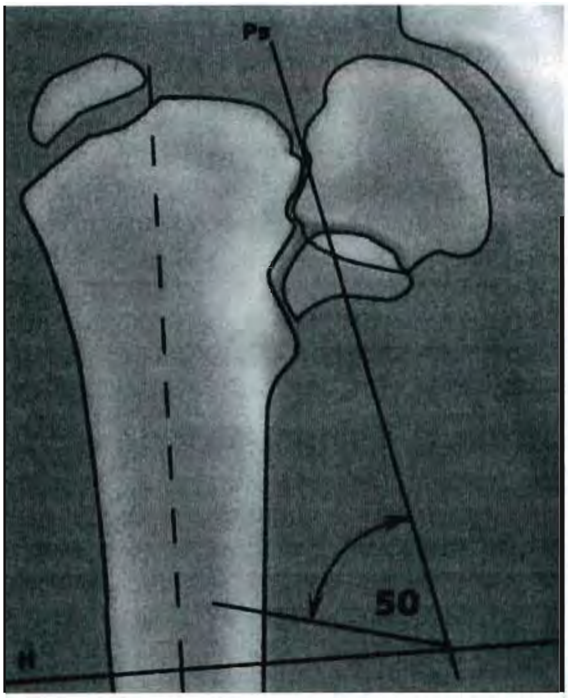


FIGURE 4-24. The Pauwels osteotomy is planned to place the physis perpendicular to the direction of the resultant compressive forces (16 degrees off the horizontal), eliminating the shearing forces. In addition, the diaphysis is used to enlarge the proximal end of the femoral neck. The osteotomy does not allow for correction of rotation.

The planning of the osteotomy is similar to planning for other osteotomies. A radiograph centered on the femoral head and in the proper degree of rotation is used for the tracing. First, the proximal femur and its axis, the acetabulum, and the physis are outlined on tracing paper. Three lines should be drawn on this outline. First, draw a horizontal line several centimeters below the lesser trochanter perpendicular to the femoral shaft (H). Second, draw a line through the physis intersecting H (Ps). Third, draw a line 16 degrees from the horizontal H line. This will place the physis at 16 degrees, which is perpendicular to the direction of the resultant compressive force. The angle formed by this third line and Ps is the size of the wedge to be removed for correction. In this illustration, this is 50 degrees.

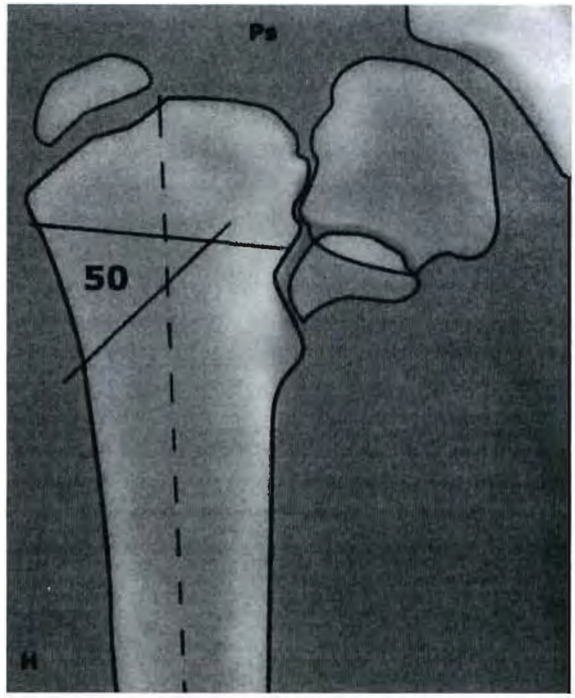
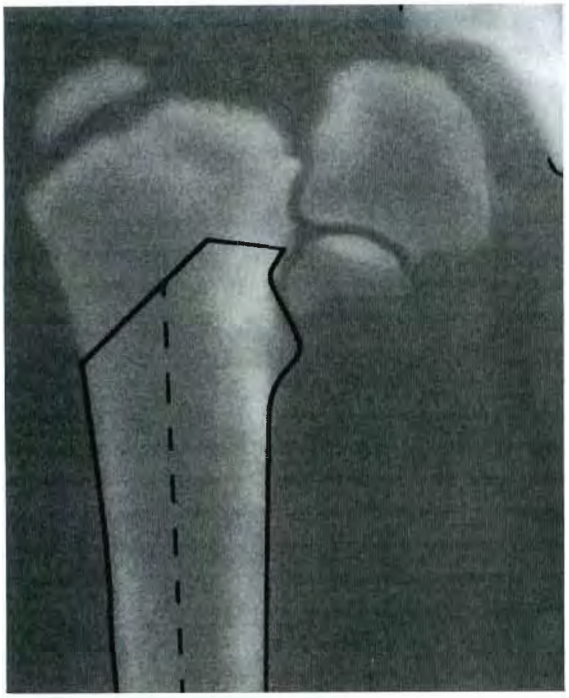
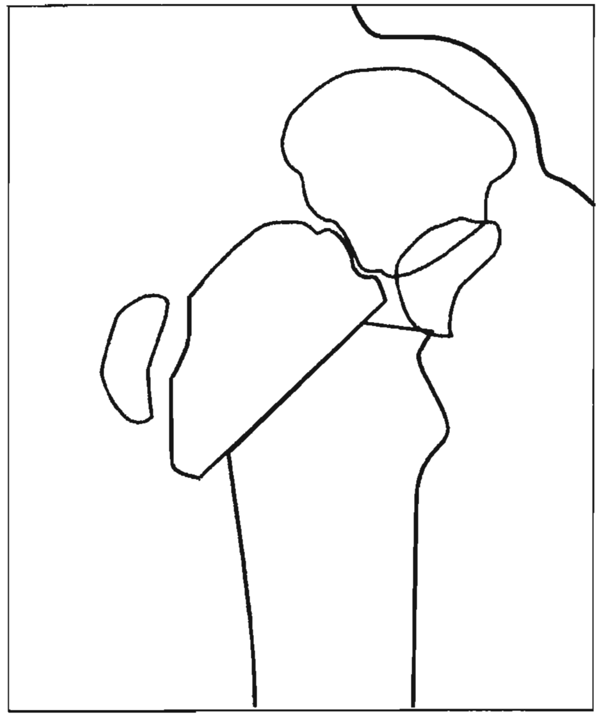


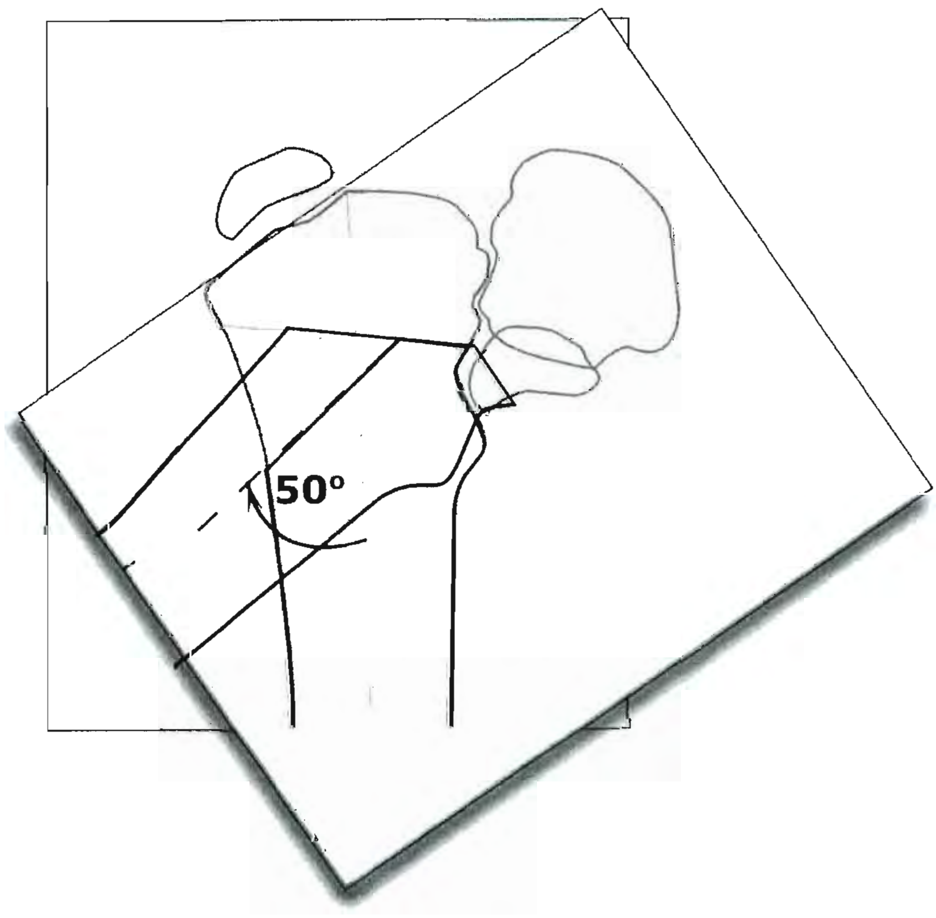
FIGURE 4-25. The upper cut of the osteotomy is now drawn so that it reaches the physis in what Pauwels called the *region of resorption.* The inferior cut is then marked so that it intersects the upper cut at a point that leaves a portion of the diaphysis equal in width to the width of the triangular fragment.



A



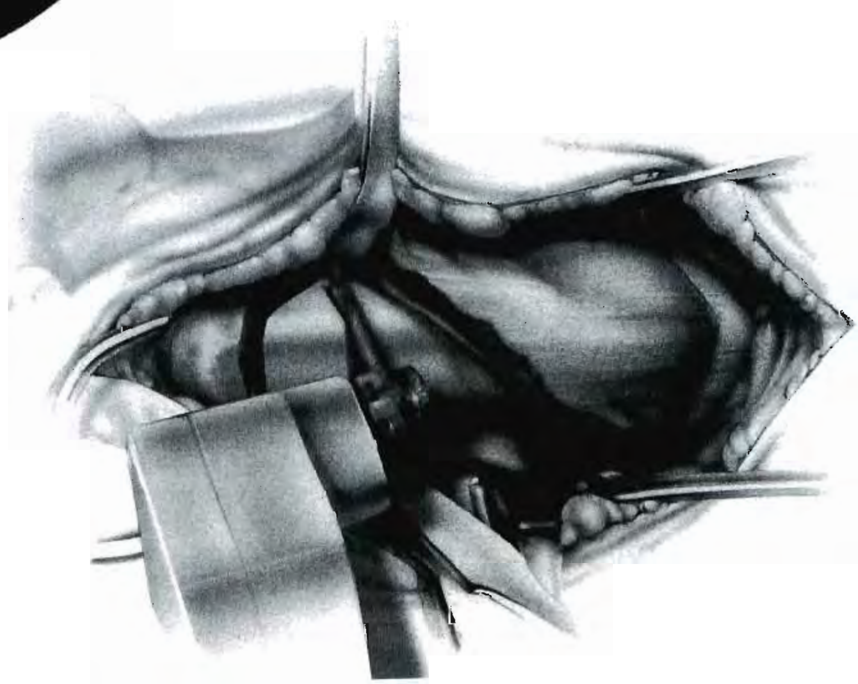
C



B

◀ **FIGURE 4-26.** Finally, the inferior portion of the osteotomy with the femoral axis is traced on a separate piece of paper **(A)**. This paper is now superimposed on the first sheet and rotated so that the osteotomy lines on the two papers come together **(B)**. The femoral axes now form a 50-degree angle. The upper fragment of the osteotomy is now traced on this second sheet. This second sheet is now rotated back and slid upward, keeping the femoral axes parallel. When the femoral head lies in the acetabulum, it is traced on this second sheet, giving the result of the osteotomy **(C)**.

A



B

FIGURE 4-27. The patient is placed either on a translucent table top or on a fracture table, depending on the size of the child and the preference of the surgeon. The femur is exposed as previously described. Kirschner wires are place under image intensifier control to mark the lines of the osteotomy **(A)**. The wedge of bone is removed with a power saw. It is easier to make the proximal cut first, leaving the medial cortex intact. The inferior cut is made and the wedge removed **(B)**. Finally, the proximal cut is completed.

A

B

FIGURE 4-28. A: A bone hook is now placed over the top of the trochanter. The trochanter and the proximal fragment are pulled down and laterally to displace the proximal fragment onto the diaphysis. The leg is abducted to close the osteotomy. **B:** Fixation can be by any method of the surgeon's choosing. In our limited experience, two Kirschner wires passed from the proximal fragment into the distal fragment, combined with a spica cast, works well in smaller children. These Kirschner wires may be combined with a tension band wire for added fixation. In larger children, a blade plate works well.

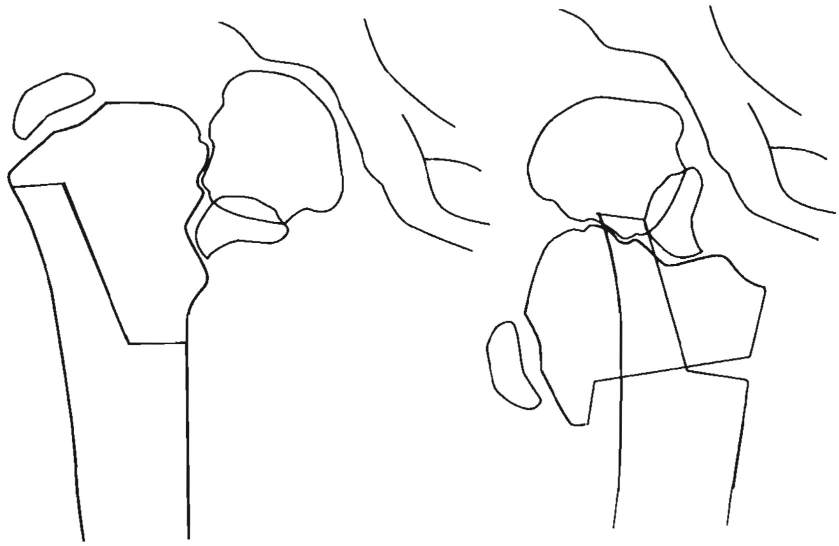


FIGURE 4-29. Amstutz and Wilson (3) discussed the various methods for correction of coxa vara, the difficulty in obtaining and maintaining the desired amount of correction, and the reasons. They thought that in the absence of good fixation in young children, an interlocking osteotomy with a long spike of cortical bone from the distal fragment mortised into a slot in the proximal fragment was best. Some cases required that the spike be placed across the physis and into the femoral head. Mobilization of the fragments was difficult, requiring adductor tenotomy, release of the abductor muscles, and subperiosteal stripping. Occasionally, Kirschner wire fixation was added. All these patients were treated in abduction with a spica cast.

FIGURE 4-30. Plykkanen (4) described an osteotomy attributed to Langenskiold. In this procedure, an intertrochanteric osteotomy is performed at the level of the triangular fragment. The distal fragment is abducted so that the lateral shaft of the distal fragment lies adjacent to the cut surface of the proximal fragment. The two fragments may be fixed with cerclage wires, Kirschner wires, or tension band wires.

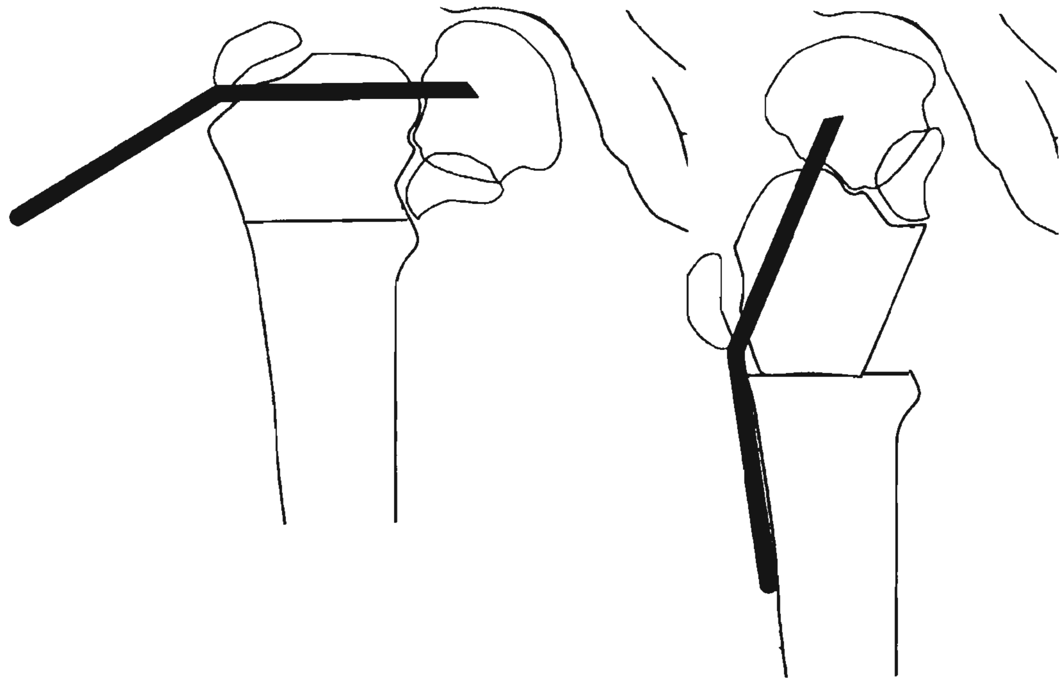


FIGURE 4-31. In the older child, the osteotomy can be accomplished with an angled blade plate as described by Borden and colleagues (5). For the child, the plate will either have to be custom made or made by bending an available device. This may also be done with some of the newer pediatric screw and plate combinations provided that the plate permits a sufficient amount of valgus. It is often necessary to cross the physis to gain sufficient purchase on the proximal fragment.

After the plate is seated, a subtrochanteric osteotomy is performed. With traction and abduction on the leg, the plate is brought into contact with the femoral shaft and secured with a clamp and then the screws.

To achieve abduction of the distal fragment, an adductor tenotomy may be necessary (6). To complete the osteotomy without increasing the pressure on the hip joint, it may also be necessary to remove a portion of the distal fragment or a wedge from the lateral aspect of the proximal fragment.

A

B

FIGURE 4-32. A: Anteroposterior radiograph of a child with bilateral developmental coxa vara. **B:** Immediately after bilateral femoral osteotomies using the technique of Amstutz in a plaster cast. (*continued.*)

C

FIGURE 4-32 (continued). C: Eighteen months later, the more horizontal growth plates are apparent along with the remodeling of the proximal femur.

POSTOPERATIVE CARE

The patient is maintained in a spica cast for 6 to 8 weeks, when healing should be sufficient to begin mobilization.

References

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2. Cordes S, Dickens DRV, Cole WG. Correction of coxa vara in childhood. J Bone Joint Surg [Br] 1991;73:3.
3. Amstutz HC, Wilson PD Jr. Dysgenesis of the proximal femur (coxa vara) and its surgical management. J Bone Joint Surg [Am] 1962;44:1.
4. Plykkanen PV. Coxa vara infantum. Acta Orthop Scand 1960;48(Suppl):1.
5. Borden J, Spencer GE Jr, Herndon CH. Treatment of coxa vara in children by means of a modified osteotomy. J Bone Joint Surg [Am] 1966;48:1106.
6. Weighill FJ. The treatment of developmental coxa vara by abduction subtrochanteric osteotomy and intertrochanteric femoral osteotomy with special reference to the role of adductor tenotomy. Clin Orthop 1976;116:116.

4.5 VALGUS OSTEOTOMY FOR HINGED ABDUCTION IN PERTHES' DISEASE

Valgus osteotomy of the hip is a seldom-used procedure in the older child. Its use is most often found today in patients who have hinged abduction of the hip after Perthes' disease. It is also indicated for nonunion or malunion of the femoral neck and is being used more commonly in the earlier stages of Perthes' disease.

In addition to altering the relationship of the femoral head to the acetabulum, valgus osteotomy of the hip lengthens the leg and lowers and lateralizes the greater trochanter. To maintain the proper axis through the knee joint, it is desirable to lateralize the femoral shaft (1). Many hips suitable for valgus osteotomy also have a short femoral neck, and the lateralization of the shaft tends to lengthen the neck.

One common problem with this osteotomy in the older child and young adolescent is that there are often not suitably sized fixation devices for these intermediate-sized bones. This often requires the modification of existing devices by bending to avoid medialization of the femoral shaft or by shortening of the blade of the blade plate devices used for adults (Figs. 4-33 to 4-41).

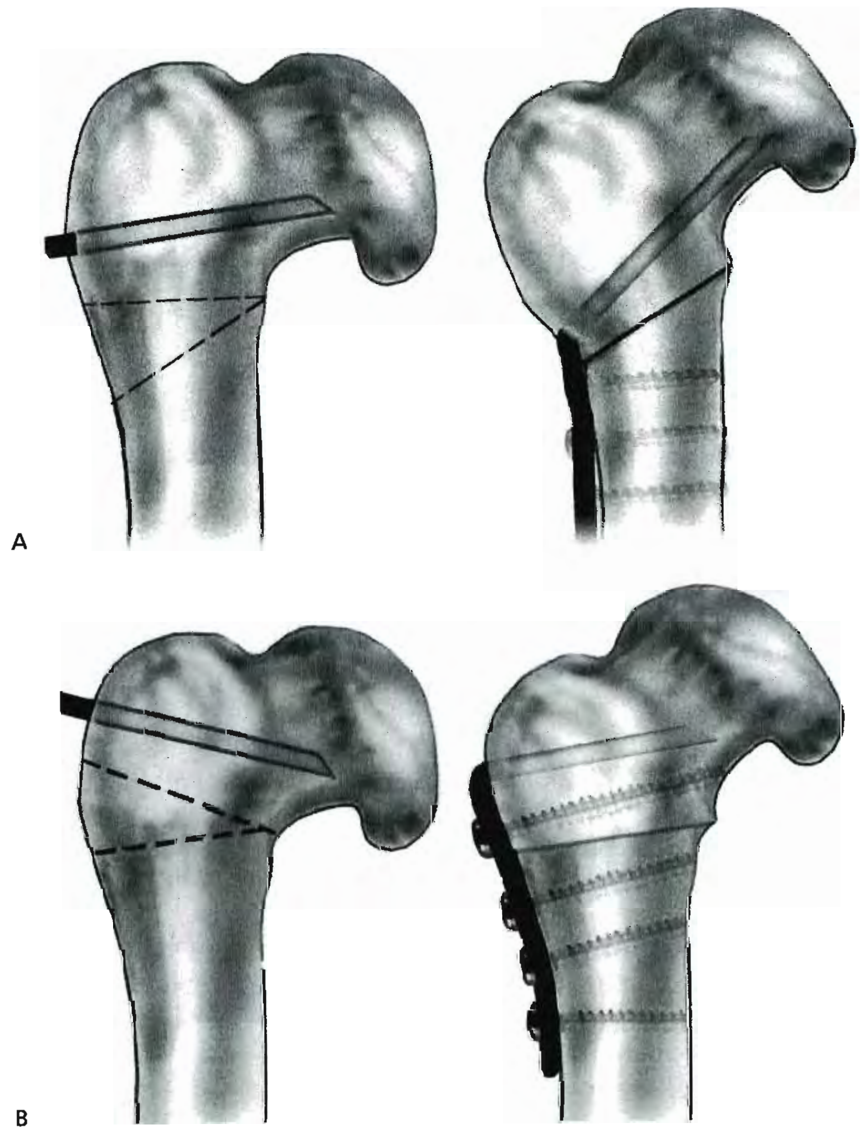
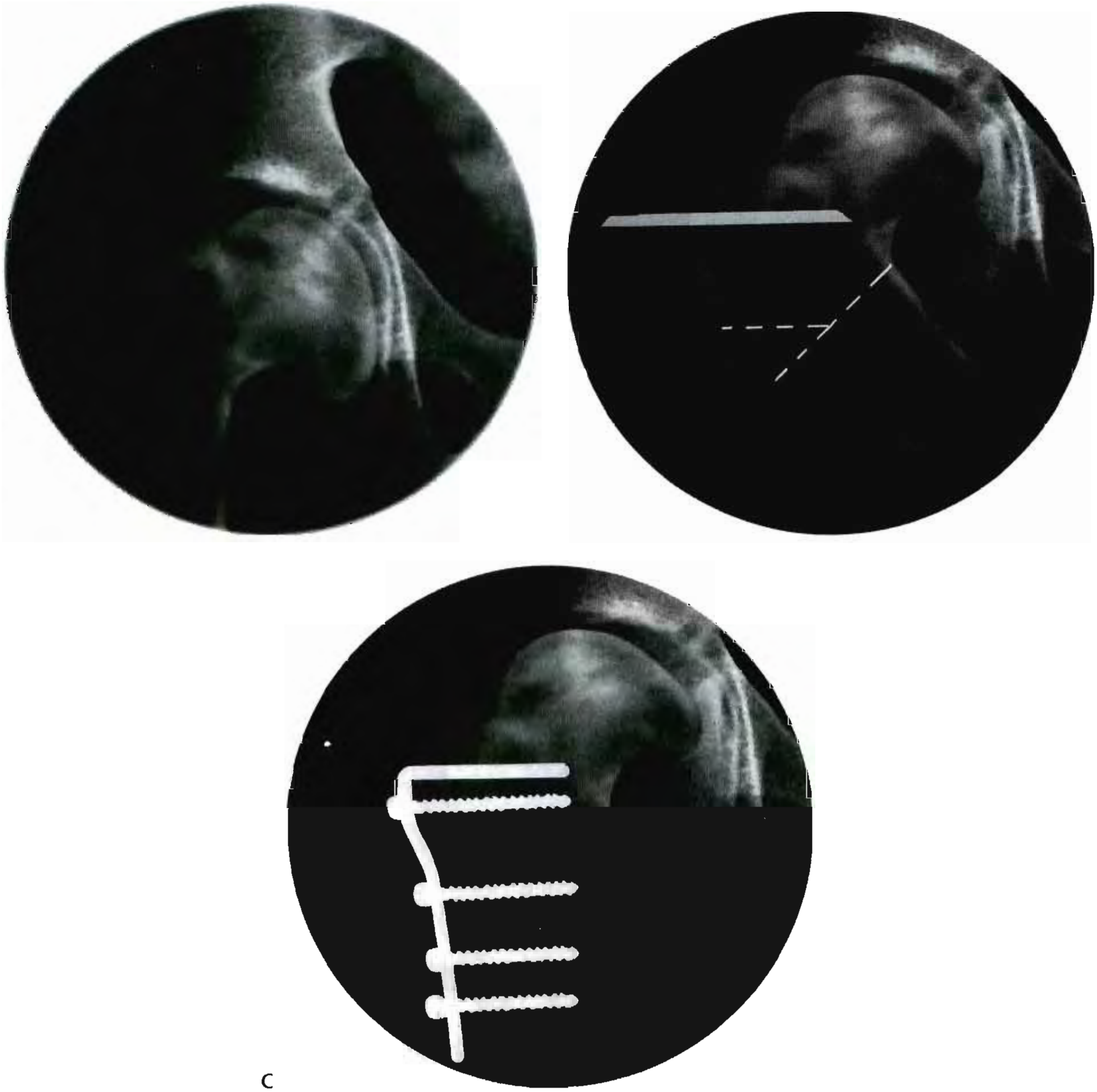


FIGURE 4-33. The simplest technique is resection of a laterally based wedge. In this procedure, a simple laterally based triangle of bone is removed from the intertrochanteric area. The angle of the wedge is equal to the desired correction. How the wedge is made depends on the type of fixation used and is designed to produce interfragmentary compression (1). If the 130-degree angled blade plate is used, the base of the osteotomy (the distal cut) is inclined and the proximal cut is horizontal **(A)**. Compression across the osteotomy site is provided by the varus stress on the proximal segment. If a 90-degree blade plate is used, the base of the osteotomy is horizontal and the interfragmentary compression is obtained by prestressing the plate **(B)**.



A B C

FIGURE 4-34. The most difficult of the valgus osteotomies to perform is the osteotomy that lateralizes the distal fragment and lengthens the femoral neck. Although preoperative planning with templates can be used, a simpler method, which is actually useful for most valgus or varus osteotomies, is one that uses intraoperative positioning of the femoral head in the proper relationship to the acetabulum while the osteotomy and fixation are achieved relative to the median and coronal planes of the patient.

Conceptually, the operation is performed with the following steps. The patient may be placed on a radiolucent table or a fracture table so that a good view of the hip joint is obtained **(A)**. The leg is adducted until the femoral head is in the desired relationship to the acetabulum **(B)**. A small amount of radiopaque dye in the hip joint may prove useful if there is a significant amount of unossified femoral head. Next, the chisel for the 90-degree fixation device is inserted perpendicular to the median plane of the body **(B)**. Finally, an osteotomy is created that will allow the femoral shaft to be brought back into the median plane of the body and secured with the plate **(C)**. The following illustrations show in more detail how this is accomplished.

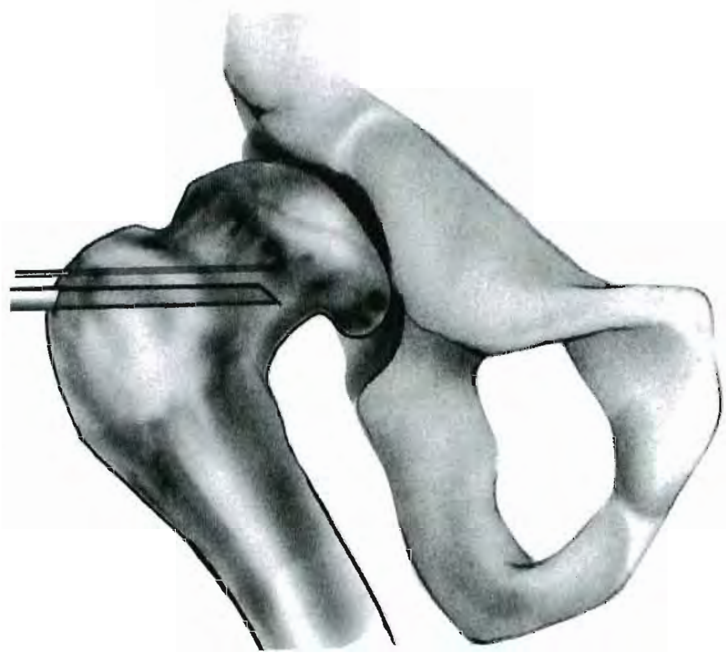
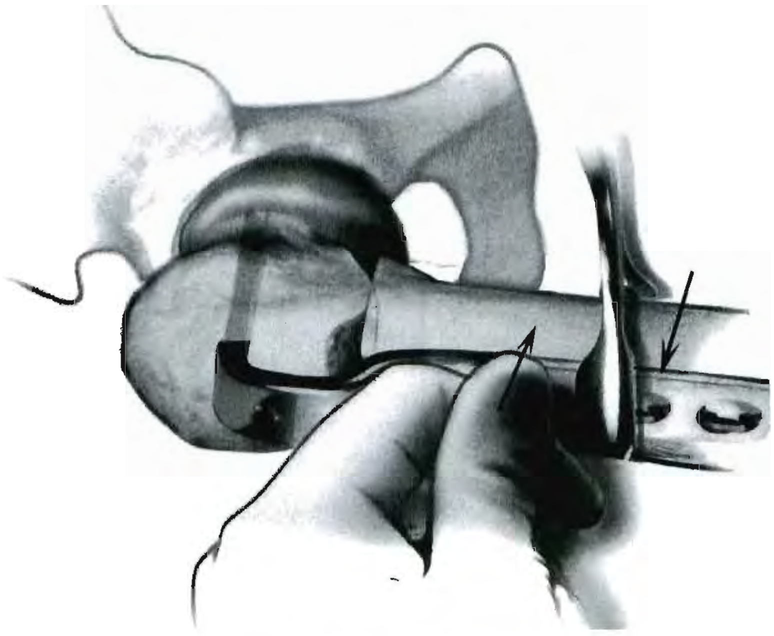


FIGURE 4-35. With the leg held in the desired position, a Steinmann pin is introduced into the most superior portion of the greater trochanter to serve as a guide for the chisel. This pin should be perpendicular to the median plane of the body and parallel to the floor of the operating room, which should be the same as the coronal plane of the patient. The position of this is verified on the image intensifier, and the chisel is driven in just below the guide pin. At this point, it is a good idea to loosen the chisel by driving it part way out so that it will not be difficult to remove after the osteotomy is completed.

FIGURE 4-36. The next step is to locate the site for the osteotomy. This should be perpendicular to the shaft of the femur and at the level of the proximal margin of the lesser trochanter. A mark in the cortex crossing the osteotomy site or a Steinmann pin in the anterior cortex distal and at right angles to the osteotomy should be placed as a reference for rotation, as illustrated in Procedure 4.6. A single osteotomy cut is made.



A

B

FIGURE 4-37. The chisel is removed and the blade of the fixation device inserted. In an adult-sized patient, the condylar blade plate is an ideal device. With the blade in place, the plate is rotated toward the shaft, while the shaft is pulled laterally with a large forceps. The idea of this is to drive the lateral edge of the proximal surface into the medullary surface of the distal fragment **(A)**.

This often proves difficult, however, and seems to make the femur too long. It is at this point that removing a portion of the proximal fragment parallel to the blade aids in the reduction and increases the contact of the two osteotomy surfaces **(B)**. If still more shortening is needed, additional bone is removed from the distal fragment. The plate is now tensioned and secured to the distal fragment.

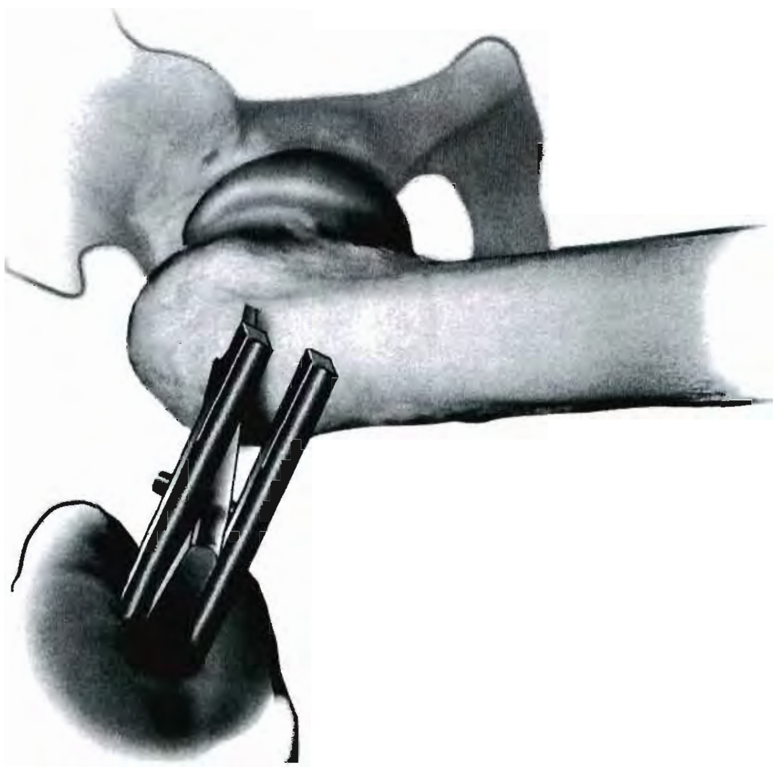


FIGURE 4-38. It is often desirable to add extension to the osteotomy, depending on the clinical and arthrographic findings. To achieve extension, the blade is not inserted at an angle perpendicular to the shaft of the femur as is usually done. Rather, it is rotated so that it will be perpendicular to the shaft after the desired correction is obtained. The chisel is guided with the slotted hammer to maintain the correct angle.

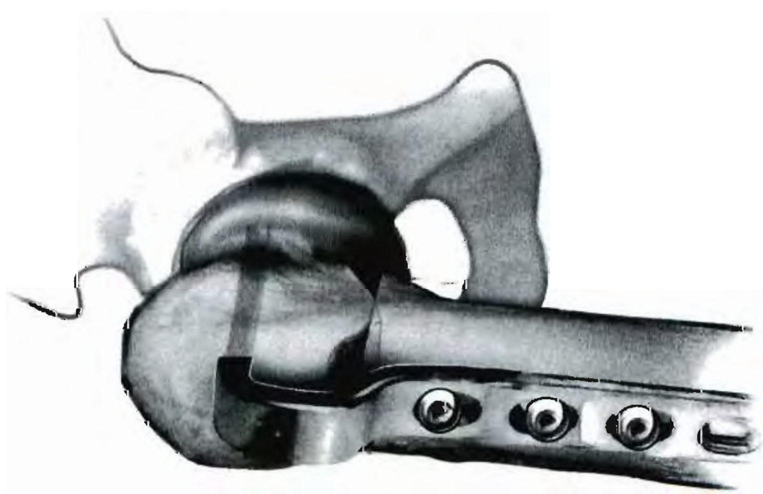
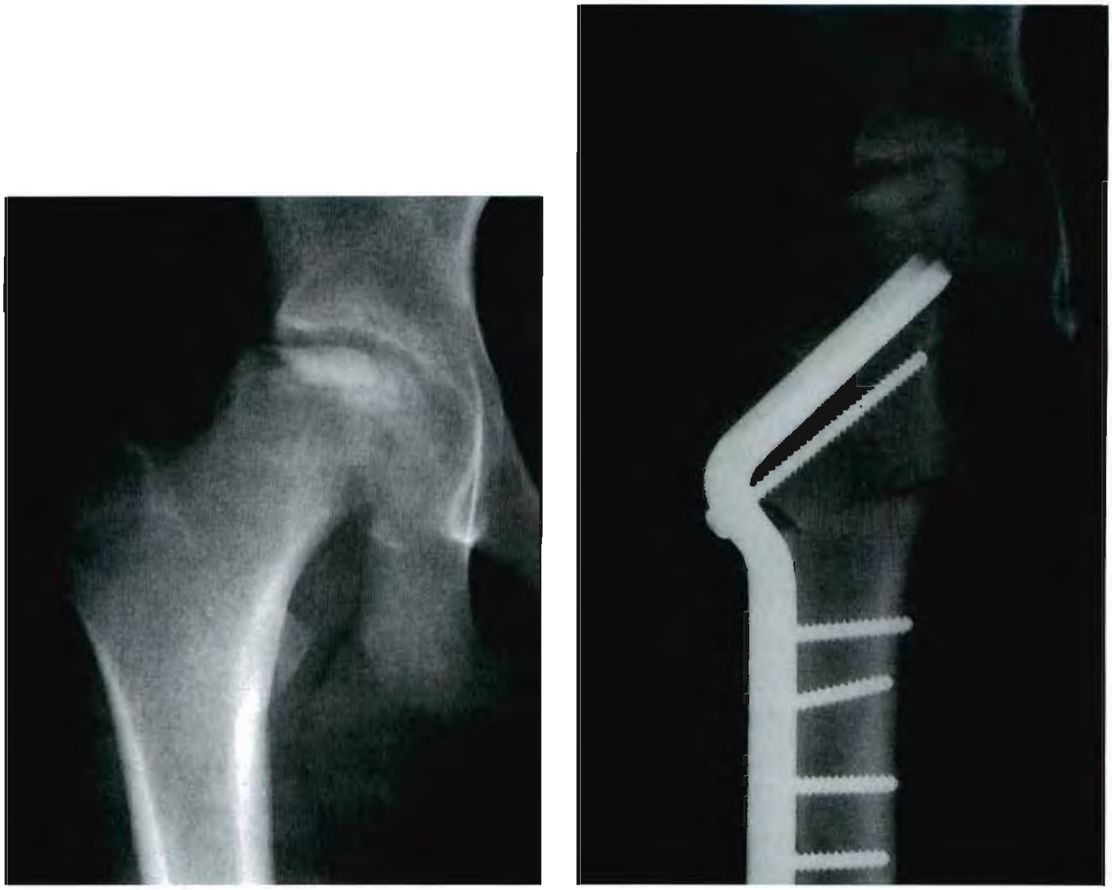


FIGURE 4-39. After the osteotomy is completed, the proximal fragment is allowed to go into flexion. The distal fragment is brought into extension and translated posteriorly. Any other corrections are made at the same time, and the shaft is then secured to the plate.



A B

FIGURE 4-40. A: Radiograph of a 13-year-old girl who developed avascular necrosis of the femoral head. To relieve the pressure on the necrotic portion and eliminate the hinged abduction, she underwent a valgus osteotomy of the proximal femur, which was fixed with a 130-degree angled blade plate. **B:** Notice the inclined angle of the osteotomy. Compression across the osteotomy surface is provided by the varus stress.

FIGURE 4-41. An 11-year-old boy with bilateral Perthes' disease had a painful left hip with marked limitation of abduction and synovitis **(A)**. His arthrogram demonstrates maximal abduction **(B)** and 30 degrees of adduction **(C)**. Results 4 months after a valgus osteotomy fixed with a 95-degree angled blade plate **(D)**.

POSTOPERATIVE CARE

Drains can be used as desired by the surgeon. The wound usually is fairly dry after the osteotomy is secured, and in our experience, little drainage is collected in the suction canister. The most important question is whether to use a spica cast. This depends on a variety of factors that the surgeon must judge: How strong is the fixation? How reliable are the parents and child? Children tolerate a cast well, adolescents less well. Adolescents are usually large enough to allow excellent fixation and seldom need a cast. On the other hand, smaller children are often best immobilized for 6 weeks in a single leg spica cast. Depending on circumstances, the cast may end above the knee, and crutch walking can be permitted.

Reference

1. Bauer R, Kerschbaumer F, Poisel S, eds. Atlas of hip surgery. New York: Thieme Medical, 1996:109.

4.6 PROXIMAL FEMORAL ROTATIONAL OSTEOTOMY

Rotational intertrochanteric osteotomy is performed as an isolated procedure for severe cases of excessive femoral anteversion but more often is performed in conjunction with other procedures associated with congenital dislocation of the hip. The technique described here is for a pure rotational osteotomy; however, the technique is equally useful when rotation is needed in combination with a varus intertrochanteric osteotomy.

Precision in the amount of rotation at the osteotomy site is the biggest problem with this osteotomy. There are several reasons for this. First, the hip has a limited arch of motion, and in some patients who need a rotational osteotomy, this arch is less than usual. Any overcorrection may produce an opposite deformity. In addition, surgeons experience difficulty in determining 30 degrees of rotation by the separation of two marks on the femoral shaft (Figs. 4-42 to 4-48).

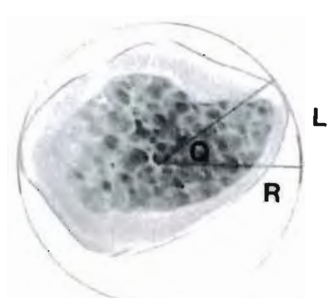
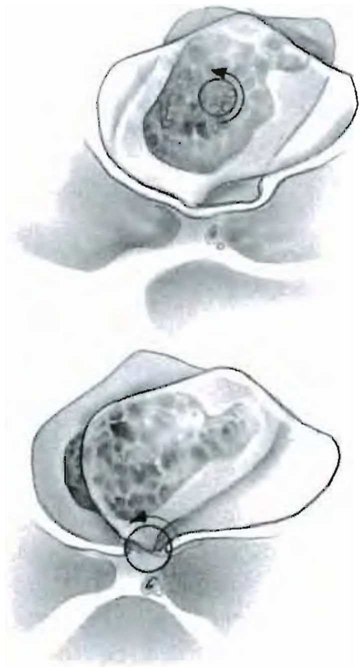


FIGURE 4-42. Crider and Leber (1) have described a geometric formula for determining the degree of rotation achieved by the distance between two marks on the femur. The formula states that the distance between the two marks (L) is equal to the radius of the bone at the osteotomy site (R) × the desired degrees of rotation (Q) × a constant (0.017). This formula assumes that the bone is a circle that is nearly true in the intertrochanteric area if the lesser trochanter is ignored. In addition, it is necessary to keep the central axis of both fragments aligned, something that is not easy to accomplish in all cases.

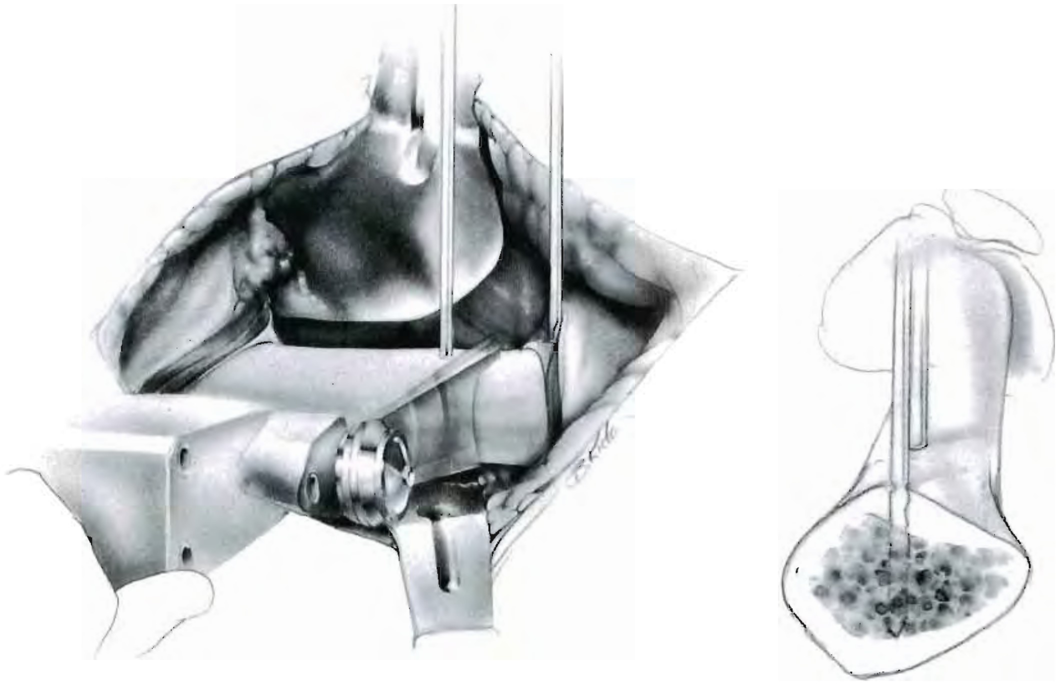
Although we believe this is a good check, we prefer to rely on a more direct method of determining rotation intraoperatively, namely the angular deviation of two pins.



A

B

FIGURE 4-43. The intertrochanteric region of the femur is exposed as previously described (see Procedure 4.2). For rotational osteotomies, it is necessary to strip the periosteum, in particular the attachments to the linea aspera, as far along the femoral shaft as possible to maintain the alignment of the axis of both fragments during rotation **(A)**. If this is not done, the attachments will act as a tether, causing translation of the fragments and rotation **(B)**. This will decrease the contact between the cut surface of the bone, making fixation more difficult, and it will be impossible to calculate the amount of rotation that has been achieved by inspecting marks on the bone.



A B

FIGURE 4-44. After the exposure is completed, two heavy 5/32-inch smooth Steinmann pins are drilled into the anterior femoral shaft. One is placed above the proposed osteotomy site and one below **(A)**. They must be parallel **(B)**. They should engage the posterior femoral cortex. The reason for this and the heavy pins is that if they are placed far enough medially on the anterior surface of the femoral shaft to be out of the way, they will be subjected to a considerable bending force from the muscle. This could bend the pins, causing a miscalculation in the amount of rotation.

FIGURE 4-45. The next step is the insertion of the seating chisel. Because no angular correction is needed, the fixed 90-degree guide can be used. The chisel should be chosen to fit the plate that is used. In adolescents, the condylar plate is ideal, but in smaller children, a right-angled plate of the appropriate size is used. A transverse osteotomy is performed at the level of the lesser trochanter.

FIGURE 4-46. While the proximal fragment is stabilized, the distal fragment is rotated, in this case externally, to correct excessive femoral anteversion. The angle templates from the Synthes osteotomy set are used to judge the amount of angular rotation between the two Steinmann pins **(A)**. Looking from above or below makes it easier to judge the amount of rotation **(B)**.

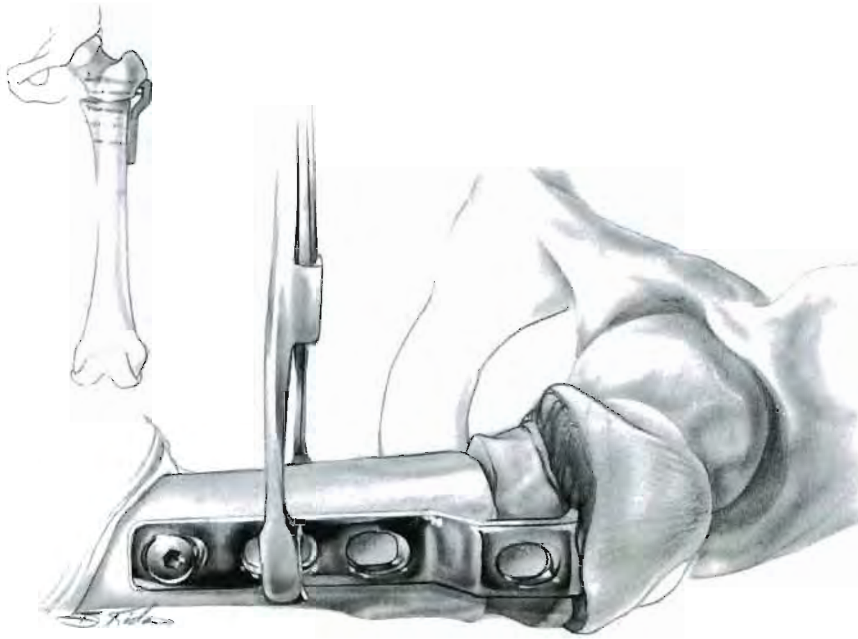


FIGURE 4-47. Because the amount of rotation is crucial, the surgeon may wish to check the rotation clinically. If this is attempted with only the clamp holding the plate, rotation of the distal fragment may occur undetected by the surgeon as he or she tests the extremes of internal and external rotation. To avoid this, first one unicortical screw is placed in the plate. After the surgeon is satisfied that the new alignment is correct, all of the screws are placed to secure the plate, and the wound is closed over a drain.

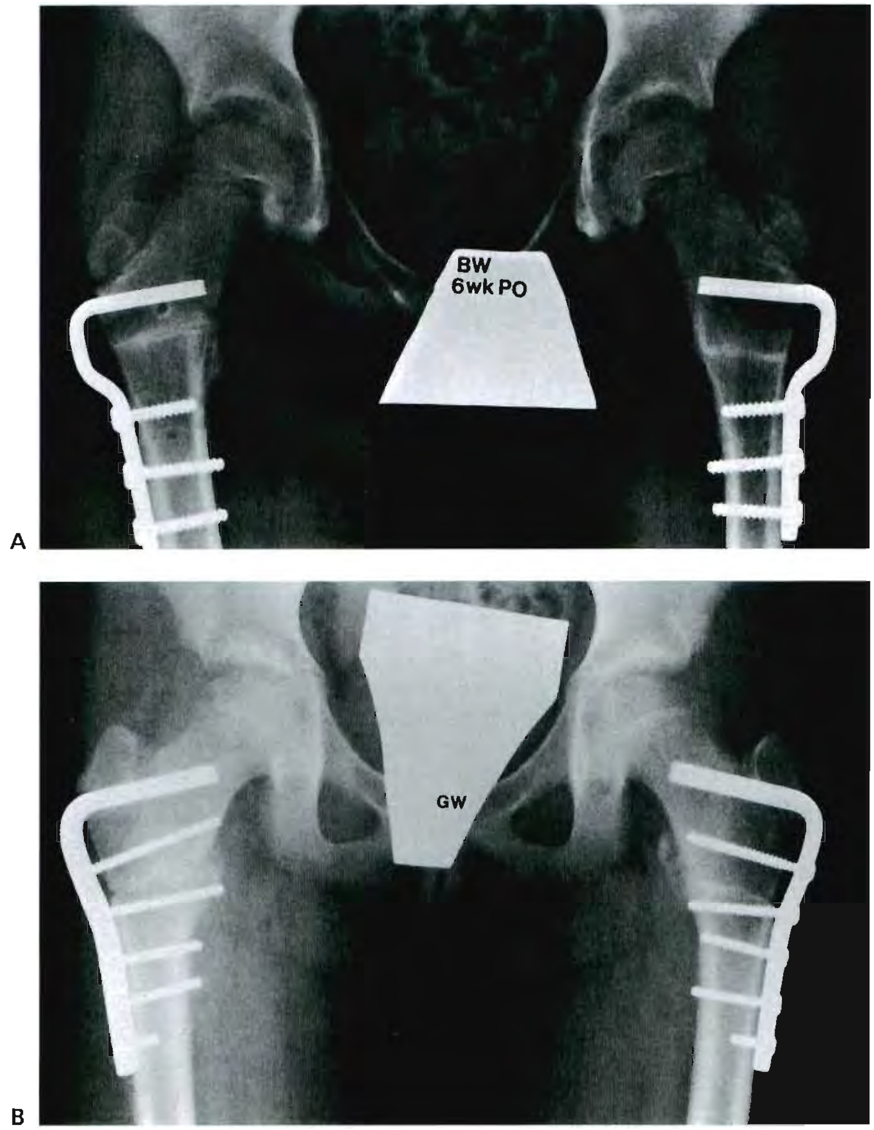


FIGURE 4-48. BW is a 9-year-old boy who had 70 degrees of internal rotation and 5 degrees of external rotation when his hips were in extension. His rotational osteotomies were fixed with the 90-degree angled plates **(A)**. Because the osteotomies do not require displacement, these plates remain slightly prominent and are not ideal. GW is a 13-year-old girl with a similar clinical picture who was large enough to permit the use of the condylar blade plates **(B)**. These are suited ideally to the contours of the proximal femur when no displacement is required.

POSTOPERATIVE CARE

The postoperative care does not differ from other intertrochanteric osteotomies. A cast, bed rest without a cast, or protected ambulation is permitted, depending on the fixation used and the ability of the patient to cooperate with limited weight bearing. As healing proceeds, it is important to increase the therapy to strengthen the hip musculature, especially the abductors and the extensors.

Reference

1. Crider RJ, Leber C. Accurate correction in rotational osteotomies. J Pediatr Orthop 1987;7:468.

4.7 SOUTHWICK BIPLANE INTERTROCHANTERIC OSTEOTOMY FOR SLIPPED CAPITAL FEMORAL EPIPHYSIS

Although Southwick (1) originally described this biplane osteotomy as a means of primary treatment for chronic slips greater than 30 degrees, it is most often used to correct residual deformity resulting from slipped capital femoral epiphysis (SCFE) after in situ fixation (2). The osteotomy is designed to create valgus and flexion, to which is added internal rotation of the distal fragment. Reported experience with this osteotomy is surprisingly small considering its widespread use (3,4). More recently, the Imhauser osteotomy has been gaining wider usage. This osteotomy produces flexion and rotation but not abduction (5).

Chondrolysis has been described as a complication after this osteotomy (3,6). In addition, it has gained a reputation as an osteotomy that is difficult to perform both from the aspect of the osteotomy itself and from the method of fixation. A more important limitation of this and other osteotomies designed to correct severe deformity resulting from SCFE is that they usually cannot produce enough change to correct the deformity completely. This does not negate the fact, however, that they can produce a considerable improvement in the range of motion.

There are three modifications to the original operation (1) that the surgeon may find helpful. First, rather than removing a wedge of bone that spans half the width of the femoral shaft, fashion the wedge to include the entire diameter of the bone. This results in some shortening, which Southwick was attempting to avoid; however, in closing the osteotomy, some lengthening of the leg is achieved. Because of the adaptive shortening of the muscles and other tissues around the hip, this results in considerable pressure in the joint unless some shortening is achieved. If the osteotomy is difficult to close, additional bone is removed to reduce the pressure in the hip joint. Second, only the maximal wedge is removed. This avoids difficulty in complex estimates of the correct amount of bone to remove and is valid because this osteotomy is done only for severe slips. Finally, use rigid internal fixation with an AO angled plate (Figs. 4-49 to 4-55).

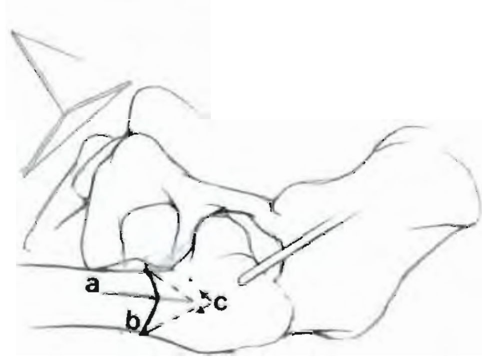


FIGURE 4-49. The intertrochanteric area of the proximal femur is exposed as described for a varus intertrochanteric osteotomy (see Procedure 4.2). Care must be taken to expose the lesser trochanter adequately if release of the iliopsoas tendon, as initially recommended by Southwick (1), is planned.

Marks outlining the desired wedges are scored on the femoral shaft using an osteotome or saw. First, a vertical line is scored in the femoral shaft separating the anterior from the lateral femoral shaft **(a)**.

Next, the base of the wedge is marked. It is the same on the lateral and anterior femoral surfaces and corresponds to a line perpendicular to the femoral shaft just cephalad to the lesser trochanter. This is the same as the definitive osteotomy line **(b)** shown in Figure 4-3 and used in planning an intertrochanteric osteotomy.

The surgeon now must determine the wedge that will be removed anteriorly to produce flexion and the one that will be removed laterally to produce valgus. The maximal angles of the original Southwick templates are 45 degrees anteriorly and 60 degrees laterally. These are unlikely to be available. The angle guides from the AO set or any other templates that are available will do. This represents the maximal wedges that can be removed. They are marked to describe a wedge that includes the entire diameter of the femoral shaft.

FIGURE 4-50. The purpose of releasing the psoas tendon is to reduce the tension on the osteotomy and lessen the pressure in the hip joint. This is done in a semiblind fashion. A Bennett retractor placed at the site of the lesser trochanter is twisted to push the soft tissues away. The iliopsoas tendon is palpated easily and can be sectioned by using a #12 Bard-Parker knife blade.

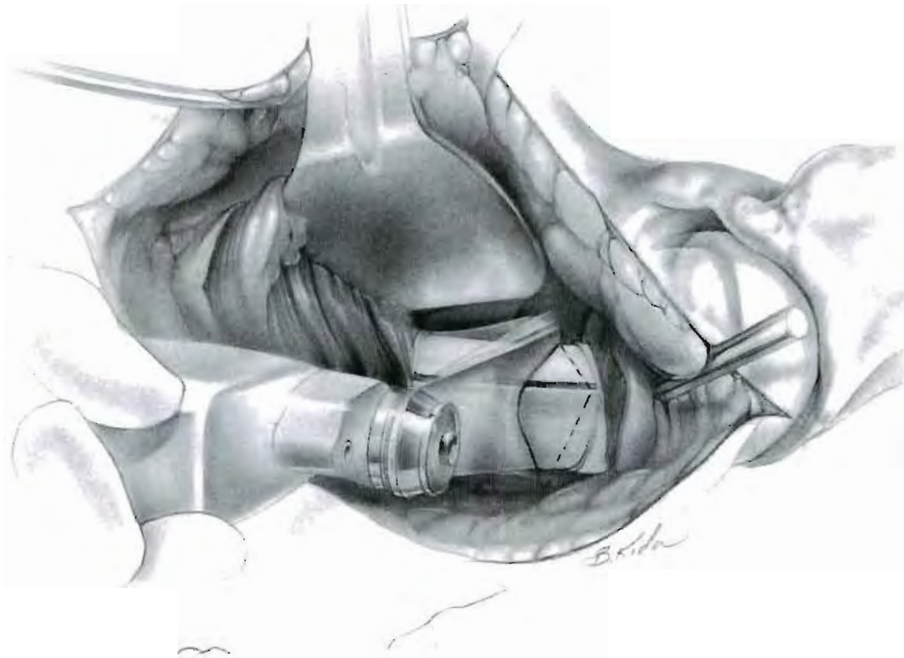


FIGURE 4-51. Before the osteotomy is made, it is necessary to gain control of the proximal fragment. This can be done with the chisel for the blade plate. It is driven in with its flat surface parallel to the osteotomy surface and at least 1.5 cm above it (see Fig. 4-14). This is a difficult part of the operation, and the surgeon may not have confidence in doing this until the correction through the osteotomy is made. In that case, a large smooth pin is drilled into the superior aspect of the greater trochanter, aiming posteriorly. This provides good fixation and keeps the pin out of the path of the seating chisel, which can be inserted after the correction is achieved and the surgeon sees a more normal orientation of the femur.

The first cut is through the base of the osteotomy (see Fig. 4-14). This cut should be made to the medial cortex, which is best left intact until the other cuts are made.

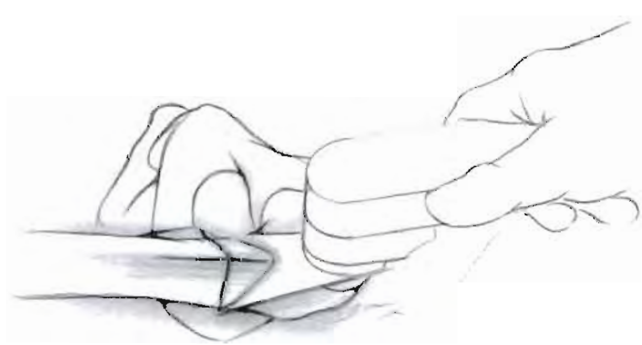


FIGURE 4-52. Confusion often arises when attempting to remove two separate wedges, one lateral and one medial. Rather, the next cut should remove one wedge: both the medial and lateral wedges as one piece. This is accomplished by starting the saw on the line separating the anterior and lateral aspects of the femoral shaft. It is angled so that it includes both wedges, aiming toward the first cut at the medial cortex.

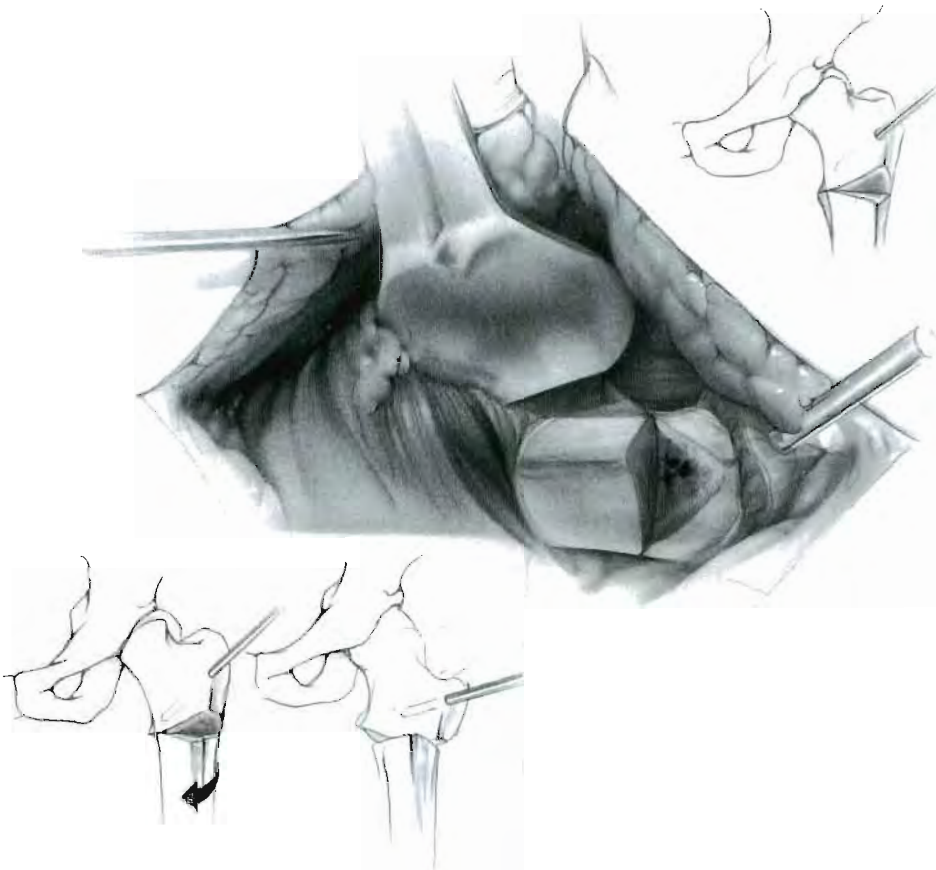


FIGURE 4-53. With the wedge of bone removed, the osteotomy is completed through the medial cortex and is ready to be closed. This is best accomplished by a combination of maneuvers. First, the fracture table, which holds the leg, is raised to produce flexion and abducted to produce valgus. The pin in the greater trochanter is used at the same time to pull down the proximal fragment, thus closing the osteotomy.

Although correcting the deformity of the proximal femur theoretically should correct the lack of internal rotation, it is usually necessary to add some internal rotation to the distal fragment. In most severe slips, this is about 30 degrees and can be noted accurately by placing two pins on either side of the osteotomy, as described for rotational intertrochanteric osteotomy.

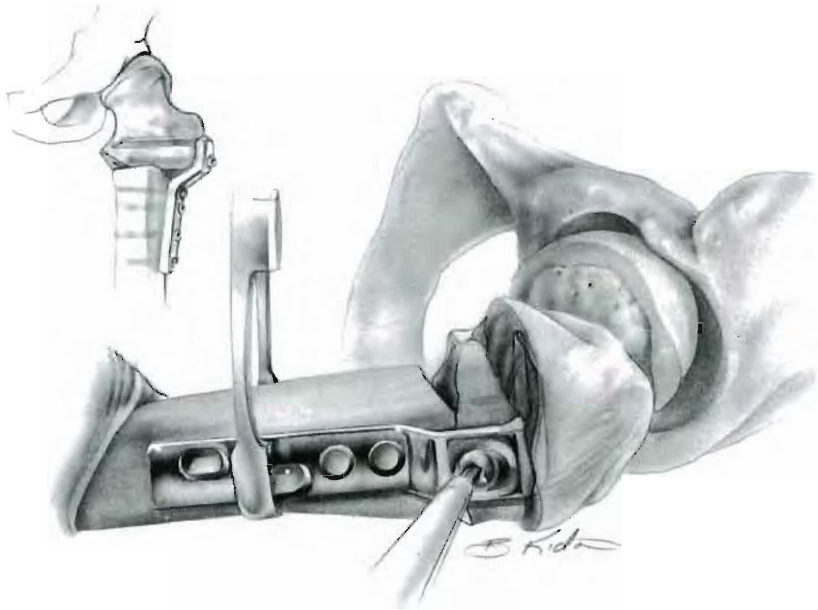
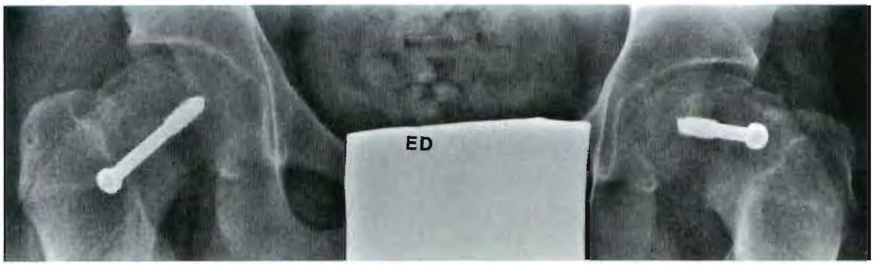


FIGURE 4-54. With the osteotomy held closed by an assistant using the heavy pin, the steps used to insert the blade plate, as described in the technique of varus intertrochanteric osteotomy (see Procedure 4.2), are performed. The angled plate used depends on the configuration of the bone at the completion of the osteotomy. It is possible to use either the 90-degree angled plate or the 120-degree repositioning plate. The 90-degree blade plate is easier to place accurately but will not provide as good fixation in the proximal fragment as the 120-degree blade plate. As supplied, however, the 120-degree blade plates often seem too long.

For those with considerable experience in the use of the AO blade plates, there is an alternate method of inserting the blade and reducing the osteotomy. The 90-degree blade plate is designed so that the blade is inserted into the proximal fragment 1.5 cm proximal to the osteotomy cut, and the blade is kept parallel to the plane of the osteotomy cut in the proximal fragment. Therefore, if the blade is inserted into the proximal fragment beginning 1.5 cm proximal to the osteotomy and the flat surface of the blade is kept parallel to the plane of the osteotomy cut in the proximal fragment, when the osteotomy is closed, the plate will lie in correct apposition to the lateral aspect of the distal fragment, and the osteotomy will be closed. Using this technique, the chisel is driven into the proximal fragment after the wedge of bone is removed, and the insertion of the Steinmann pin to control the proximal fragment is not necessary.

At least four screws should attach the plate to the femoral shaft to provide sufficient fixation to avoid the need for a cast. The wound is closed and drained as for other intertrochanteric osteotomies.

A



B

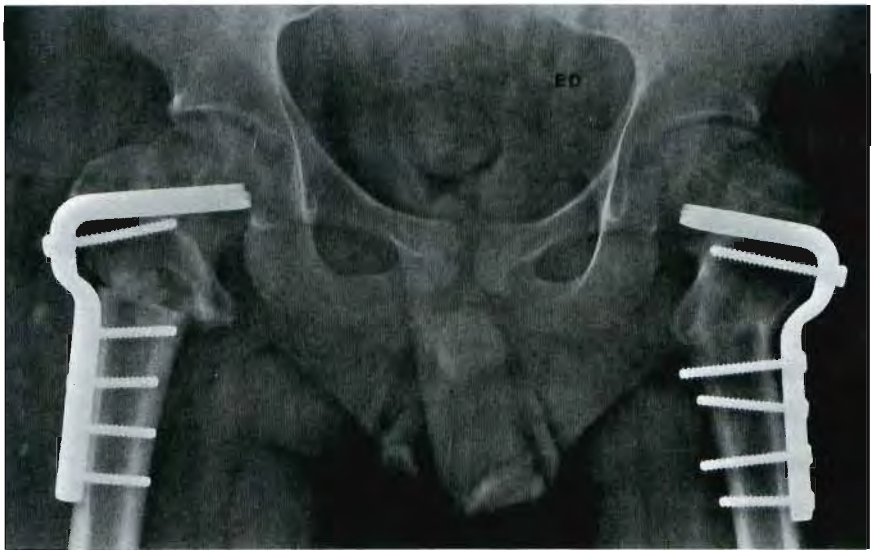


FIGURE 4-55. ED is a 13-year-old boy with bilateral slipped capital femoral epiphysis. He was treated initially with in situ fixation using a single cannulated screw **(A)**. After 18 months, he still had minus 25 degrees of internal rotation in each hip, and flexion was limited to 60 degrees bilaterally. He was treated with bilateral Southwick osteotomies done 3 months apart, at the patient's request, to permit continued ambulation. The osteotomies were fixed with 90-degree angled blade plates **(B)**. This permitted early weight bearing and resulted in prompt healing of the osteotomies.

POSTOPERATIVE CARE

It is usually undesirable and unnecessary to use a cast after a Southwick osteotomy that is adequately fixed. If there are questions about the patient's ability to comply with a partial weight-bearing crutch gait, bed rest and a wheelchair may be used for the first 6 weeks. Full weight bearing is permitted at the first signs of radiographic healing, usually 6 to 8 weeks. Range of motion exercises are started from the first postoperative day and progress to muscle strengthening exercises as healing nears completion.

References

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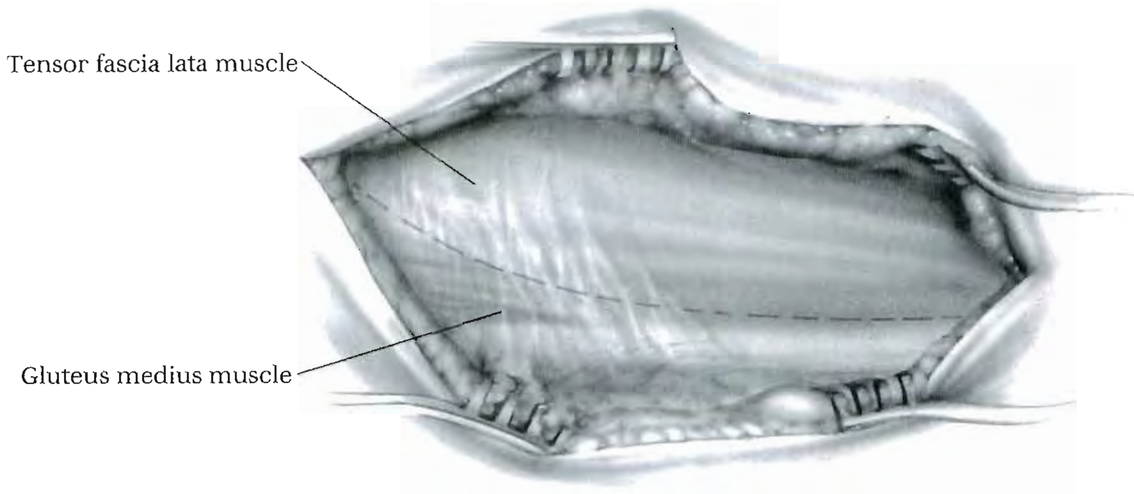
4.8 OSTEOTOMY AT THE BASE OF THE FEMORAL NECK FOR SLIPPED CAPITAL FEMORAL EPIPHYSIS

Many osteotomies of the femoral neck were proposed, abandoned, and rediscovered during the 20th century (1). One osteotomy that has remained popular during the past 20 years is that originally proposed by Kramer and colleagues (2). This osteotomy removes a wedge of bone at the base of the femoral neck, which is designed to compensate for the deformity created by the slip. Its appeal and the advantage claimed for it are that it is performed far enough distally on the femoral neck to not jeopardize the blood supply to the femoral head. According to Harty (3), the capsule of the hip reaches the trochanteric line anteriorly, but posteriorly the lateral third of the neck is extracapsular, and the vessels that supply the femoral head would not be injured by an osteotomy in this area.

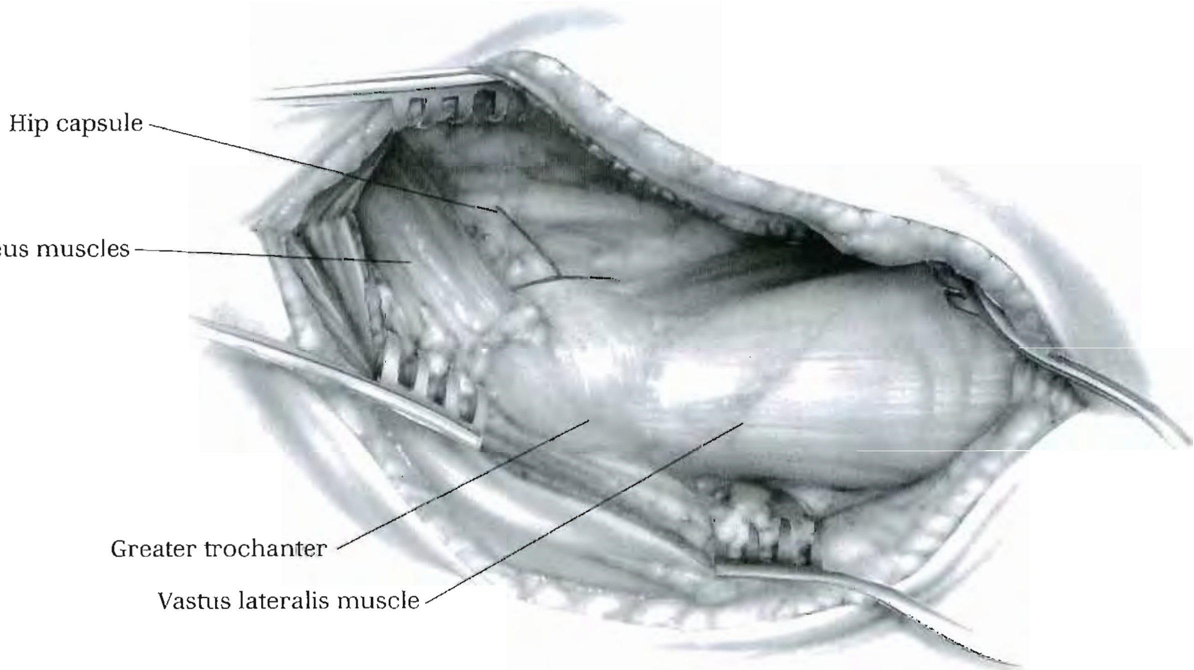
The disadvantage cited for this osteotomy is that it cannot provide sufficient correction for the severe slip. Gage and colleagues (1) and Crawford (4) believe that the maximal correction is about 50 degrees. In addition, this osteotomy shortens the femoral neck. Kramer and colleagues (2) recommended a trochanteric epiphysiodesis at the time of the osteotomy to avoid trochanteric overgrowth. Crawford (4) states that this procedure may leave the leg so short that epiphysiodesis of the opposite leg (at the distal femur) may be necessary. Finally, despite the anatomic considerations for the safety of this procedure, Gage and colleagues (1) have reported avascular necrosis.

The operation may be performed through either a transverse incision, as described for open reduction of the hip, or an anterolateral approach, as described by Watson-Jones. If the surgeon uses multiple heavy Steinmann pins for fixation, as described by Kramer and colleagues (2), the Watson-Jones approach is best because the osteotomy and the pin insertion can be performed through the same incision. If the surgeon chooses to use cannulated screws, which can be placed percutaneously, the anterior transverse incision is best. The advantage of using the Steinmann pins is that they can be placed in the distal fragment before closing the osteotomy; this provides better control of the fragments, a point both Kramer and colleagues (2) and Gage and colleagues (1) emphasize to prevent possible posterior displacement at the osteotomy site with possible damage to the blood vessels to the femoral head. Finally, the surgeon may choose to use a fracture table to support the leg, which is usually large, or a regular operating table with strong steady assistants to hold the leg. The Watson-Jones approach with three heavy Steinmann pins is the procedure described here (Figs. 4-56 to 4-60).

FIGURE 4-56. The incision begins about 2 cm distal and lateral to the anterosuperior iliac spine. It curves over the tip of the trochanter, staying slightly posterior, and ends far enough distally to permit the insertion of the pins at the proper angle into the neck.



A



B

FIGURE 4-57. The interval between the tensor fascia lata muscle and the gluteus medius muscle can be difficult to identify until experience is gained with this approach. To identify this interval, incise the fascia lata distally and continue this incision proximally, staying along the posterior border of the tensor fascia lata muscle. The interval is identified more easily distally, where the difference in insertion and direction of the fibers is more apparent **(A)**. Retract the tensor fascia lata muscle anteriorly, and with blunt dissection, find and develop the plane between this muscle and the gluteus medius muscle. There are some vessels that will need to be divided in this interval, but the dissection should not continue so far anteriorly to divide the branch of the superior gluteal nerve to the tensor fascia lata muscle **(B)**.

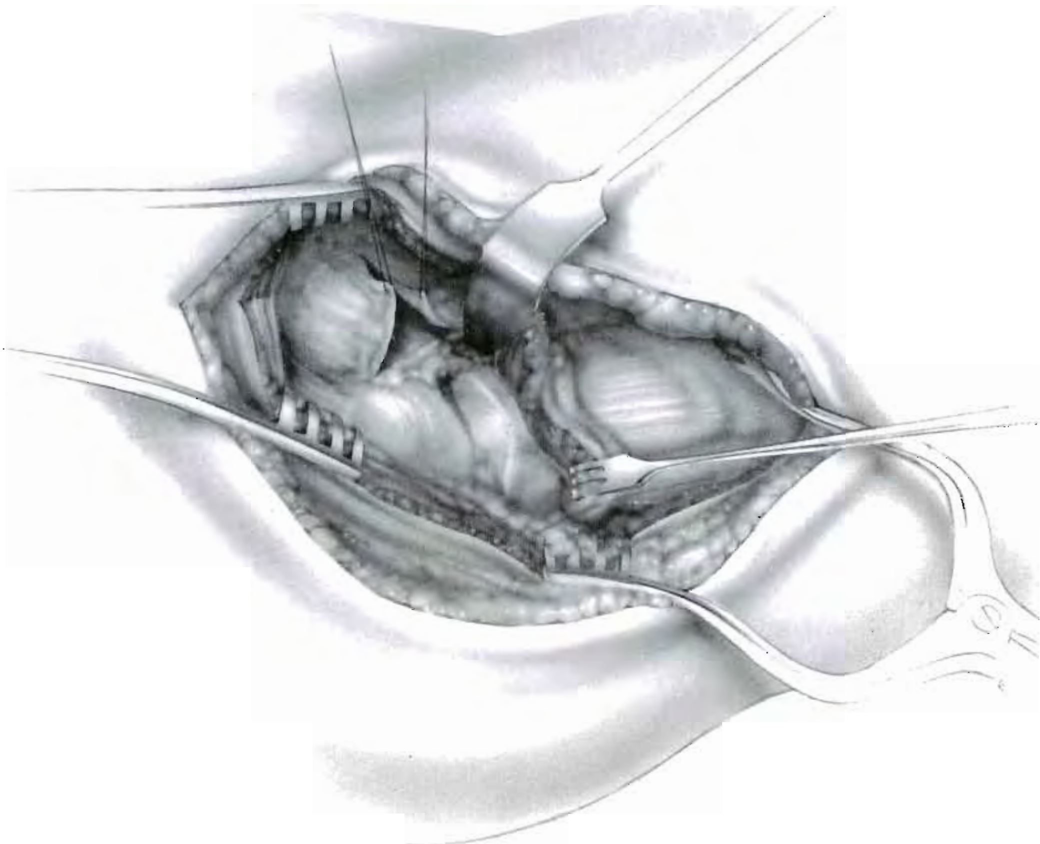
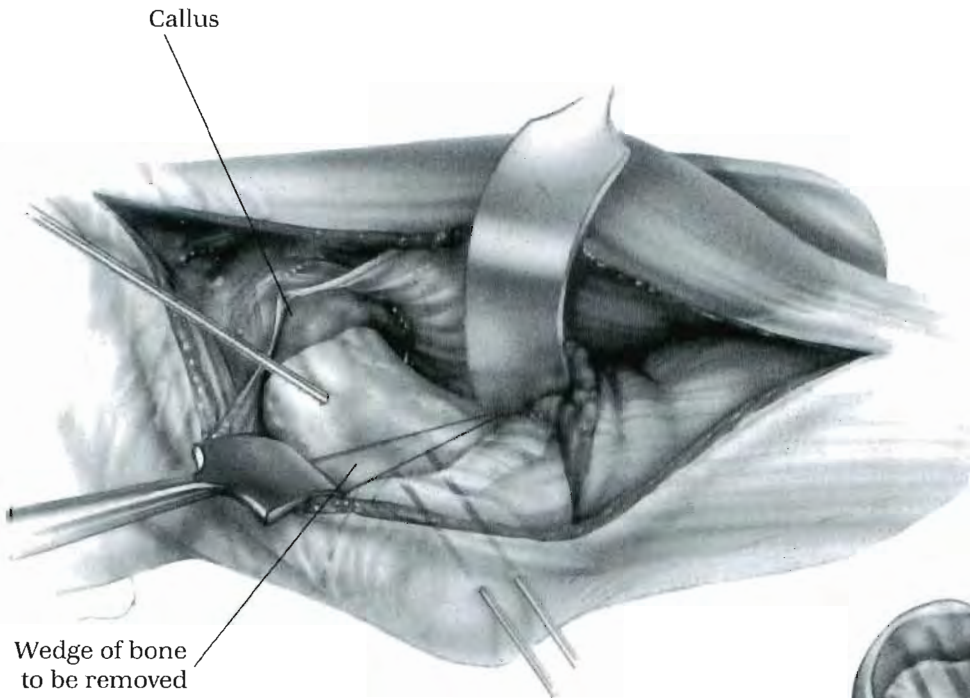
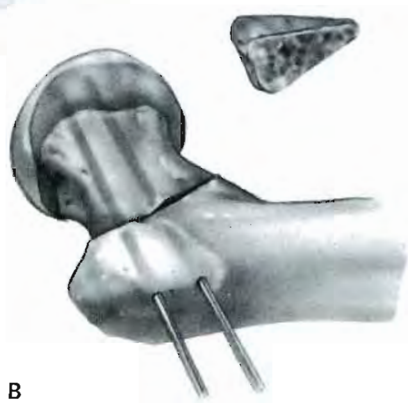


FIGURE 4-58. After the interval is developed, the tensor fascia lata muscle is retracted anteriorly and the gluteus medius posteriorly. The fibrofatty tissue seen is that covering the hip capsule. To expose the capsule externally, rotate the hip. This tissue is incised and dissected off the anterior capsule, often along with capsular origins of the iliacus muscle joining the psoas medially and capsular insertions of the gluteus muscle laterally. In addition, it is often necessary to incise the origin of the vastus lateralis muscle along the trochanteric line, reflecting it distally a short distance.

The capsule of the hip joint is now opened with an H-shaped incision with the transverse arm of the H near the base of the neck. This permits adequate inspection of the callus at the site of the slip, which Kramer and colleagues (2) recommend to determine the size of the wedge, and adequate exposure at the base of the neck for the osteotomy. It is probably important that retractors not be placed around the neck of the femur to avoid damage to the vessels in the retinaculum posteriorly.



A



B

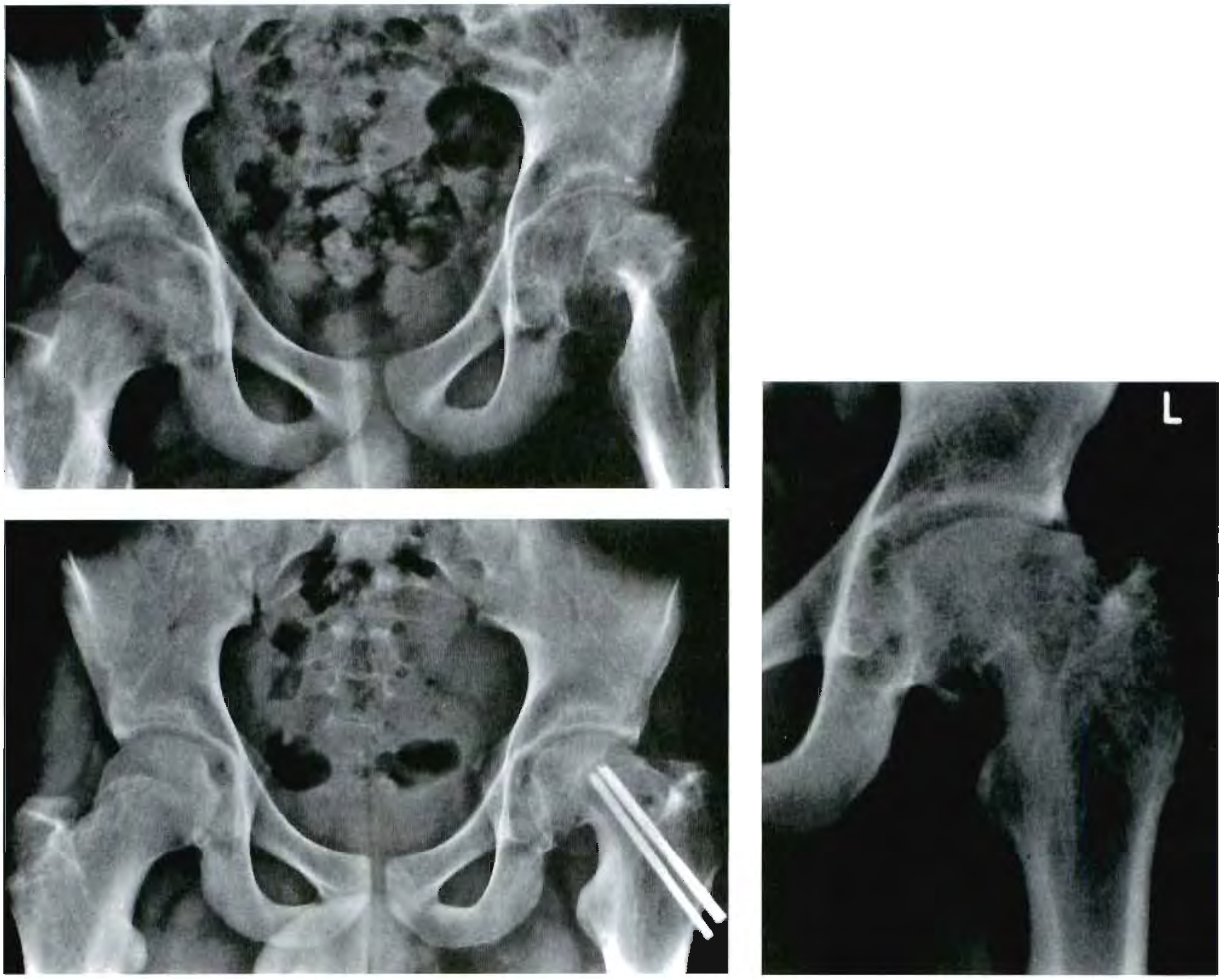
◀ **FIGURE 4-59.** The amount of bone to be removed is difficult to calculate. Kramer and colleagues (2) describe measuring the callus at the site of the slip both superiorly and anteriorly to define the dimensions of the wedge. Only two thirds of the measured amount is removed anteriorly to avoid overcorrection of the retroversion, whereas the full amount measured is removed superiorly. This can also be estimated preoperatively by measuring the head–neck angle on the anteroposterior and lateral radiograph. Kramer and colleagues (2) stated that a common error is to remove too much bone anteriorly and not enough superiorly. The idea is to make the distal cut perpendicular to the femoral neck and the proximal cut perpendicular to the physeal surface of the femoral head.

The wedge can be removed with an osteotome, as described by Kramer and colleagues (2), or with a high-speed bur, as described by Gage and colleagues (1). It is easier to start with the osteotome but safer to finish with a bur. The bur is used to thin the posterior and inferior cortex but not break it, a point on which all surgeons seem to agree.

A heavy Steinmann pin is now placed in the proximal fragment to control it. The Steinmann pins that will be used to fix the osteotomy site are drilled into the distal fragment from the lateral cortex in line with the femoral neck. The posterior and inferior cortices are thinned until they can be fractured easily in a greenstick fashion by manipulating the Steinmann pins to close the osteotomy site **(A)**. This can be aided by abducting and internally rotating the leg. When the osteotomy site is closed, the Steinmann pins are advanced from the lateral cortex across the osteotomy site, across the physeal plate, and into the femoral head **(B)**.

The pin in the proximal fragment is removed, and the pins are cut at the lateral cortex, leaving them long enough for removal after healing and closure of the physis. At this point, Kramer and colleagues (2) recommend performing an epiphysiodesis of the greater trochanter to prevent overgrowth. The shortening of the femoral neck leads to a decrease in the articulotrochanteric distance, but this will not be corrected by a greater trochanteric epiphysiodesis in this age group because insufficient growth remains. This makes their second recommendation, a trochanteric transfer, more reasonable when the articulotrochanteric distance is decreased significantly.

The capsule and the wound are closed.



A

B

C

FIGURE 4-60. A: The preoperative radiograph of a 15-year-old boy with the residual deformity of chronic slipped capital epiphysis. **B:** Six months after an osteotomy at the base of the neck, the amount of correction is seen. Although the articulotrochanteric distance is decreased, his gait was improved markedly. **C:** Three years after surgery and after removal of the pins.

POSTOPERATIVE CARE

A spica cast is probably not necessary unless a trochanteric transfer has been performed and the surgeon doubts the Steinmann pin fixation. The patient is mobilized with a three-point partial weight-bearing crutch gait, which is maintained until healing, usually 6 to 8 weeks. The pins are removed when the physis is closed.

References

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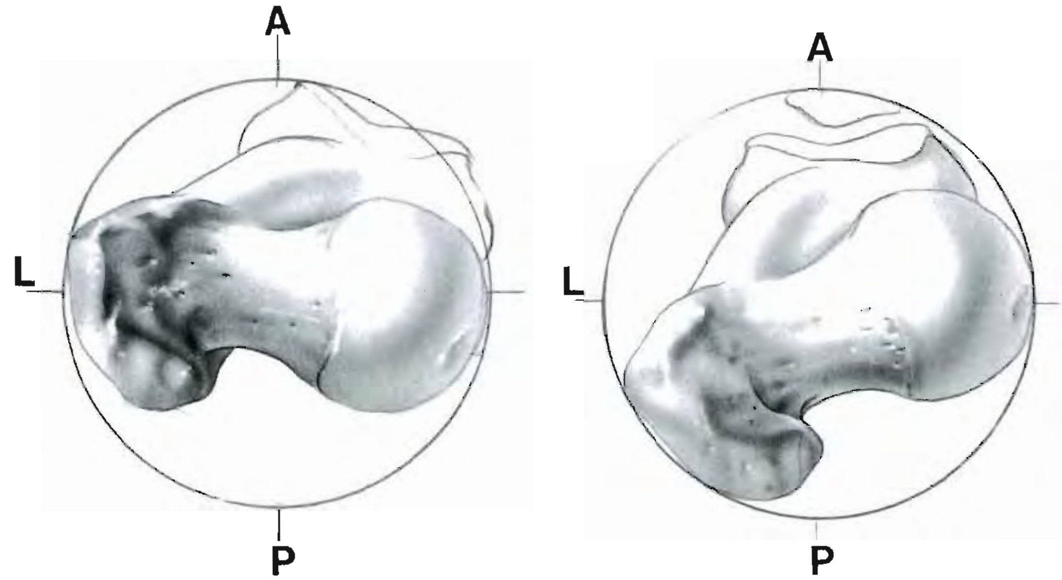
4.9 TRANSFER OF GREATER TROCHANTER

Whenever the growth of the proximal femoral physis is disrupted and that of the greater trochanter is not, an imbalance of the abductor musculature results. This usually occurs as a result of Perthes' disease or avascular necrosis following treatment of congenital dislocation of the hip. The imbalance occurs because of the shortened resting length of the muscle as the insertion approaches the origin, altering this Blix curve. The effectiveness of the abductor musculature is dependent not only on the height of the greater trochanter relative to the femoral head but also on the distance of the greater trochanter from the center of the femoral head, which is the lever arm through which the force works.

Under normal circumstances, the tip of the greater trochanter lies on a horizontal line connecting the center of the femoral heads and lateral to it by a distance that is equal to 2 to 2.5 times the radius of the femoral head (1). These relationships are important to the surgeon who is planning a transfer of the greater trochanter.

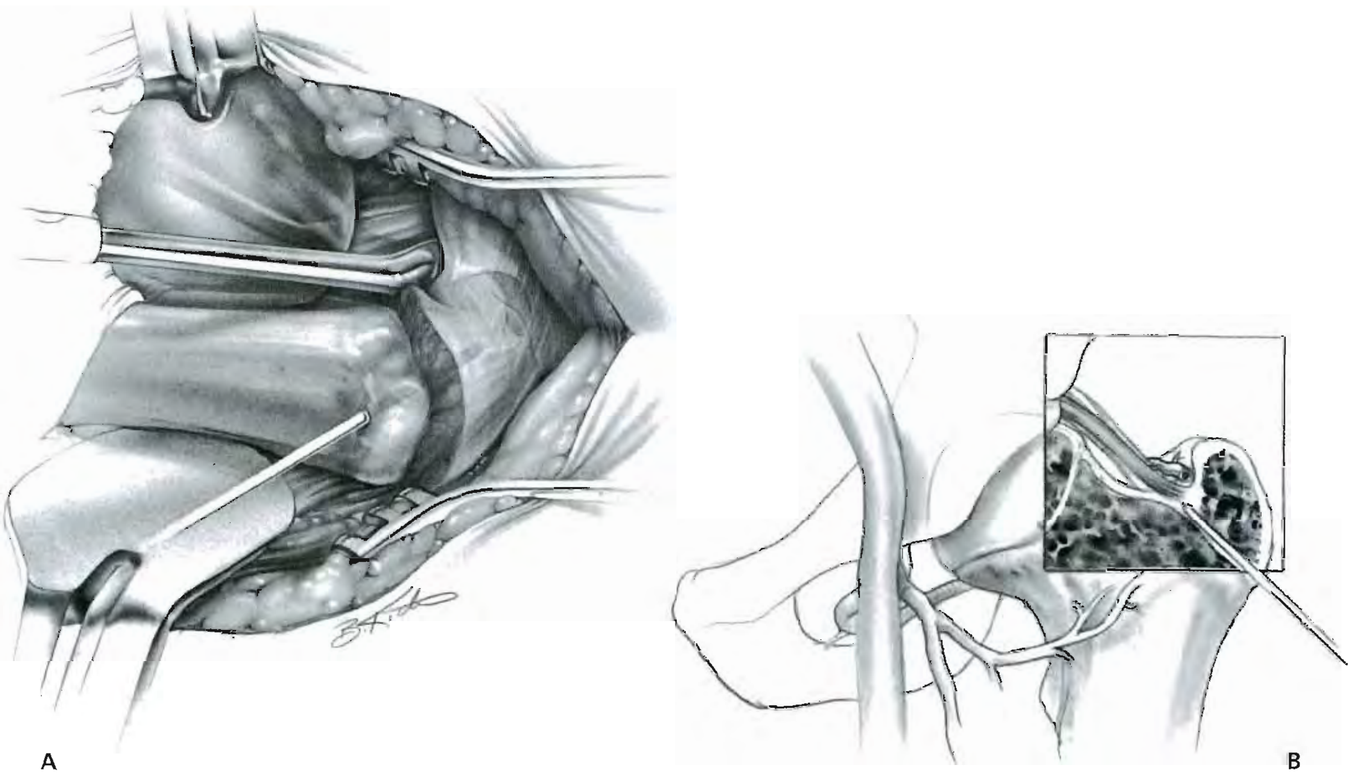
The indication for the operation should be based on clinical symptoms and findings rather than on radiographic findings. A gluteus medius limp, especially after walking or standing, that is unacceptable to the patient is the usual indication. This situation is often associated with a deformity of the femoral neck or acetabulum. It is usually possible and preferable to correct all of these abnormalities during the same operation. It is not advisable to operate based on the results of radiographic findings of relative trochanteric overgrowth in the absence of clinical symptoms or findings. Although this operation is common, there have been few reports in the English literature on the results of transfer of the greater trochanter to correct the clinical problem of a gluteus medius limp (2,3).

Epiphysiodesis of the greater trochanter has been advocated as a method of preventing relative overgrowth of the greater trochanter in young patients, generally those younger than 8 years of age (4). This often destroys the important lateral growth of the greater trochanter and neglects one of the important biomechanical parameters of abductor function. We prefer to wait until about 10 years of age, when the trochanter is a sizable piece of bone whose transfer results in lateral displacement (Figs. 4-61 to 4-67).



A B

FIGURE 4-61. Because the patient is usually older when this procedure is performed, it is easier to operate with the patient on a fracture table. This permits good radiographic control and frees the surgeon from struggling with a large leg. The image intensifier should be positioned on the opposite side of the operating table for an unobstructed anteroposterior view of the femoral head and greater trochanteric region. In addition, the leg should be rotated internally so that the trochanter is directly lateral **(A)** rather than behind the femoral shaft **(B)**. With the greater trochanter now in profile, the physeal plate (if present) should be seen clearly as a single straight line. With the greater trochanter in this position, it is easy to remove all of it without leaving a portion anterior or posterior. A straight lateral incision is used extending from the tip of the greater trochanter distally for a distance that will allow sufficient exposure for the new location of the greater trochanter. The exposure is the same as that for an intertrochanteric femoral osteotomy, including elevation of the vastus lateralis from the lateral femoral shaft. A, anterior; L, lateral; P, posterior.



A B

FIGURE 4-62. The anterior edge of the abductor muscles is identified and freed by blunt dissection. If the surgeon desires, a blunt elevator (e.g., a Cushing or Crego elevator) can be passed between the abductor muscles and the capsule of the hip joint **(A)**. To accomplish this, the elevator is passed beneath the abductor muscles, staying in close contact with the capsule over the femoral neck and aiming toward the trochanteric fossa. This step is not necessary if image intensification is available but is otherwise useful. The posterior border of the abductor muscles can be identified by blunt dissection.

A Kirschner wire is now drilled into the greater trochanter to serve as a guide for the osteotomy **(B)**. In most circumstances, this wire lies along a line extending from the femoral neck. It can be placed under image intensifier control. Because of the location of the critical anastomosis of the ascending medial and lateral femoral circumflex arteries at the base of the femoral neck, it is important to avoid drilling this wire completely through the bone **(A)**. It is important that as much bone as possible be included in the trochanteric fragment because lateral displacement is an important component of the transfer.

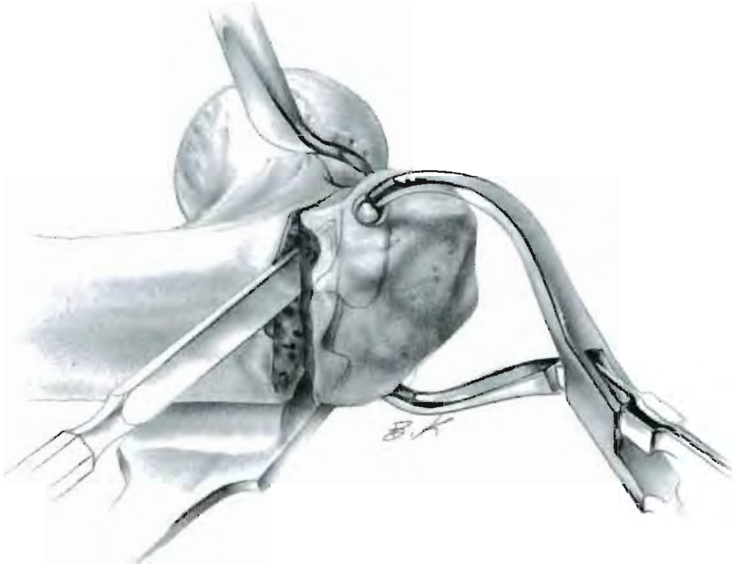


FIGURE 4-63. A retractor is placed posteriorly to protect the tissues while the elevator under the abductor muscles or another retractor protects the tissues anteriorly. An oscillating saw or an osteotome is used to create the osteotomy. It is best, however, if the saw does not penetrate the cortex to avoid damaging the vessels. An osteotome is used to crack through the remaining cortex, creating a greenstick fracture. The greater trochanter can be elevated and pulled cephalad by grasping it with a large bone-holding forceps or inserting a bone hook in the cut surface and pulling cephalad.

FIGURE 4-64. At first, the trochanter seems rigidly tethered with no sense of stretch when it is pulled. This is because of the fibrous connections between the muscle and the hip capsule. These fibrous connections and adhesions must be released carefully, which can be achieved with a combination of sharp and blunt dissection, taking care to avoid cutting into the muscle or damaging the retinacular vessels. When there is a feeling of elasticity as the trochanter is pulled, the release is complete.

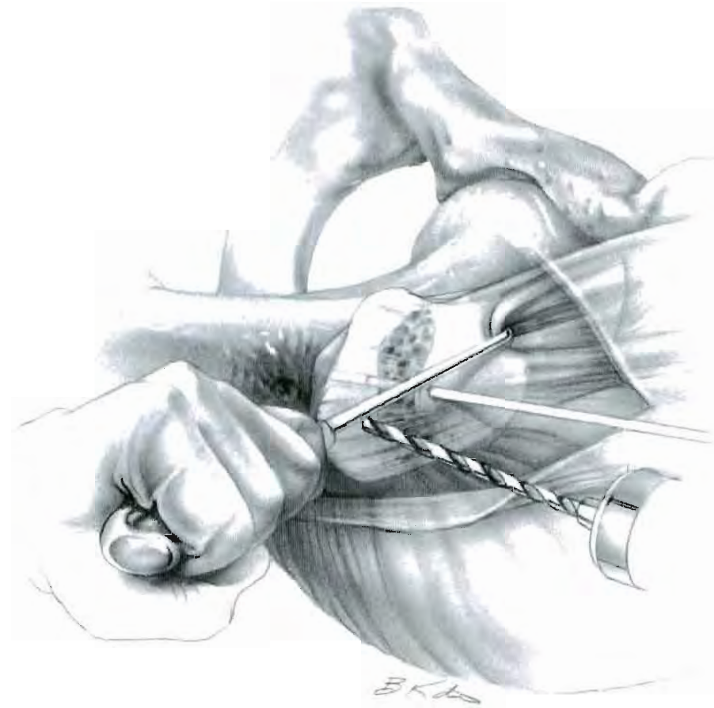


FIGURE 4-65. After roughening the cortex of the area to which the trochanter is to be transferred and contouring the surface of the fragment to provide good contact with the femur, the leg is abducted. The trochanteric fragment is then placed in the desired area and secured with two Kirschner wires. The use of a large bone hook to pull the greater trochanter distally avoids the complication of splitting the bone when a penetrating bone-holding clamp is used to grasp the bone. At this point, the location of the trochanter can be verified with the image intensifier. Ideally, the tip of the trochanter should lie on a horizontal line, connecting the center of the femoral heads, and it should be about 2 to 2.5 times the radius of the femoral head lateral to the center of the femoral head.

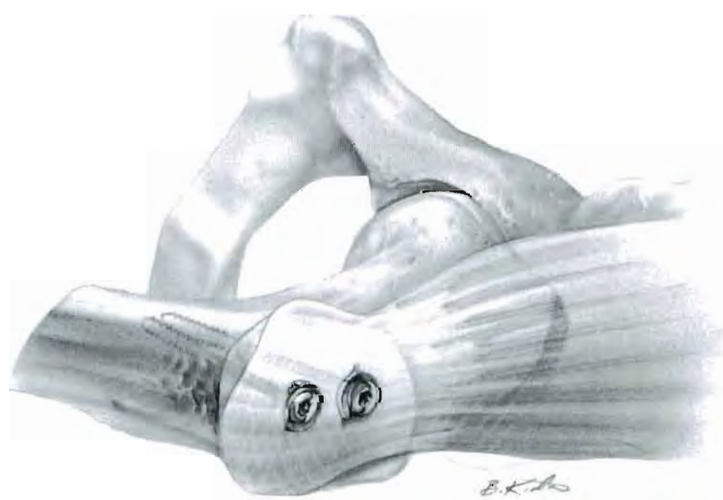


FIGURE 4-66. The trochanter is now fixed with two strong screws and washers. These screws should be directed distally and medially and should penetrate the medial cortex. If the surgeon is unsure of the fixation, a tension band can also be used. The wound is closed in a routine manner over a drain.

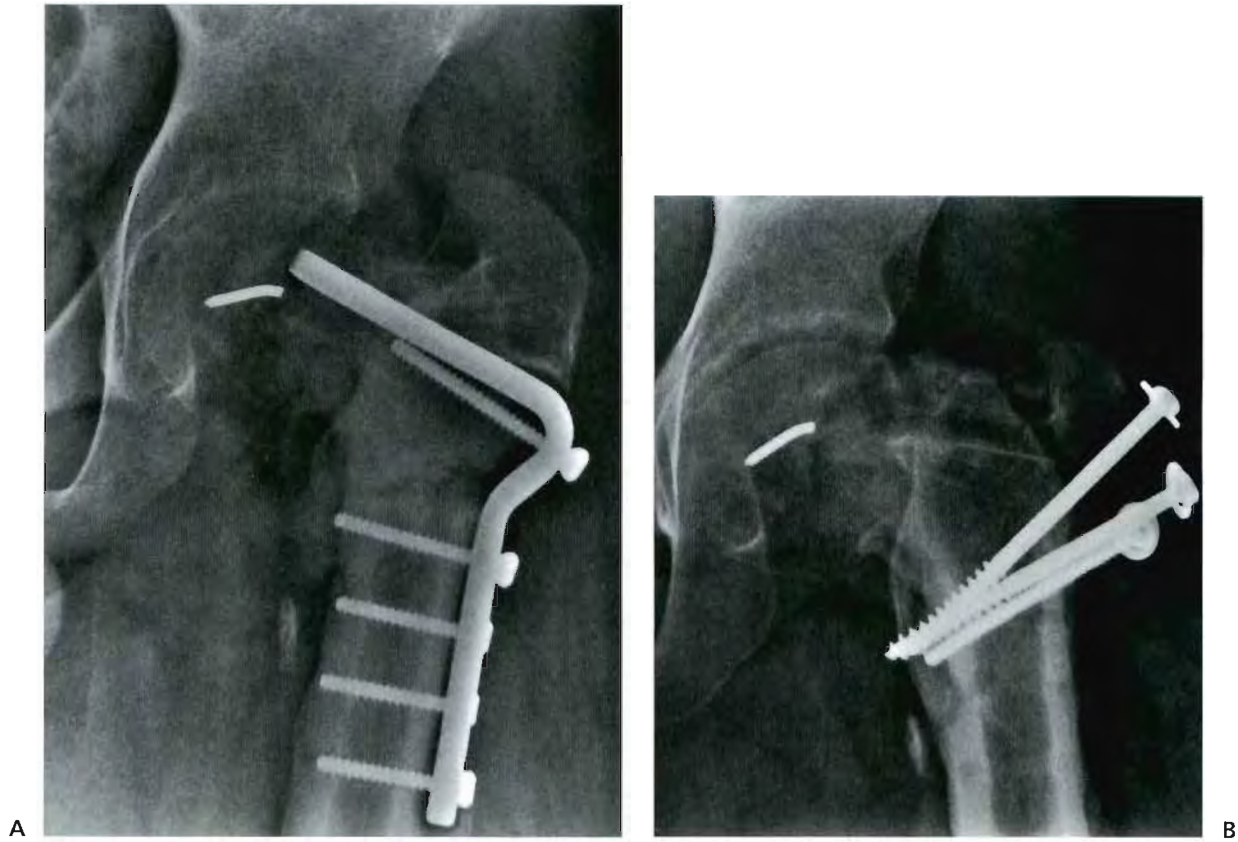


FIGURE 4-67. Radiograph of a patient with a severe slipped capital femoral epiphysis who underwent a Southwick osteotomy to correct the residual deformity **(A)**. This radiograph 6 months after the Southwick osteotomy demonstrates what turned out to be a delayed union with some loss of correction. This does not account for the entire problem with the trochanter; however, the varus component of the deformity was so severe that the largest wedge possible could not provide complete correction. One year after Southwick osteotomy, the bone had healed, and the patient was satisfied with his range of motion. He retained the abductor lurch during gait, however, which he had before the Southwick osteotomy.

Three months after transfer of the greater trochanter **(B)**, the patient's abductor lurch was almost completely eliminated. Note that although the tip of the greater trochanter does not lie at the ideal level in relation to the femoral head, it has been lateralized to a significant degree.

POSTOPERATIVE CARE

The patient is placed in traction with the leg slightly flexed and in abduction. Physical therapy begins with passive- and active-assisted motion the morning after surgery. By the second postoperative day, the patient is usually ready to begin ambulation with a three-point partial weight-bearing crutch gait. The abduction contracture gradually disappears. When healing of the fragment is confirmed radiographically, the patient is started on exercises to strengthen the abductor and extensor muscles around the hip. It is not unusual for it to take 6 months for the patient to recover full strength in the abductor muscles and for the lurching gait to disappear.

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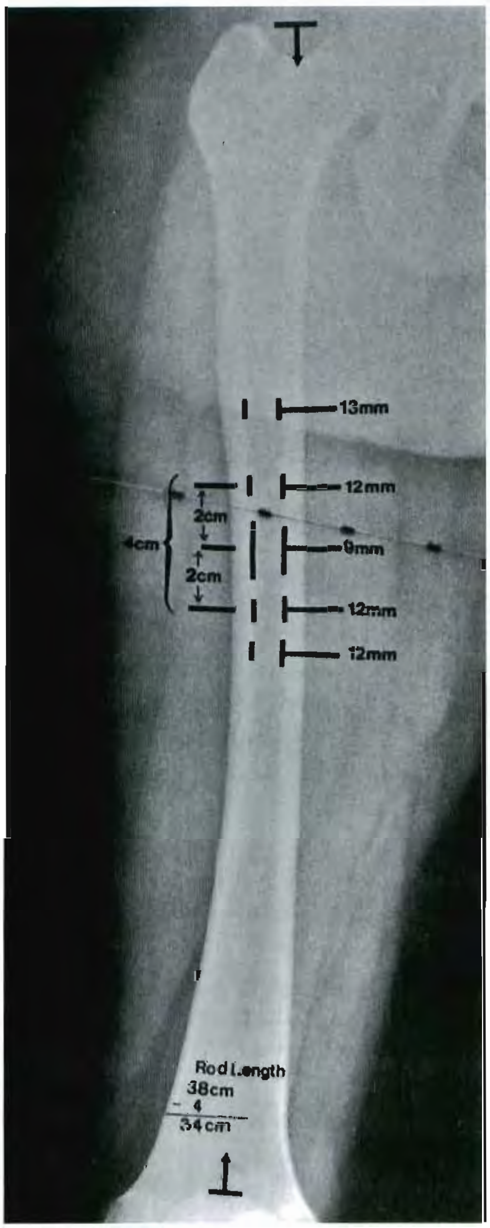
4.10 CLOSED INTRAMEDULLARY SHORTENING OF THE FEMUR

Despite current trends, shortening is often preferable to lengthening in the femur as a means of achieving leg-length equalization for the patient at or near skeletal maturity. Closed intramedullary shortening of the femur is preferable to open techniques because morbidity is less and immediate weight bearing is possible. Many surgeons are familiar with the technique of closed intramedullary rod placement for fixation of femur fractures, making this technique a viable option for an increasing number of surgeons who wish to learn it. In the hands of a surgeon skilled in the use of closed intramedullary shortening, this technique can also be applied to rotational femoral osteotomies and the correction of some angular deformities.

The key to the procedure is the intramedullary bone saw. This was initially developed by Kuntscher in 1962 and was improved greatly by Robert Winquist, working with the Boeing Company, in 1973 (1). This saw allows a segment of bone to be cut from the diaphysis of the femur using the usual incision in the buttocks that is used for closed femoral rod placement.

The procedure may be indicated in any patient at or near skeletal maturity who has a leg-length discrepancy of 6 cm or less that requires equalization. Shortening of greater than 6 cm is not advised because of the difficulty in quadriceps rehabilitation with greater shortening. A more detailed description of the preoperative clinical assessment and indications is given by Winquist (2) and by Blair and colleagues (3). Winquist (4) has also written about the details of the shortening procedure as well as the use of this technique in rotational and angular corrective osteotomies of the femur.

With the widespread use of this technique, complications seen with intramedullary fixation of femoral fractures, such as respiratory distress syndrome (5) and avascular necrosis (6), are also being reported (Figs. 4-68 to 4-80).

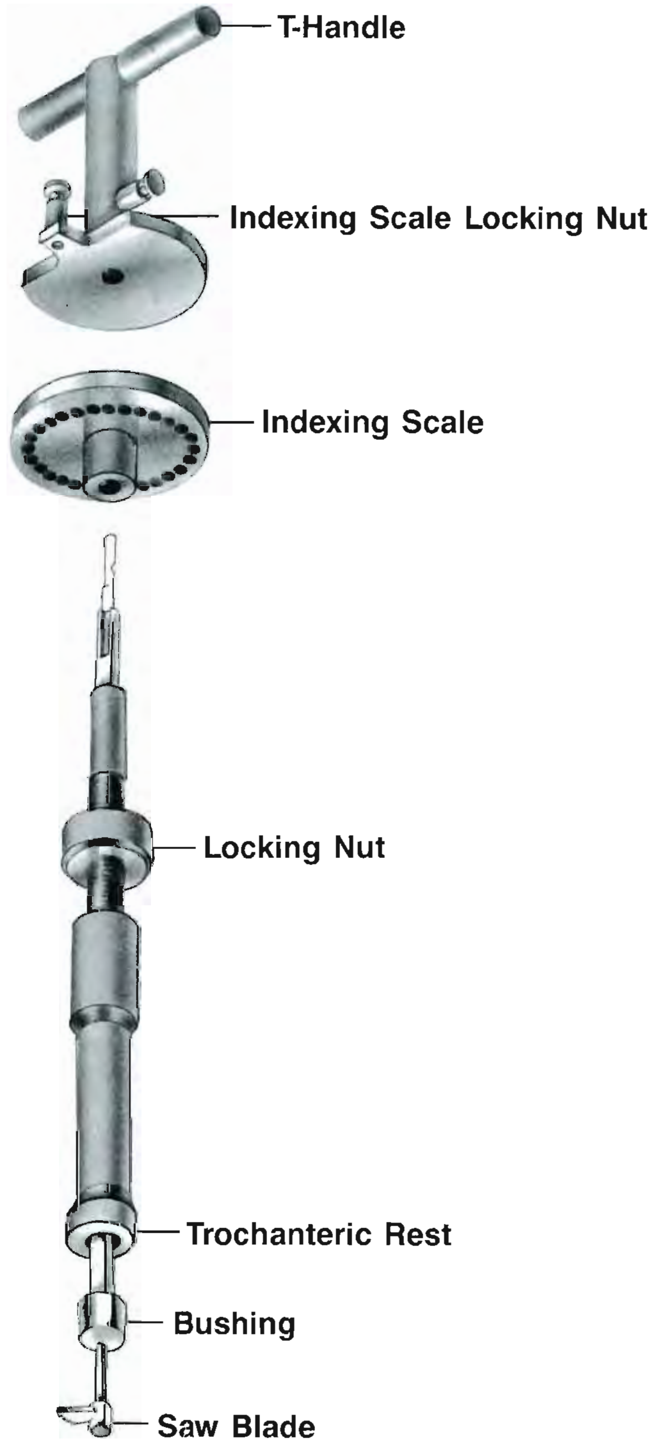

13mm
12mm
2cm
4cm
9mm
2cm
12mm
12mm
Rod Length
38cm
- 4
34cm

◀ **FIGURE 4-68.** An anteroposterior and lateral radiograph of the entire femur is necessary for preoperative planning. Before the availability of interlocking intramedullary nails, this step was crucial so that the rod would gain the best purchase on the two fragments to prevent rotation and pistoning. Measurements should be made with a translucent Ossimeter (Biomet, Warsaw, IN), which accounts for the magnification on the radiograph.

On the anteroposterior view, the narrowest intramedullary diameter should be identified. In the case illustrated, it is 9 mm. The segment of bone to be removed is marked on the radiograph, an equal portion (2 cm in this case) being taken from each side of the narrowest point. The width of the intramedullary canal and the outside diameter of the cortex is measured 2.5 cm proximal and distal to these proposed osteotomy sites. A rod of sufficient width should be used to provide secure fixation in this 2.5-cm section proximal and distal to the osteotomy. The largest diameter is proximal and measures 13 cm. The cortex is thick in this region; therefore, a 14- or 15-mm rod is necessary for secure fixation. If it is determined that this area is too wide for the widest available rod, an interlocking rod should be used to achieve rotational stability.

On the lateral view, note any unusual bow because this will cause eccentric reaming of the femur. The thickness of the linea aspera should be measured. This is the thickest part of the femur, and this measurement helps the surgeon determine how much reaming is necessary to allow passage of a saw large enough to cut through the linea aspera.

Finally, the length of the rod is determined. The distance from the tip of the greater trochanter to the epiphyseal scar of the distal femur is measured. From this, the amount to be shortened is subtracted. An additional 2 cm can be subtracted because a slightly shorter nail lessens the tendency to distract the osteotomy site and does not result in substantial loss of fixation.


T-Handle
Indexing Scale Locking Nut
Indexing Scale
Locking Nut
Trochanteric Rest
Bushing
Saw Blade

◀ **FIGURE 4-69.** The intramedullary bone saw set is required equipment in addition to all of the equipment necessary for closed intramedullary femoral rod placement.

The saw consists of two shafts: an inner one with a saw blade on the end and an outer one with a bushing set eccentrically on it just proximal to the saw blade. This bushing fits tightly inside the medullary canal. The size of the bushing on the saw defines the size of the saw, which ranges from 12 to 17 mm. In reality, the size of the bushing is 0.5-mm smaller than the stated size; therefore, it will fit into a canal reamed to the stated size. On the shaft opposite the saw blade is a T handle, an indexing scale marked 1 through 20, and a spring-loaded index scale locking nut. This T handle rotates the saw blade out from behind the bushing. There is a measuring device on a threaded portion of the outer shaft. It consists of a trochanteric rest distally and a locking nut proximally. The use of this part of the saw to measure the amount of bone to be removed is illustrated and described in Figure 4-76.

The intramedullary chisel is a sharp thick hook on the end of a strong rod. This is hooked on the distal end of the piece of bone to be split and is driven out of the bone with the slotted hammer. Because the piece of bone to be split is a rigid ring, splitting one side of it results in the other side of it splitting (see Fig. 4-78).

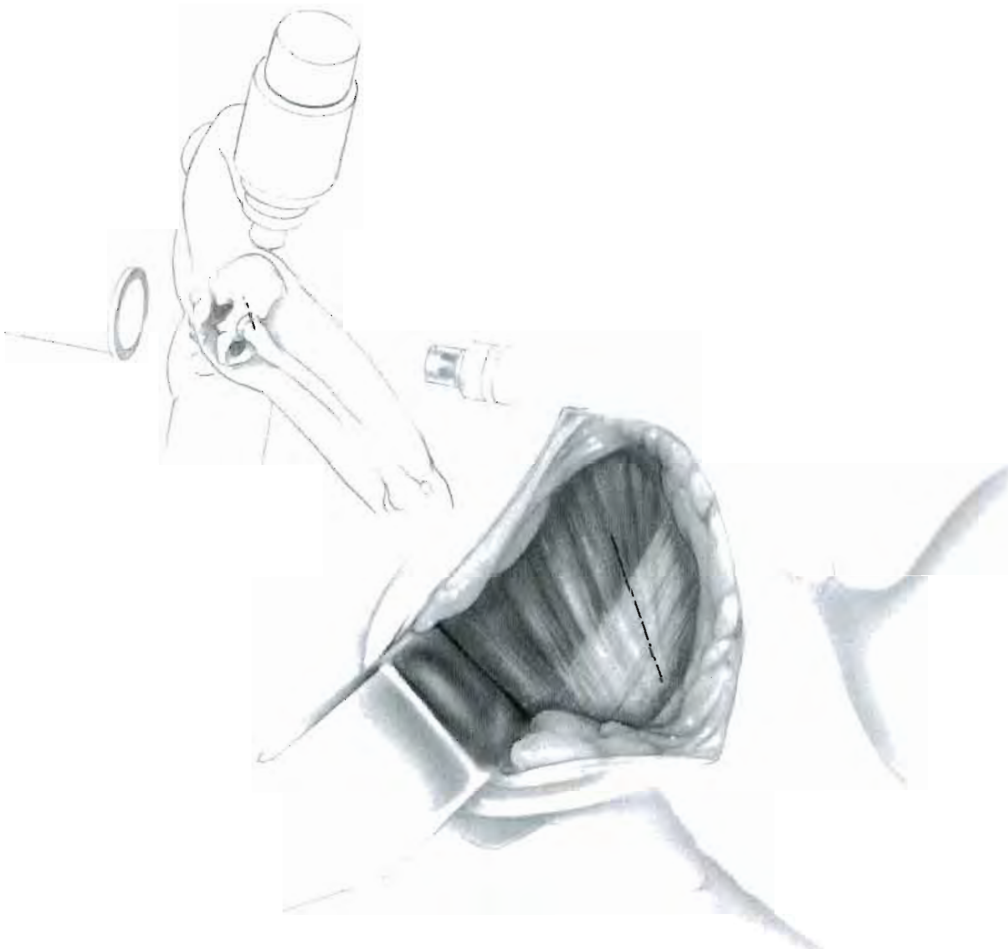


FIGURE 4-70. The operation begins as for any closed intramedullary rod placement in the femur. The patient is placed on a suitable fracture table in either the supine or lateral position. The gluteal area and the leg down to and slightly below the osteotomy site are prepared. The reason for preparing the limb to the osteotomy site is in case of the need to insert a percutaneous osteotome, as is described later. A transparent plastic barrier drape is ideal for draping the sterile field. The image intensifier is checked in both the anterior and lateral planes to be certain that an unobstructed view of the entire femur can be seen.

A 4-cm incision is made on the buttocks beginning 1 cm proximal to the tip of the greater trochanter and in line with the femoral shaft. This is deepened through the subcutaneous fat to expose the fascia of the gluteus muscles. The fascia is split sharply in the direction of the muscle fibers, and the muscle fibers are split bluntly, exposing the tip of the greater trochanter and allowing palpation of the piriformis fossa.

FIGURE 4-71. The T-handled awl is used to start the hole for reaming. It is crucial that this be in the correct place, just medial to the tip of the greater trochanter and slightly anterior to the piriformis fossa. This should be checked with the image intensifier in both the anteroposterior and lateral planes.

FIGURE 4-72. After this hole has been made, the bulb tip guide is passed to the distal end of the femur, and reaming is started with the 8-mm reamer. Reaming can be continued in 1-mm increments until cortical bone is encountered; it then progresses in 0.5-mm increments until the desired size of reamer is reached. Reaming should be monitored on the lateral view because the anterior cortex is thinned the most, and excessive thinning of this cortex should be avoided.

Reaming deposits a large amount of bone distally within the medullary space that will interfere with the final few centimeters of rod passage, causing distraction at the osteotomy site. This problem can be lessened by passing a 60-cm long, 12.5-mm end-cutting reamer down the canal as the final reamer. This helps to remove the bone debris. To make passage of the saw easier, the proximal 3 cm of the femur can be over-reamed an additional 0.5 mm.

FIGURE 4-73. The saw is now advanced down the medullary canal. The distal cut is made first. The measuring device is set to allow the saw to pass down the shaft to the distance that was determined on the preoperative radiographs. This can be checked on the image intensifier; however, this will not be as precise. It is of critical importance that the trochanteric rest be held firmly against the tip of the greater trochanter at all times. Not only is this the reference point for all measurements, but it also ensures that the saw remains in the same cut in the bone.

To begin the osteotomy, the index scale locking nut is pulled back and the indexing scale is advanced one hole past the zero mark. The T handle is then used to turn the saw through one or two complete revolutions. The osteotomy proceeds by advancing the indexing scale one hole at a time. Each time after it is advanced the saw is turned 360 degrees, cutting a small thickness of the bone. Each time the indexing scale is advanced, the saw protrudes slightly more. When the saw has been advanced to the number 20 on the indexing device, it has reached its maximal penetration. The indexing device is returned to the zero mark, and the saw is withdrawn.

Occasionally, after the anterior cortex has been cut through, the saw catches when it is rotated. Be certain that the measuring device is held firmly against the tip of the trochanter. If this fails to correct the problem, retract the saw three or four stops and begin to advance it one stop at a time. Care should be used because it is possible to break the saw.

FIGURE 4-74. At this point, osteoclasis of the femur is accomplished. This is a crucial step in the operation. The periosteum must be completely torn and stripped from the segment of bone that is to be removed. If this is not accomplished, it may not be possible to push the fragments of bone out of the way to allow shortening of the femur.

Osteoclasis is performed by the unscrubbed surgeon, who is probably the most important person in this operation. The surgeon removes the foot from traction, and with the knee in extension, bends the femur into varus to complete the osteotomy. Next, the two fragments of the femoral shaft are reduced, and the knee is flexed to 90 degrees to relax the sciatic nerve. The distal fragment is hyperextended at the osteotomy site to tear the linea aspera. The distal fragment then is bent into 60 to 70 degrees of valgus and then into the same amount of varus. With the osteotomy site held in valgus and then varus, the unscrubbed surgeon pushes the distal fragment cephalad to strip the periosteum from the fragment that will later be split and pushed to the side. Complete displacement and overlapping of the femoral fragments should be verified on the image intensifier. During this procedure, the intramedullary saw should not be used to stabilize the proximal fragment because it can bend or break. If stabilization is necessary, a small intramedullary rod is passed down the canal to the site of the osteotomy.

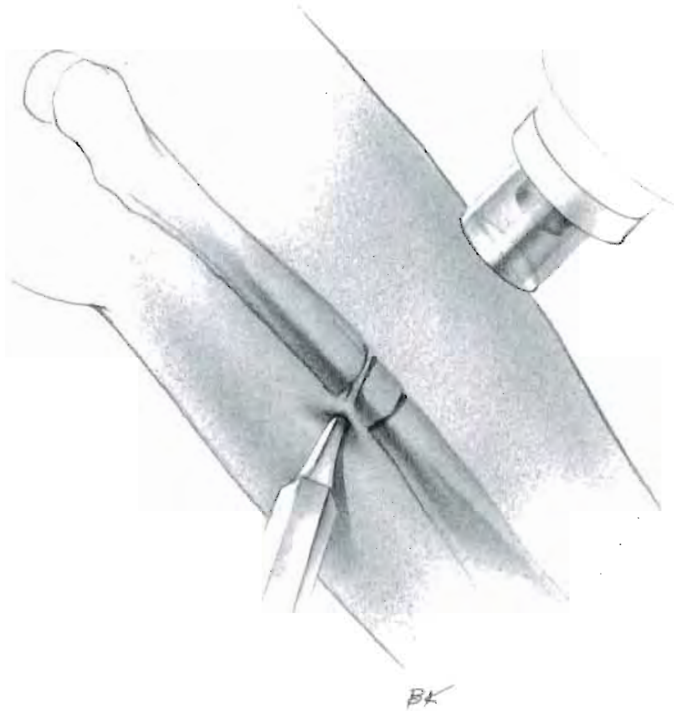


FIGURE 4-75. In some circumstances, the femur may not break. This is usually because the saw has failed to cut through the linea aspera. There are two ways to deal with this problem. The canal can be reamed larger and a larger saw inserted. If this is not possible, the osteotomy can be completed by inserting a 1/4-inch osteotome through a stab wound in the lateral thigh over the osteotomy site. The osteotome is passed into the osteotomy site under image intensifier guidance. The osteotome is then maneuvered posteriorly toward the linea aspera. With a firm grasp on the osteotome and the hand held firmly against the thigh, the osteotome is struck sharply with a mallet to complete the osteotomy.

FIGURE 4-76. The measuring device is adjusted so that when the saw is pushed back down the medullary canal, the next cut will define the correct length of bone to be cut. To make this adjustment, the locking nut is held firmly in place while the portion that rests on the trochanter is advanced down the shaft toward the saw blade. When the desired amount of shortening is measured between the trochanteric portion and the locking nut, the locking nut is tightened down on the trochanteric rest to prevent its movement.

FIGURE 4-77. The saw is now pushed down the shaft until the trochanteric rest sits firmly against the tip of the trochanter, and the entire procedure of cutting the bone is repeated at the proximal osteotomy site. It is necessary to complete this osteotomy. This can be done by using the distal fragment of the femoral shaft as a lever to break this intercalary piece of bone off the proximal fragment. If this is not possible, either of the two methods used to complete the first osteotomy can be used.

FIGURE 4-78. The intercalary fragment of femoral shaft created by the two osteotomies must now be split and moved out of the way to allow the femur to shorten. If the entire piece of bone or one large piece of bone is displaced, it may create a symptomatic enlargement that interferes with muscle movement.

The intramedullary chisel is inserted through the proximal and intercalary fragments, and the hook is directed posterolaterally to catch on a thick part of the intercalary fragment. It is usually not possible to split the linea aspera, and if the thin anterior cortex is split, one large and one small fragment will result. With the hook in the proper location, the slotted hammer is used to drive the hook out of the canal. The image intensifier is used to verify that the intercalary fragment is split and to avoid splitting the proximal femoral shaft.

After the fragment is split, the hook is used to displace the pieces to each side. Additional manipulation of the fragments can be accomplished by pushing on them with the distal fragment of the femoral shaft as it is brought into apposition with the proximal fragment. It must be possible to displace the split fragments and bring the distal and proximal shaft into apposition.

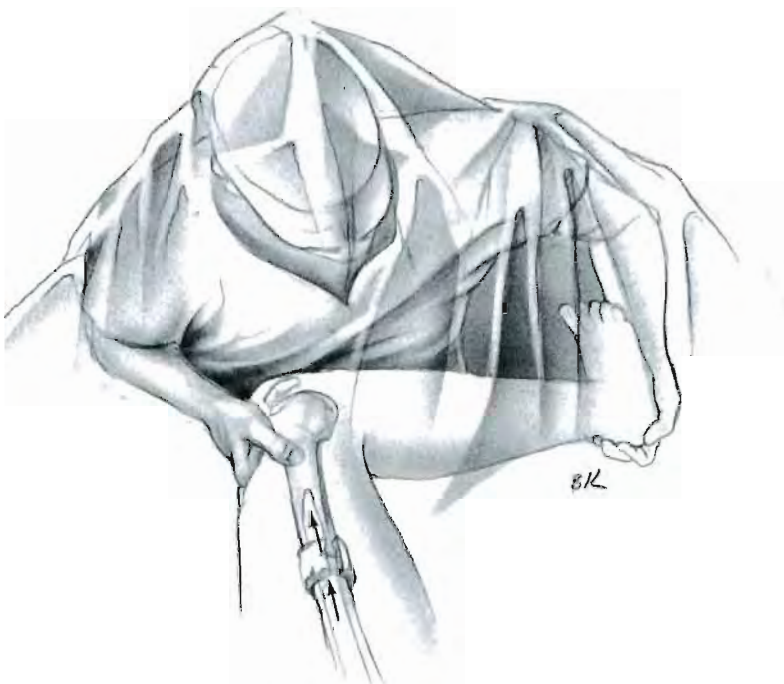
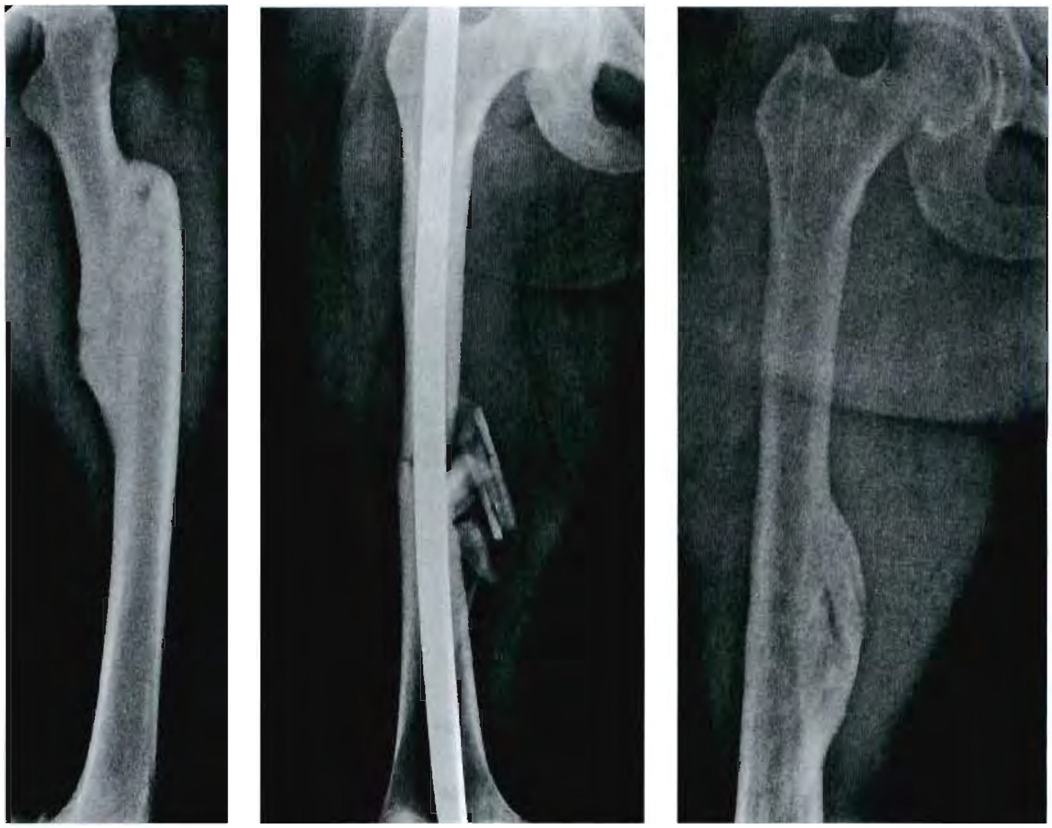


FIGURE 4-79. With the two fragments now in apposition, the distal one held by the unscrubbed surgeon, the rod of correct size is driven down the canal. During this part of the operation, it is important for the unscrubbed surgeon to maintain the correct rotation of the distal fragment while pushing cephalad on the bent knee to keep the osteotomy site from distracting. It is especially important to monitor the rod passing the osteotomy site on both the anteroposterior and lateral views. Next, the distal end of the rod is monitored. Remember that a rod shorter than usual was selected to avoid the problem of overdistraction.

Maintaining the correct rotation is difficult. This is especially true because the leg will be removed from traction during the procedure. Visually maintaining the alignment of the leg as it was before the osteotomy and placing the leg in 20 degrees of internal rotation, as is recommended for intramedullary nailing of fractures, is usually reliable. Because of its importance, this procedure requires the most experienced member of the operating team. When shortening of greater than 3.5 to 4 cm is done, Winquist (7) recommends the use of an interlocking rod to maintain the correct rotation. The use of an interlocking rod necessitates absolute accuracy in the rotation of the two fragments because no adjustment will be possible after completion of the operation. This can be accomplished by placing one pin proximal and one pin distal to the osteotomy sites before they are made. The proximal pin is placed as far anteriorly in the greater trochanter as possible to avoid interference with the reaming and rod passage. The second pin is placed in the lateral femoral condyle below the epiphyseal scar parallel to the first pin. These two pins provide a visual reference for rotational alignment.

Occasionally, a small spike results from the osteoclasis in the region of the linea aspera. If this does not occur at both osteotomy sites and form a mirror image on the proximal and distal fragment, it will hold the fragments apart. Attempts should be made to break this off, but if it is not too large, it can be accepted.

After the nail is in satisfactory position, the wound is closed. A drain is not necessary and, if used, usually blocks off early because of the debris that drains from the medullary canal. The patient is moved to the stretcher, and the rotation of both legs is inspected to ensure that no serious rotational malalignment exists. If manipulation of the leg cannot correct a discrepancy in rotation, it may be necessary to redo the nailing. If there is poor rotational stability, this needs to be accounted for in the postoperative management.



A, B C

FIGURE 4-80. TL is a 14-year-old girl who 3 years previously sustained a closed fracture of the femur. She was treated with traction for 3 weeks, followed by a spica cast for 3 months. Her final result was malunion with 4 cm of shortening **(A)**. Closed intramedullary shortening of the femur was chosen as the method to achieve leg-length equalization. The preoperative planning on the anteroposterior radiograph of the opposite leg is shown in Figure 4-68. **B:** The patient's immediate postoperative radiograph. Note the excessive amount of bone medially that resulted from splitting the intercalary fragment in the wrong area. This was symptomatic for about 6 months when bending the knee past 60 degrees. **C:** The final result 18 months after rod removal.

POSTOPERATIVE CARE

The patient should be placed in a derotation boot in the operating room to prevent external rotation of the leg if an interlocking nail was not used. This is maintained for 2 to 3 weeks while the patient is in bed. The hematocrit should be followed closely for several days because considerable bleeding into the thigh may occur.

Quadriceps exercises are started the day after surgery, and partial weight bearing is started within 24 to 48 hours. The patient is continued on crutches for 6 to 8 weeks. The rod can be removed at 1 year.

If there is no rotational stability or if pistoning of the bone is encountered, it is wise to apply a one-leg spica cast down to the knee when the swelling has decreased before discharge from the hospital. Within 3 to 4 weeks, muscle tone and healing provide sufficient stability to allow removal of the cast. These complications are avoided by the use of an interlocking rod.

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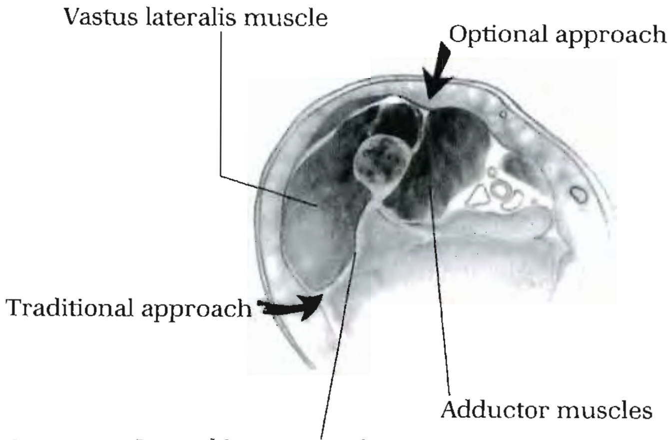
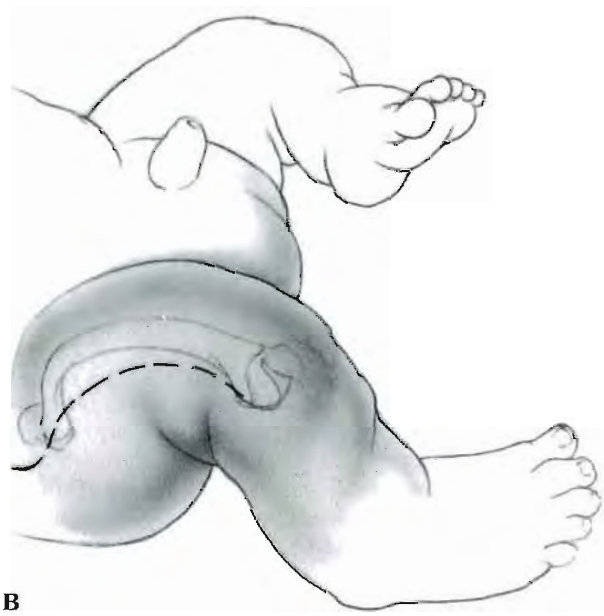
4.11 FRAGMENTATION, REALIGNMENT, AND INTRAMEDULLARY FIXATION FOR FEMORAL DEFORMITY IN OSTEOGENESIS IMPERFECTA (SOFIELD PROCEDURE)

In 1959, Soefield and Millar (1) reported their 10-year experience using fragmentation, realignment, and intramedullary rod fixation in 52 children with osteogenesis imperfecta, congenital pseudarthrosis of the tibia, rachitic deformities, and fibrous dysplasia. They used Steinmann pins, Rush rods, and Kuntscher rods depending on the size of the bone. In 1965, Williams (2) reported on his experience using two heavy Steinmann pins that were threaded on one end so that they could be screwed together. (These rods and the technique for their use are described in the treatment for congenital pseudarthrosis of the tibia.) Bailey and Dubow (3) developed a telescoping rod with a T piece at each end to hold the rods at the ends of the bone so that they elongate as the bone grows. There is a fixed T piece at one end of the solid central rod and a second T piece that screws onto the end of the hollow rod. Use of these rods is reported by other investigators (4,5).

The surgeon chooses whether to use an extendable rod or a solid rod of fixed length. Rush rods are easily inserted and relatively inexpensive, and multiple rods of all sizes can be stocked easily. The length is adjusted by cutting the end of the rod. When the rod becomes too short, it can be replaced through a small incision on an outpatient basis. The solid rod also has the advantage of greater strength, but it must be replaced every 2 to 4 years depending on growth. The extendable rod is designed to elongate with the growth of the bone. Its insertion, however, requires an arthrotomy of the knee joint to insert one of the rods. The T piece can come loose, requiring subsequent arthrotomy for repair. At times, these rods become locked and do not elongate, and they are more likely to bend in the bone (6). There is evidence in the literature to support whatever method the surgeon chooses, and the choice probably reflects which method the surgeon is most familiar (7,8) (Figs. 4-81 to 4-87).



A



B

FIGURE 4-81. Keeping the approach to the femur through anatomic planes may prove difficult in the severely bowed femur. If the dissection proves impossible or unsafe, a small muscle-splitting incision over the maximal apex of the bow can be used **(A)**. It should be kept as far from the lateral incision as possible. Through this small and limited incision, the bone at the apex is exposed and excised. This allows the proximal and distal segments to be pushed toward the lateral incision to facilitate the remainder of the dissection. Some surgeons may not mind splitting the muscle to reach the bone, although for this operation, it would be an extensive muscle-splitting incision.

In planning the procedure, the radiographs will be of value only in determining that the bone is of sufficient diameter to accept whatever fixation is chosen. Because these deformities are complex and involve rotation as well as angulation, the true deformity is seldom appreciated on the radiographs. In addition, it is easy to underestimate the amount of bowing; this may lead to the surgeon planning too limited a resection of bone. Even in milder deformities, there is usually more deformity at the metaphyseal ends than the surgeon suspects.

The incision should extend from the proximal to the distal metaphysis **(B)**. The bone should be exposed from the metaphyseal flare of the femur distal to the level of the lesser trochanter so that all of the deformity can be appreciated. If this is not done, it often leads to the rod passing out of the distal fragment or being eccentric (2,10).

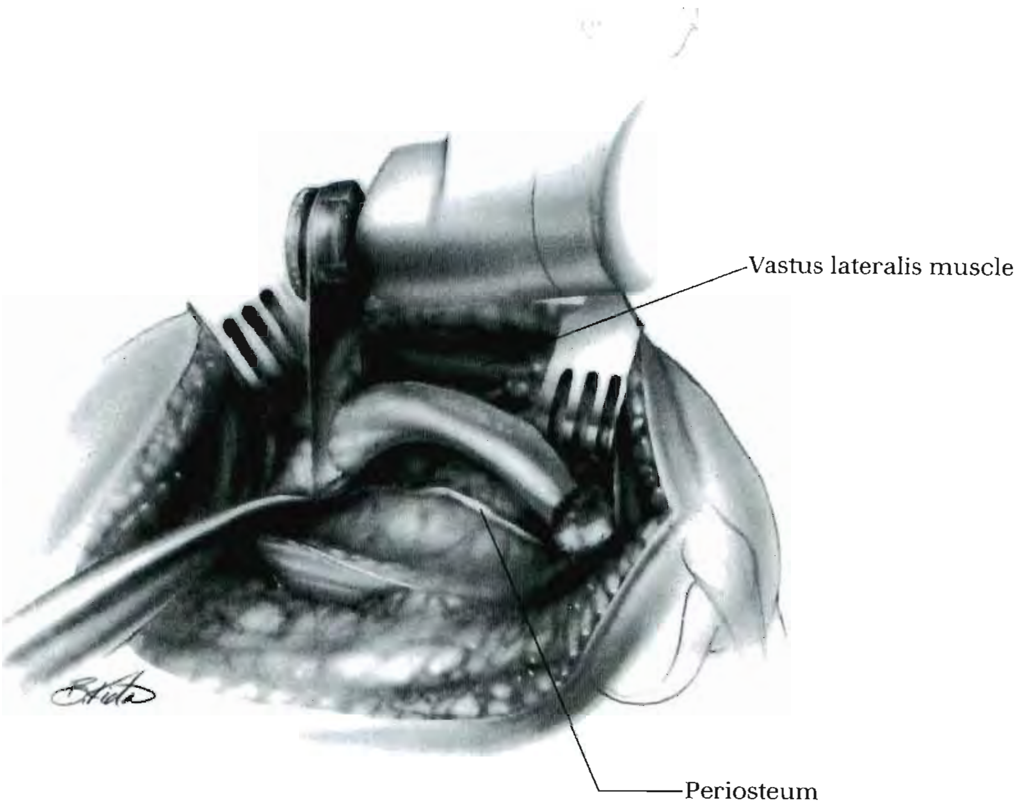


FIGURE 4-82. The fascia lata is divided, and the plane along the anterior aspect of the intermuscular septum is followed to the femur. The periosteum is divided with care to coagulate the perforating arteries, which can be identified before they are divided. The periosteum is stripped circumferentially from the shaft. Care should be taken to preserve the periosteum because it will be the source of blood supply and healing for the removed and now devitalized bone. The bone is divided at each end with an oscillating saw and removed to the back table. The osteotomies are usually just below the lesser trochanter and well into the flare of the metaphysis distally.

FIGURE 4-83. The deformed piece of bone is now divided into multiple pieces in such a way that each piece is straight. The bone must be handled with great care because it can break easily. The most bent pieces of bone probably will be discarded because the soft tissues cannot elongate sufficiently to allow all of the bone to be replaced.

Depending on the bone, it may be necessary to drill holes in each segment to accept the rod. Because the bone is fragile, it is best if the rod passes easily into each of the segments. If there is a small canal, the drilling should start with a small drill and increase in size gradually to avoid breaking the fragments. Slight overdrilling is also desirable.

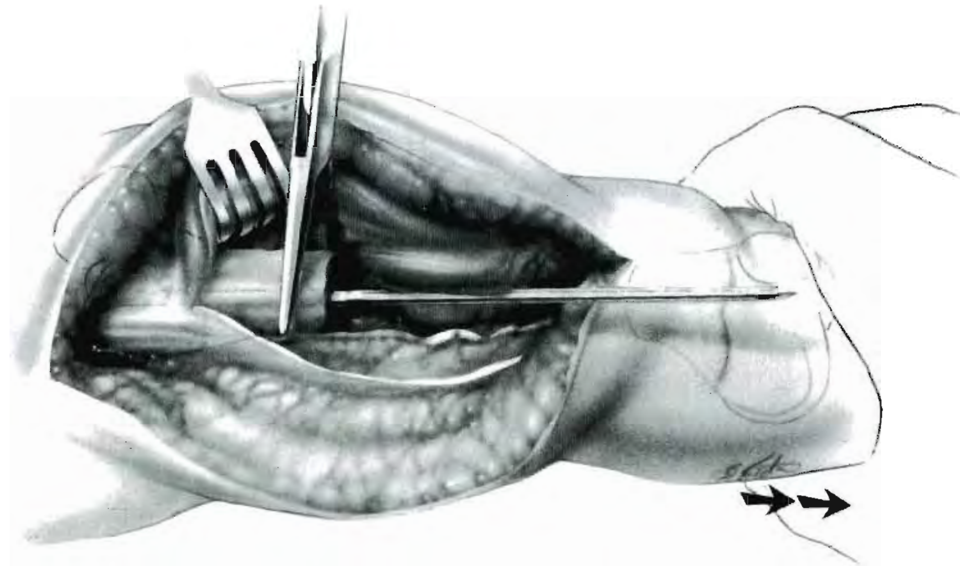


FIGURE 4-84. The length of the Rush rod is now estimated with the image intensifier. The hooked end of the rod is located in the proper relationship to the greater trochanter. With traction on the leg, the image intensifier is moved distally to determine the length of the rod in relation to the desired length of the leg. The tip of the rod should penetrate the epiphysis. This provides better fixation because of the denser bone at the physis and should not damage the growth (9). If one rod is too long and the next too short, the longer rod is cut to the correct length.

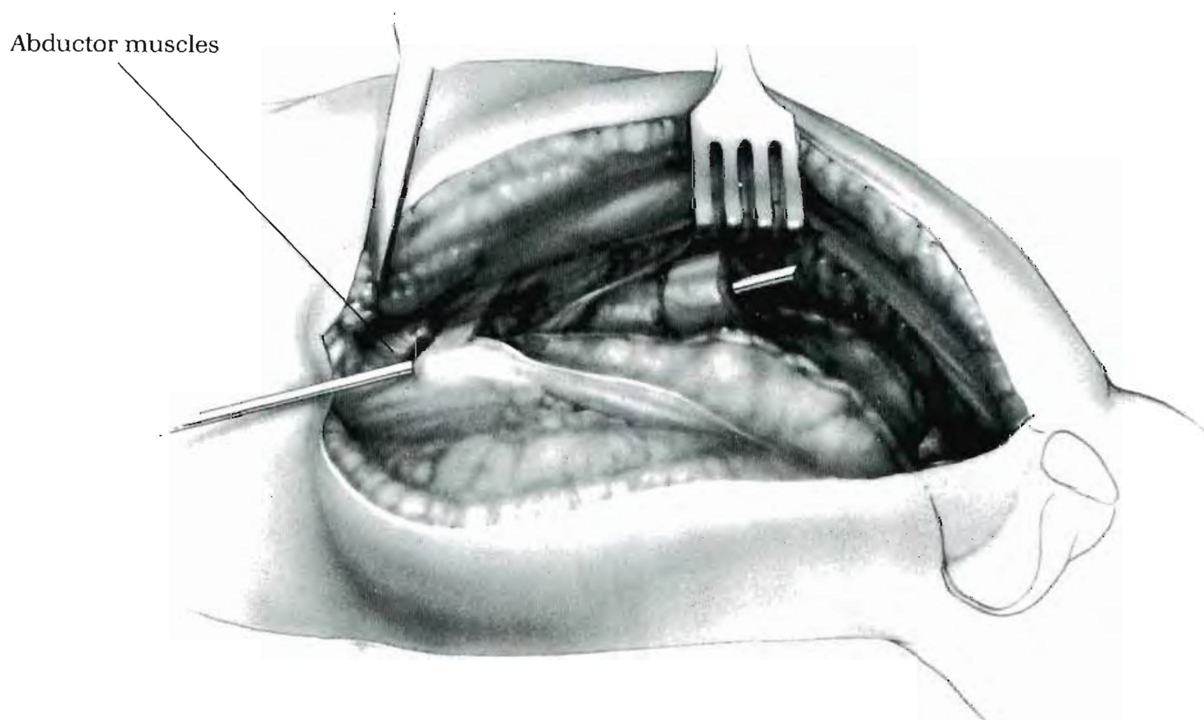
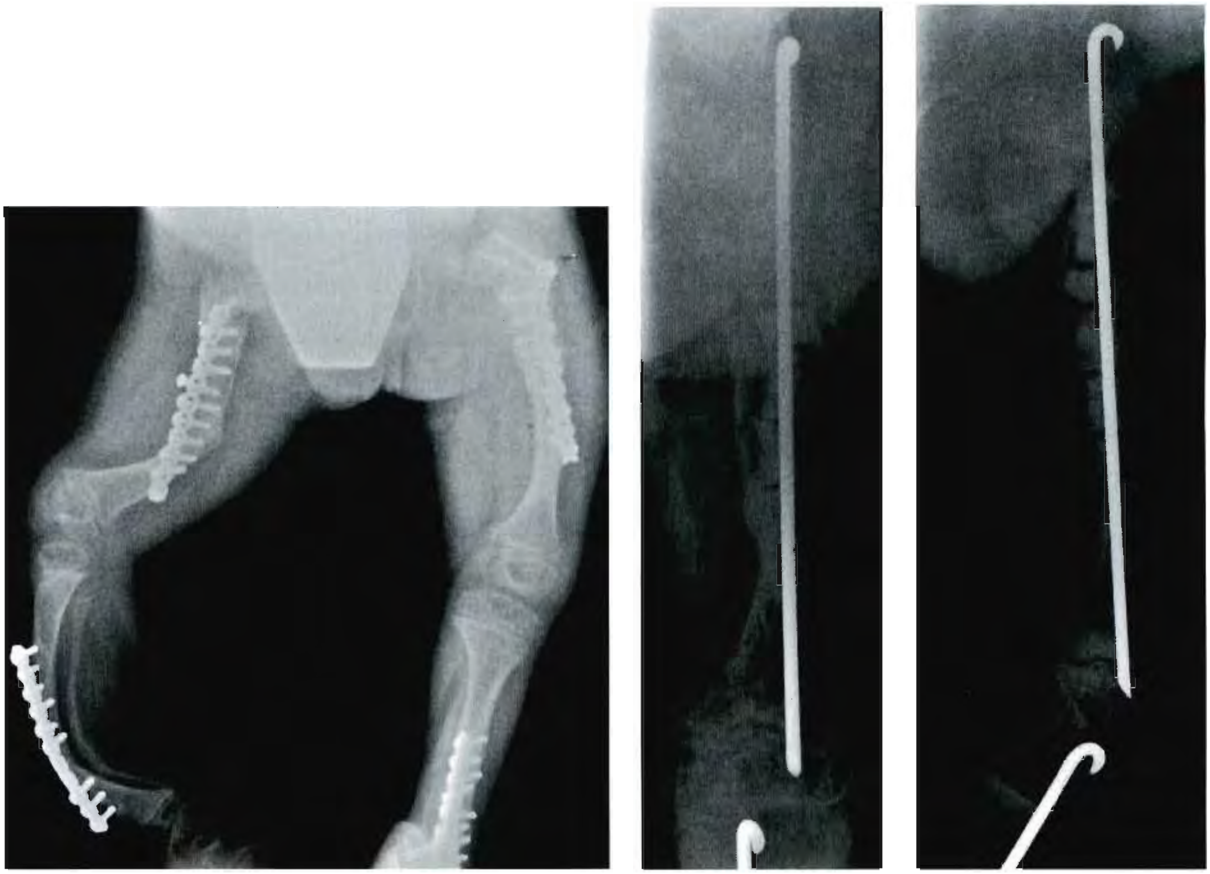


FIGURE 4-85. The awl for the Rush rod (or the instrument or drill that is appropriate for the rod to be used) is passed retrograde in the proximal fragment to exit just medial to the greater trochanter. The cautery can be used to make a small cruciate cut directly over this exit hole. This facilitates insertion of the Rush rod. A rod of the appropriate size is now passed through the proximal fragment and advanced so that the fragments of bone that have been prepared can be placed on the rod.

FIGURE 4-86. The fragments are threaded on the rod. They are not placed in any particular order. The rod is advanced into the distal fragment. This is the most important and difficult part of the operation. It is best to use the awl to prepare the path. This permits verification on the image intensifier that the position is correct. As the rod is advanced into the distal fragment, it is checked again with the image intensifier to be certain of proper positioning. If the proper position cannot be obtained, there probably is still a residual bow in the distal fragment.

After the fixation is complete, the periosteum, the fascia lata, the crural fascia, and the skin are closed over drains. A light-weight spica cast is applied.



A B, C

FIGURE 4-87. Radiographs of a 6-year-old boy with osteogenesis imperfecta who previously underwent multiple osteotomies and fixation with reconstruction plates. This demonstrates the reason for using a load-sharing device to solve this problem: the soft bone continues to bend unless reinforced because the bone is too soft to hold screws **(A)**. What cannot be appreciated from these radiographs is the magnitude and the three-dimensional nature of the deformity. The anteroposterior and lateral radiographs at the time of cast removal 6 weeks after surgery demonstrate the multiple osteotomies, the position of the intramedullary rod, and the initial healing from the periosteum **(B, C)**.

POSTOPERATIVE CARE

Because postoperative bleeding can be significant, especially because the surgeon usually operates on both femurs at the same time, the hematocrit should be checked at appropriate intervals. The patient remains in the spica cast for about 6 weeks, at which time sufficient healing has occurred to permit gentle range of motion.

The course of therapy and the use and type of orthotics depend on the patient and the ability to ambulate.

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4.12 CLOSED REDUCTION AND SPICA CAST APPLICATION FOR THE TREATMENT OF FEMORAL SHAFT FRACTURE

Closed reduction and cast treatment for femoral shaft fracture has been used for many years and in many different ways (1–3). McCarthy (4) has reported on a technique for early reduction and casting. A recent comparison of different methods of treating femur fractures in children demonstrated the efficacy, lack of complications, and cost effectiveness of this method (5).

Despite all of the reports of its usefulness, this method is still not in widespread use in the United States. The most common method still in use is traction until initial healing renders some stability to the fracture, and then application of a spica cast. Part of the problem with the method of early reduction and spica cast treatment is the skill needed to apply a spica cast that will hold the fracture reduced. It requires a knowledge of the forces acting on the fracture along with close attention to the position of the limb and the molding of the cast.

There are many variations on the technique, and no one method is correct. The important principle is to apply a cast that will hold the reduction (Figs. 4-88 to 4-93).

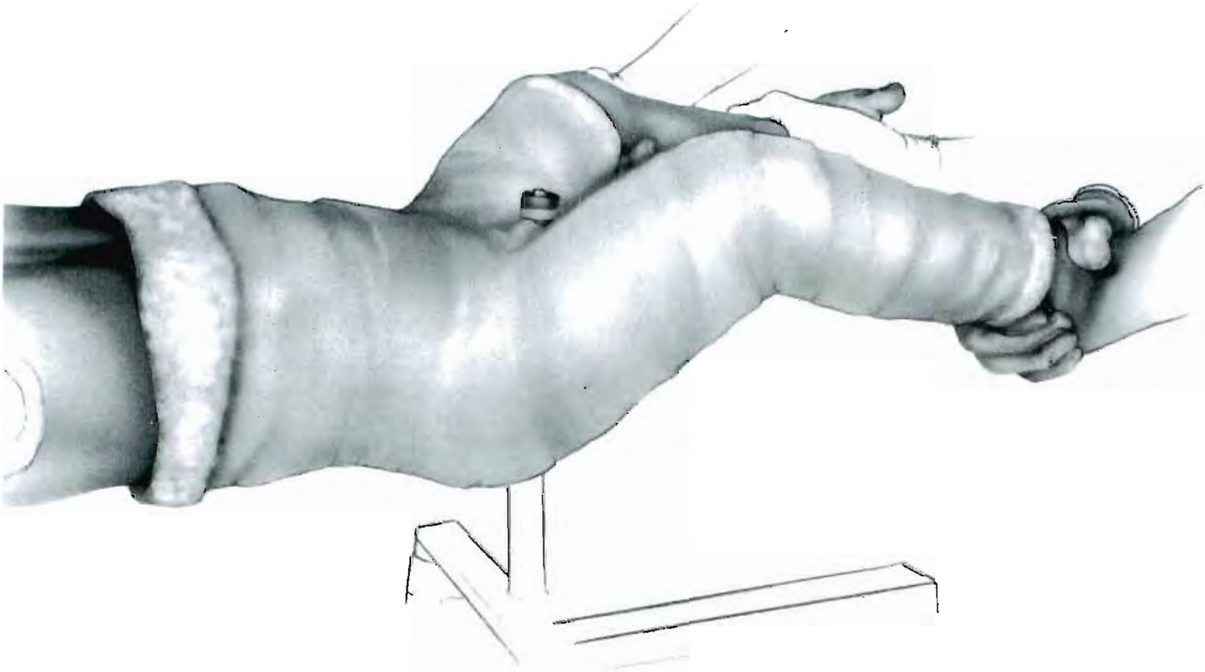

FIGURE 4-88. In children younger than 2 years of age with a spiral fracture, the reduction and cast can be applied in the emergency room with intravenous sedation. If there is no other reason for admission and child abuse is not an issue, the patient can be discharged home from the emergency room. In older patients, especially those with a transverse fracture, a general anesthetic is necessary.

A general anesthetic is administered with the patient on the operating table. A stockinette is applied to the torso, the affected leg to the ankle, and the opposite leg to the knee.

After this is completed, the patient is placed on a small spica table. The legs are held by an assistant in the approximate position in which they will be casted. The soft padding is wrapped around the body and legs. Extra turns of the soft roll or felt pieces are placed over the bony prominences. A towel or some spacer should be placed on the chest so that the cast does not restrict breathing. Only one to two layers are applied to the affected leg. Multiple layers are applied to those areas where the cast will rub, especially where the cast ends at the chest and distally on the legs. The cast only needs to be applied to the ankle above the malleolus on the affected side because rotation of the distal fragment will be controlled by the bent knee.

If the surgeon wishes to check the fracture alignment or attempt to gain end-to-end apposition of the fragments, he or she should do so at this time.

FIGURE 4-89. First, a long leg cast is applied. This provides a firm area over the posterior aspect of the calf on which to apply traction to the femur. In addition, bringing the cast above the knee assures that there is not a bent or sharp area in the cast behind the knee.

The hip and knee should be in no less than 60 degrees of flexion, more if the fracture is in the proximal one third. The leg is held gently in alignment. The casting material is pulled snugly, particularly around the thigh. Only two to three layers of casting material are wrapped over the thigh, where the mold to hold the fracture will be applied. The cast is molded over the fracture. These molds remain flexible so that they can be increased when the remainder of the cast is applied.

The ideal situation is when the femur is overcorrected. For example, a transverse midshaft fracture that is in 5 degrees of posterior and medial angulation would be ideal at the conclusion of casting. This is because the fracture in this location tends to bow anteriorly and laterally. The molds are applied, but at this time, the leg is gently held in alignment.

FIGURE 4-90. When the leg section has dried, the remainder of the cast is applied proximally to just below the nipple line and is stopped 3 to 4 cm above the flexion crease of the knee on the opposite leg. Traction is applied to the affected leg by the assistant while the cast is rolled and molded. The rigid leg section allows the assistant to pull without causing undue pressure on the calf or denting of the cast. A good mold is applied around the iliac crests, over the pubis, and continuing down onto the anterior and lateral thigh, where the long leg cast portion was molded. One hand presses over the lateral thigh and the other over the anterior thigh to produce a quadrilateral mold. It is often surprising to note how close to the groin the anterior mold needs to be applied. This can be checked on the postoperative radiographs.

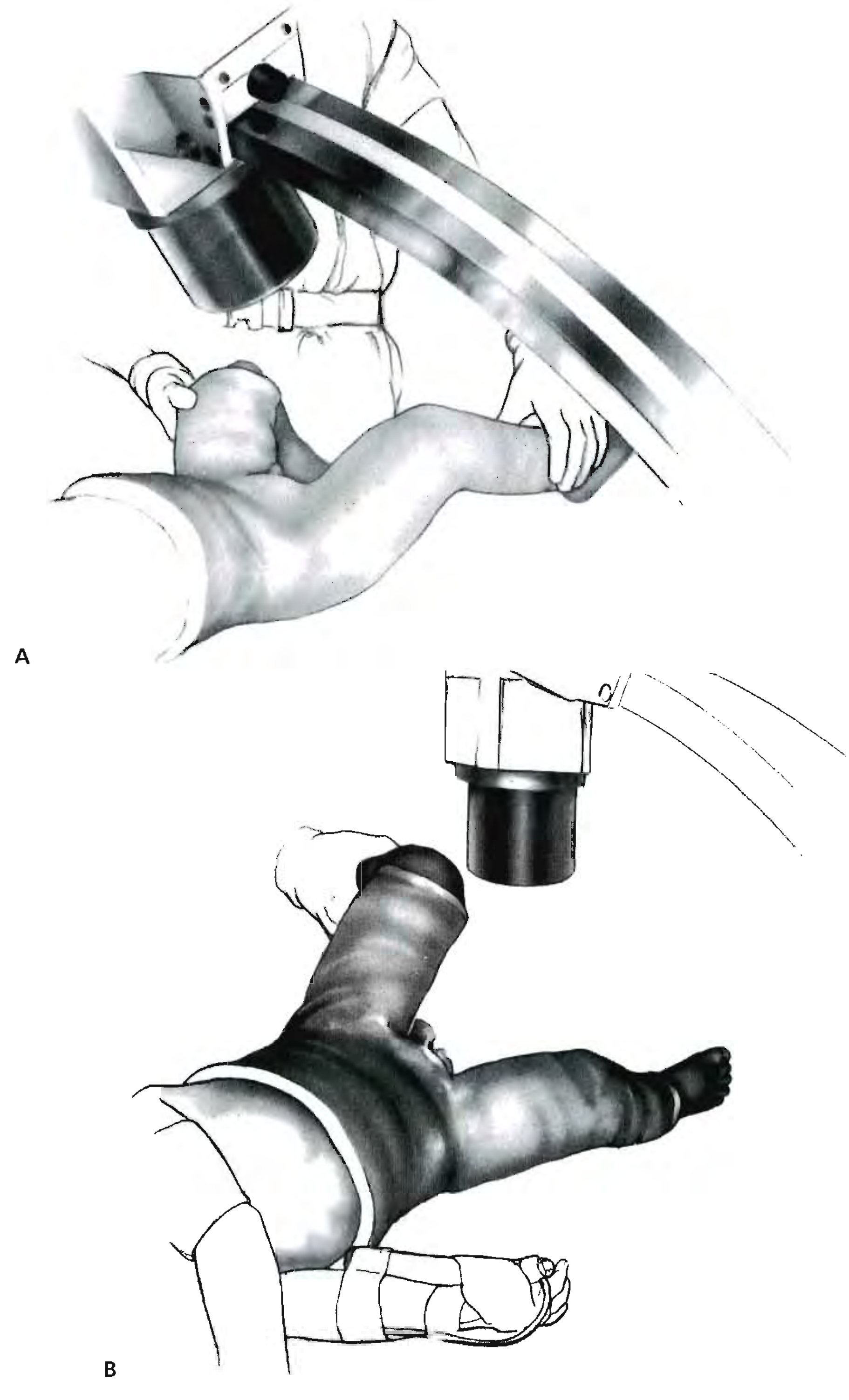

FIGURE 4-91. When the cast has hardened, the image intensifier or portable radiograph machine is used to check the alignment in the anteroposterior and lateral projections. To obtain a good anteroposterior view, the tube is tilted so that the beam is perpendicular to the femur **(A)**. To obtain the lateral view, the tube is brought back into its normal position, and the patient is tilted to a position slightly off of true lateral so that the opposite leg does not get in the way **(B)**.

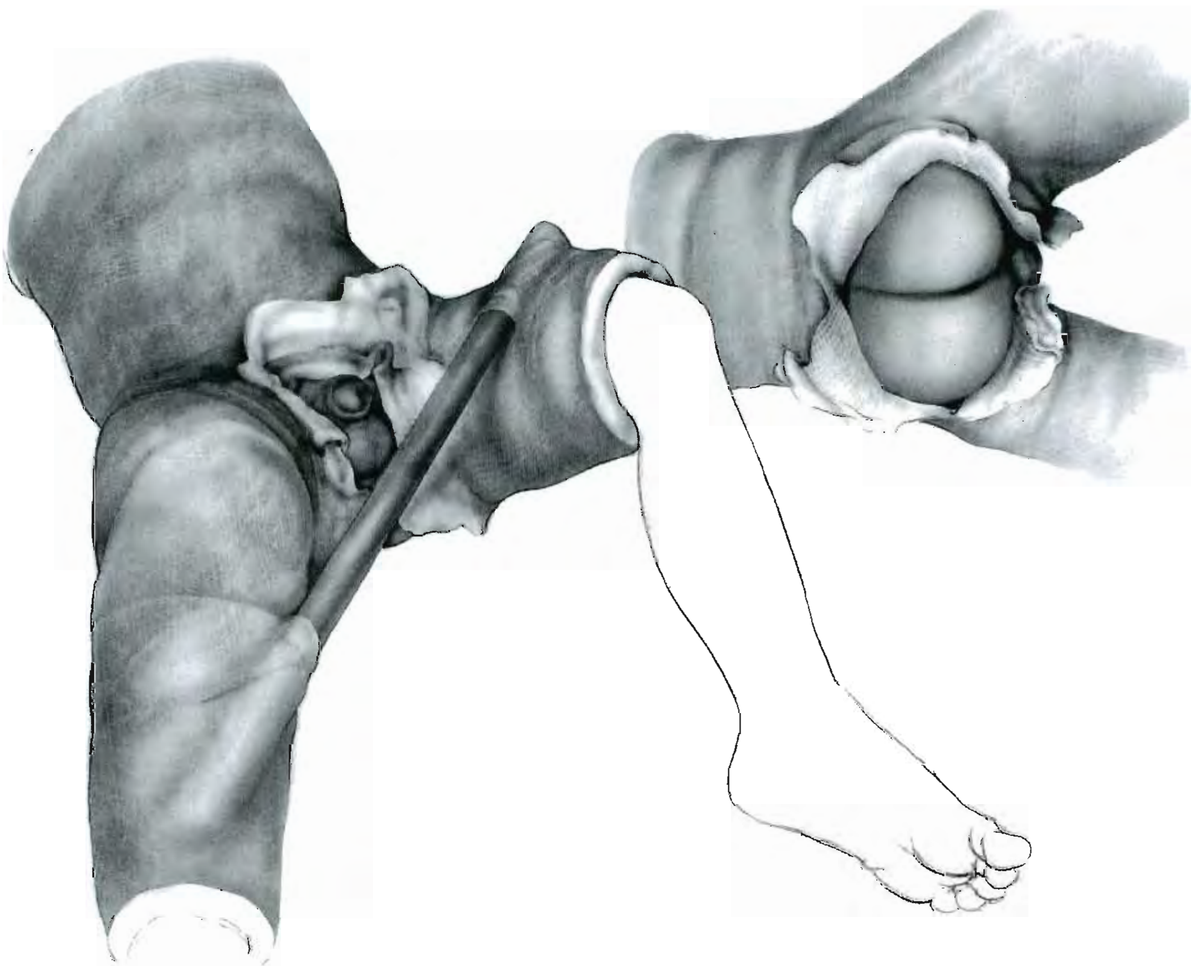

FIGURE 4-92. If the alignment is not acceptable, the cast can be changed or wedged. If the alignment is good, the perineal area is trimmed sufficiently to permit toileting, and a crossbar is applied. Posteriorly, the cast should be trimmed above the natal cleft, and there should be at least four to five finger breadths of space in the perineal area. The crossbar should be as distal as possible on both legs to avoid interfering with perineal care. Its purposes are to add rigidity to the leg sections of the cast and to prevent the leg section from breaking when the patient is turned on the side.

FIGURE 4-93. A: Anteroposterior radiograph of the femur of a 7-year-old girl. She underwent a closed reduction under general anesthesia shortly after arrival at the emergency room. **B, C:** The reduction that was achieved. It was not considered necessary to achieve the end-to-end reduction. Note the anterior mold in the cast to prevent anterior angulation of the fragments. **D:** Radiograph taken 2 weeks after reduction. Note that the fracture has slipped and shortened. The shortening was measured at just under 2 cm. **E, F:** Twelve weeks after fracture, the bone has consolidated. There is no clinical deformity, and the pelvis levels with a 0.5-inch lift. No significant shortening is anticipated. ▶


A
B, C
D
E, F

POSTOPERATIVE CARE

Small children may undergo this procedure in the emergency room with conscious sedation, especially those with spiral fractures. Others may be done as outpatients or kept over night. Swelling and mild discoloration of the foot are common, and the parents are instructed to watch for signs of vascular embarrassment as well as the care of the cast. The patient is seen as an outpatient in about 10 days and then after 20 days for radiographic assessment of the angulation and shortening of the fracture. Shortening is best determined on the lateral radiograph because with the lateral view, the x-ray beam is more likely to be perpendicular to the shaft of the femur. Up to 2 cm of shortening is acceptable at any age and more in some circumstances in which overgrowth may be more reliable. Angulation can usually be corrected with wedging. Significant shortening, however, necessitates removal of the cast and some other form of treatment depending on the circumstances. If the fracture has remained stable for the first 3 weeks, it is usually not necessary to repeat the radiographs until the cast is removed.

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4.13 FLEXIBLE INTRAMEDULLARY NAILING OF FEMORAL SHAFT FRACTURES

The idea of internal stabilization of femoral shaft fractures in children is not a new one, having been performed by Kuntscher more than 50 years ago. Several factors, however, have brought about a renewed interest in this technique: realization of the factors that lead to a bad result with closed treatment, successful application and improvement of internal fixation of these fractures in adults, and inexperience in casting techniques among orthopaedic physicians. Cost, however, is not a factor that merits consideration. There is little difference in the cost of treating a child with flexible intramedullary rods, external fixation, or traction for 2 weeks in the hospital followed by spica cast (1,2).

Factors that lead to a bad result with closed reduction and casting form the basis for the indications for closed reduction and flexible intramedullary nailing of femoral shaft fractures in children. In children older than 9 or 10 years of age, it is often difficult to maintain acceptable alignment of the fracture because of the size of the child, and this has led to the preferable use of some alternative to cast treatment in the adolescent (3–5). With proper technique of closed reduction and early spica cast immobilization, however, most younger children are treated successfully (6–8). Nevertheless, there are certain circumstances even in these young children, including children with multiple system injury, multiple fractures, ipsilateral tibial fracture, head injury with coma, and some pathologic fractures, in which this form of treatment does not produce consistently good results or makes the treatment of concomitant conditions difficult. These circumstances constitute the solid indications for some form of fixation. A new indication is mentioned increasingly in the literature: social indication (1,9). This is explained as "conservative treatment alternatives unacceptable to the patient's parents" (10).

Having decided on an alternative to closed reduction and cast immobilization, there are many alternatives, such as external fixation, open reduction and plating (11), and intramedullary nailing with flexible or rigid rods. The ideal indications for intramedullary fixation are a child with open growth plates and a transverse uncomminuted diaphyseal that, for any reason, is unsuitable for early cast treatment. External fixation has the disadvantage, in this particular fracture configuration, of lack of callus formation, slow healing, and an incidence of refracture (2,12). Reports of avascular necrosis in children 12 years of age and younger treated with rigid intramedullary rods should produce caution in the use of these devices in this age group (13,14). In older children, rigid rods are preferable to flexible rods.

Several reports in the literature record the experience with the use of flexible intramedullary rods in children's femoral shaft fractures (1,15–18). Flexible intramedullary rods come in stainless steel or titanium in a variety of sizes.

It is important to understand the mechanics of internal fixation with flexible intramedullary rods. These rods permit a greater degree of bending at the fracture site than conventional intramedullary rods and thus do not provide rigid fixation of the fracture. This may be the advantage they offer with early callus formation and healing compared with more rigid forms of fixation (19). In addition, they provide little in torsional stiffness and allow considerable slip of the fragments on the rods. What they do provide is axial stability. This form of fixation works best when there is good cortical contact at the fracture site (Figs. 4-94 to 4-98).

FIGURE 4-94. The patient may be placed on either a fracture table or a radiolucent table. The important thing is that the surgeon be able to reduce the fracture while driving the rods across the fracture fragment. The legs, especially the contralateral leg, is abducted to allow the surgeon to stand on the medial as well as the lateral side of the leg. This facilitates insertion of the nail or nails from the medial side. Particular attention to rotation should be given at the time of reduction and insertion of the nails into the proximal fragment. This is most easily judged by the skin lines. The limb is prepared and draped to give access to the entire femur and knee joint and to permit manual manipulation of the thigh.

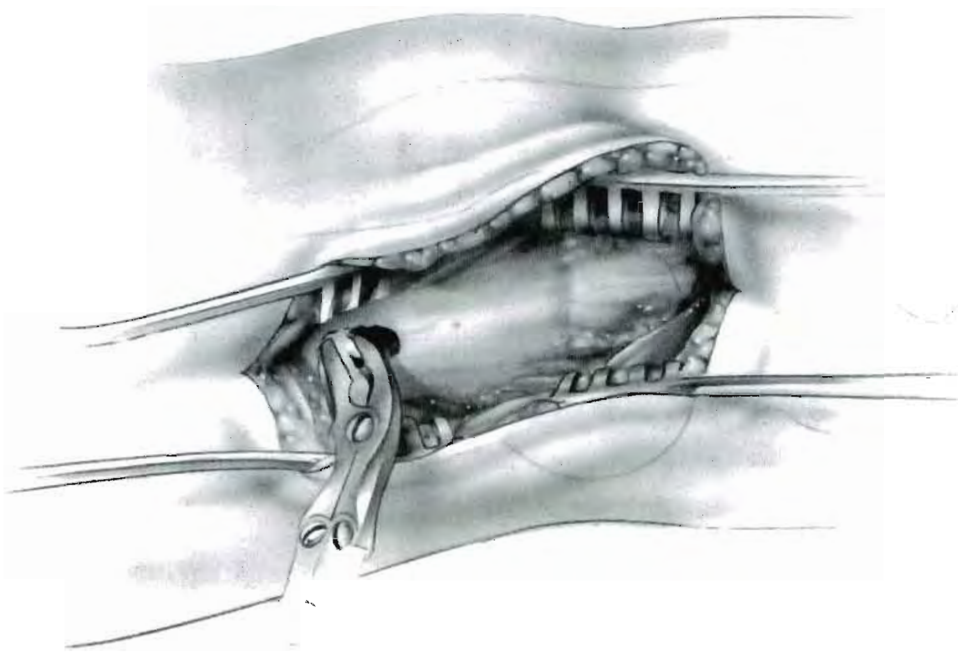


FIGURE 4-95. The insertion point for the nails is medial and lateral at the top of the flare of the medial and lateral condyles so that after insertion, they will tend to bind against the flare of the condyle. If the nails are started too low, they will tend to back out, which is a troublesome complication. In addition, the insertion should be posterior to the midlateral line so that if the nails back out, they will be less likely to enter the synovial pouch.

An incision is made on the lateral side of the leg extending about two finger breadths above the superior pole of the patella. (The superior pole of the patella lies slightly above the level of the physis.) The fascia lata is incised, and the vastus lateralis muscle is retracted dorsally. A drill hole is made with a 6.4-mm drill bit at the level of the superior pole of the patella. Using a rongeur, the hole is extended cephalad to elongate the hole and avoid cracking of the cortex when the rod is inserted.

The insertion point on the medial side is made in the same manner by elevating the vastus medialis muscle.

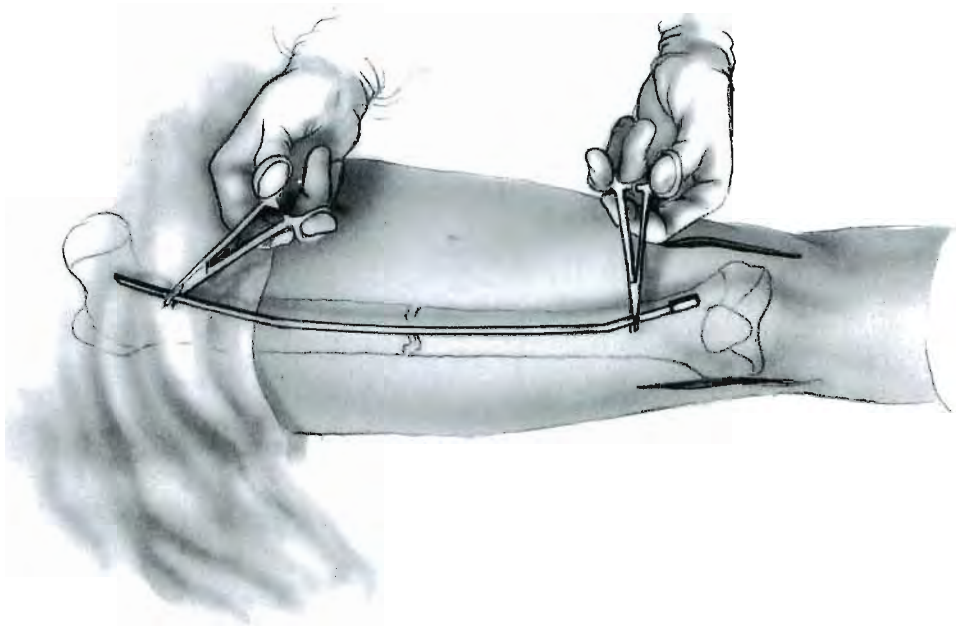


FIGURE 4-96. If nails of fixed lengths are used, the correct size of nail is selected by placing the nail on top of the drapes directly over the femur and seeing its length in relation to the femur. If the femur is not reduced, an allowance should be made for the length of the nail after the femur is reduced. Ideally, the lateral nail should extend to the level of the greater trochanter and the medial nail into the femoral neck. Assuming a midshaft diaphyseal fracture, if both nails reach above the level of the lesser trochanter, the fixation will be adequate.

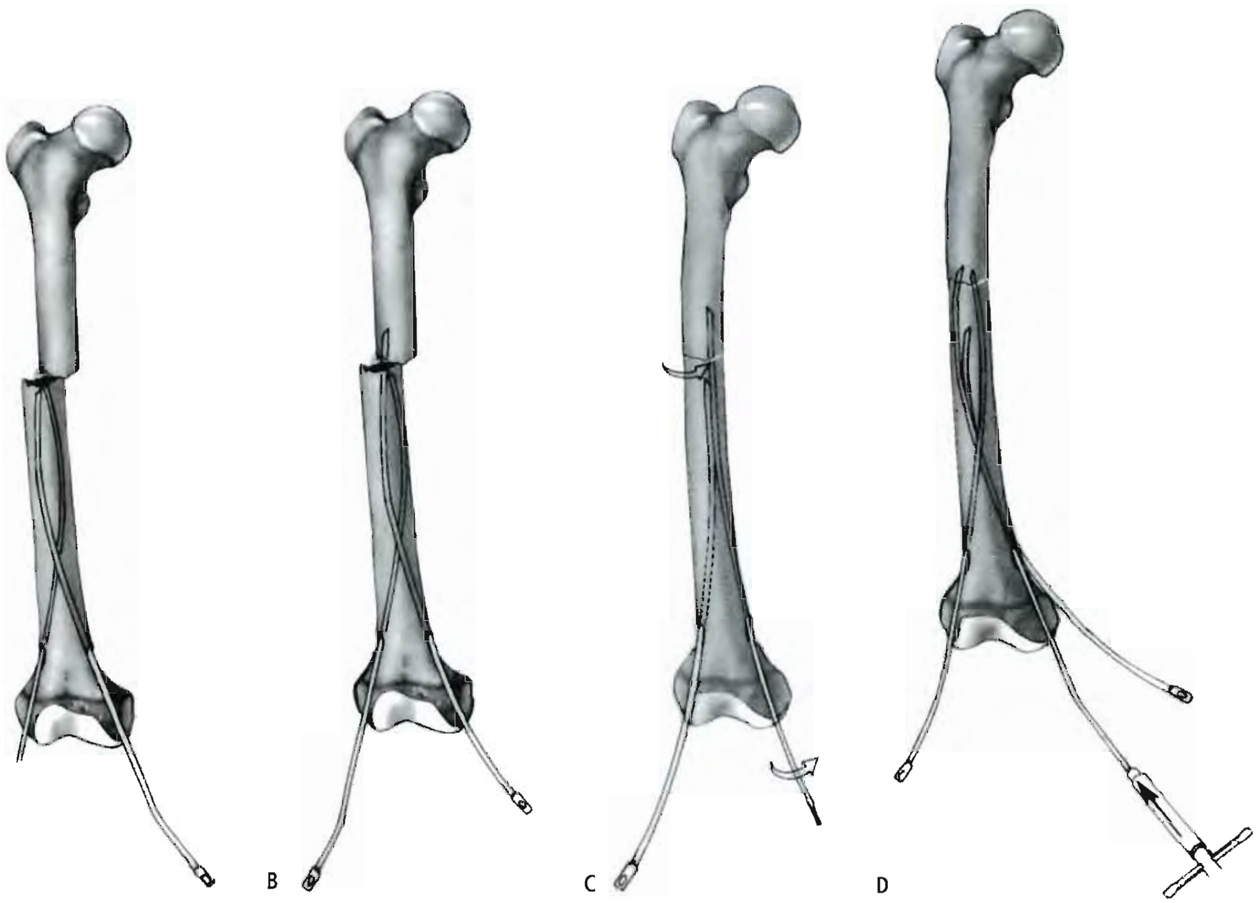
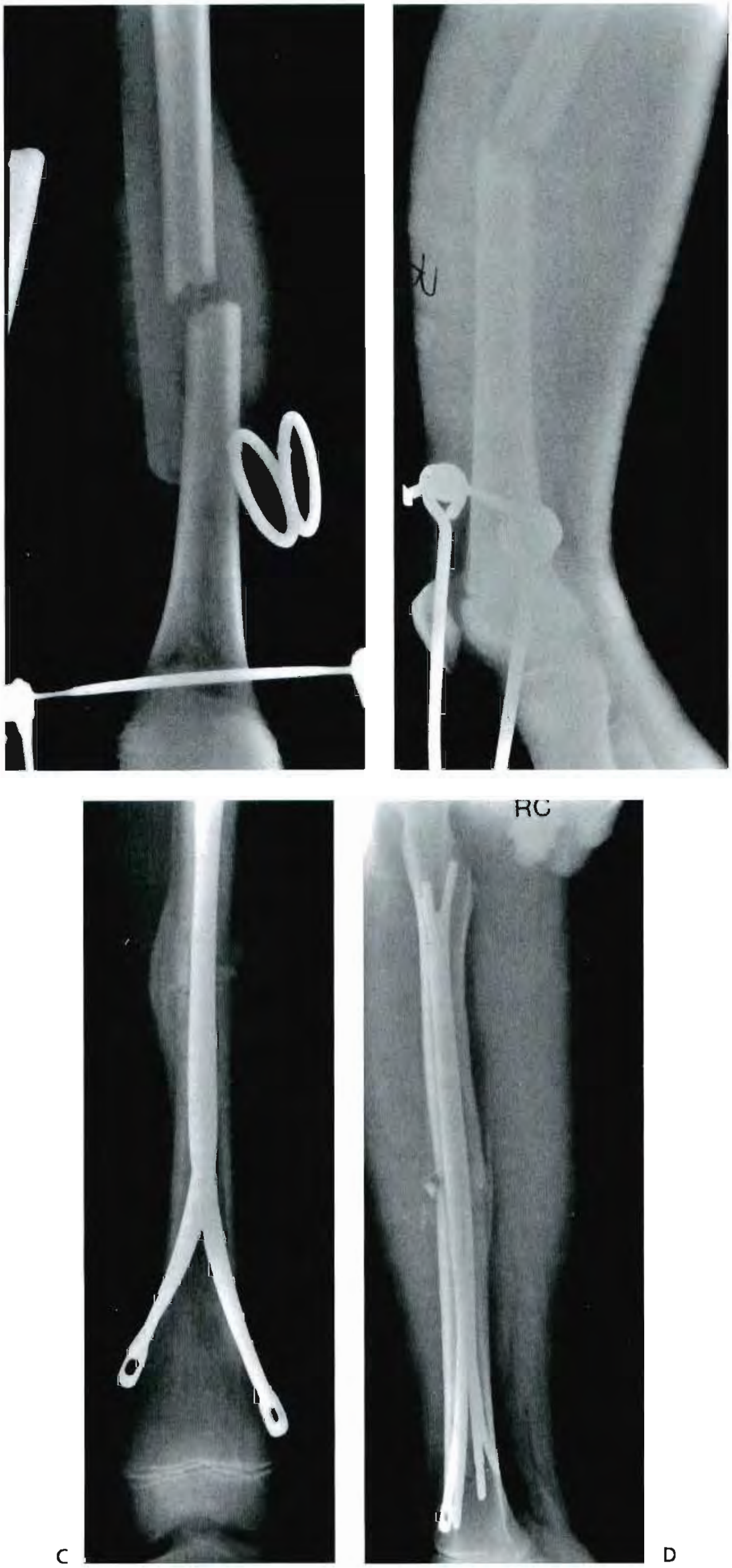


FIGURE 4-97. In many cases, the fracture fragments will not be reduced perfectly, making it more difficult to pass the nails into the proximal fragment. In this situation, one nail is inserted medially and one laterally. Both are driven up to the fracture site **(A)**. It is important that sufficient reduction of the fragments is achieved so that about half of the medullary canals overlap. Viewing with the image intensifier demonstrates which nail will be the easiest to drive across the fracture site. This nail is advanced about 2 cm and then rotated **(B)**. Motion of the proximal fragment demonstrates that the nail is in the proximal fragment **(C)**. At this point, it is advanced further.

By rotating this nail, further reduction of the fracture can be accomplished, and then the second nail is advanced. It is important not to advance the first rod far past the fracture site until the second rod has passed the fracture site. If the first rod is advanced too far, it will shift the fragments and make passing of the second rod difficult or impossible. The traction is released, and both nails are advanced to their full length. The entire femur is seen with the image intensifier to ensure that the fracture is reduced and not distracted and that the nails are properly positioned.

In many children, it is possible to insert a third nail. Inserting a third nail is most easily accomplished if it is inserted before either of the other two nails are advanced fully **(D)**. This has the advantage of providing more rotational and slip stability by filling the canal and enhancing cortical contact.

After insertion of the nails, the wounds are closed.



A B C D

E

FIGURE 4-98. A, B: Anteroposterior and lateral radiographs of the left femur of a 12-year-old boy who sustained bilateral femur fractures in an automobile accident. He was transferred to the Scottish Rite Children's Medical Center in bilateral skeletal traction. It was elected to treat this fracture with intramedullary fixation while his other femur fracture was treated with an external fixator. This plan was designed to use the best method of fixation for the type of fracture. **C, D:** Six weeks after injury, healing of the fracture is demonstrated. Note that four rods were used to achieve a tight fit within the medullary cavity, producing excellent fixation. **E:** Both femurs 10 weeks after injury.

POSTOPERATIVE CARE

With the usual transverse fracture, no external immobilization is necessary. The patient is started on range of motion of the knee and a three-point touchdown weight-bearing gait the day after surgery. When early callus formation is observed, weight bearing can be increased, and external support can be discontinued when radiographic healing is complete. It is important that the patient bear weight because this provides the motion at the fracture site that leads to early callus formation.

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4.14 CLOSED REDUCTION AND EXTERNAL FIXATION OF FEMORAL SHAFT FRACTURE

The use of external fixation for fractures of the femoral shaft in children followed its use in adults and was first reported in the United States in the early 1980s (1,2). Subsequent reports of the use of external fixation in complicated femoral shaft fractures confirmed the usefulness of this technique (3–6). This technique has become so popular in some centers that it seems to be an equal or preferred alternative to closed reduction and spica casting. What the technique is, however, is one more method that can be used to treat femoral shaft fractures. What is important with this and all of the other methods is to understand its advantages and disadvantages for the particular fracture in a particular child.

Transverse diaphyseal fractures are not the best indication for this technique given the slow healing and refracture when this technique is used. Flexible intramedullary nailing is a better choice for this situation. However, the long oblique, spiral, or comminuted fracture, which is usually not amenable to flexible intramedullary nailing, is the fracture for which external fixation provides the solution.

One of the most serious complications encountered with the use of external fixation in femoral shaft fractures is refracture. Although there is little information in the literature (3), the complication is commonly known in centers that have experience in the use of external fixation. These refractures occur in transverse fractures. Refracture of the femur was reported to be as high as 8% in adults before the routine use of intramedullary rod fixation (4). This demonstrates the prolonged time required for complete restoration of the femur to normal strength and the potential value of intramedullary fixation, which remains in place for several months while sharing the load.

An additional consideration is the stiffness of the fixation (7). Micromovement at the fracture site is probably important for healing. Consideration of the balance between rigidity and motion at the various stages of fracture healing is important. In most fixators, increased motion is allowed as the healing progresses by making alterations in the fixator. This is called *dynamization* of the fixator.

Although there are many external fixators available, those that allow adjustment in all planes after the pins are secured to the fracture are best for fracture treatment. There are numerous fixators on the market today, each with its own advantages and disadvantages (Figs. 4-99 to 4-105).

FIGURE 4-99. The patient is positioned on a radiolucent operating table. Often, a small, folded towel placed under the midshaft of the femur helps restore the normal anterior bow to the femur. Some surgeons prefer to place the patient on a fracture table and gain alignment and length before beginning the insertion of the pins, but this is not an essential step.

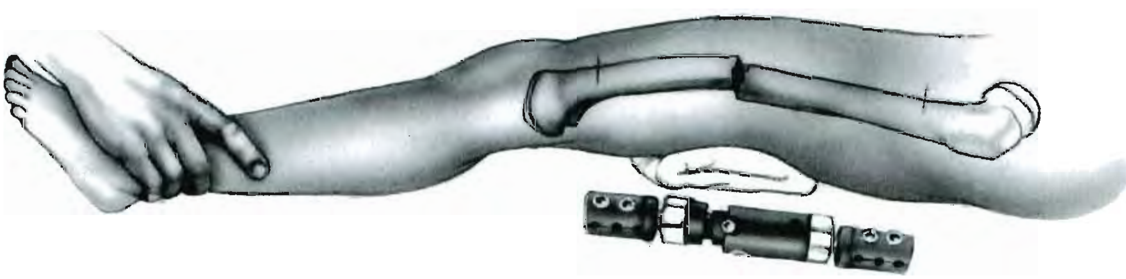


FIGURE 4-100. To select the proper size of fixator, have an assistant pull the leg out to length. Determine the location of the fracture and the eventual positions of the proximal and distal pins. If necessary, the image intensifier can be used to help in this part of the operation, especially if the fracture is near the end of the bone.

It is important to select a size of fixator that will allow it to be applied partially lengthened. This is important for two reasons. During correction of angulation, the fixator may need to be shortened. After the reduction is complete, the fixator needs to shorten to allow dynamization.

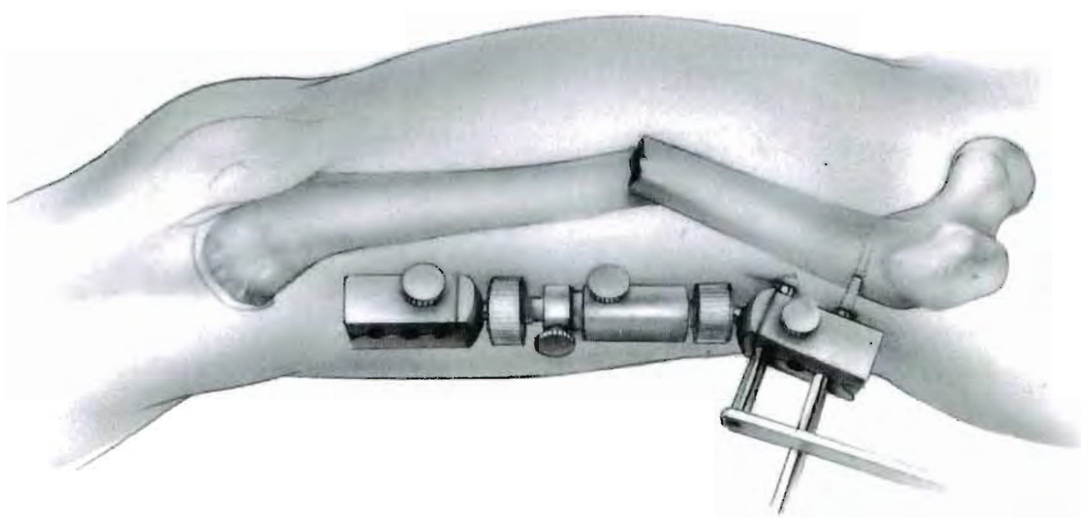


FIGURE 4-101. Unlike the insertion of the pins for leg lengthening, all of the pins are inserted into one fragment and then the other fragment. This means that the pins in the proximal fragment must be aligned with the proximal fragment but bear no relationship to the distal fragment. Approximate alignment of the fragments, however, means that the fixator will be better aligned after reduction of the fragments. In this regard, it is helpful to achieve near-normal rotational alignment before inserting the second set of pins.

Begin by placing the proximal pins first. The technique for inserting the Orthofix pins is described in Figures 4-110 through 4-113 (see Procedure 4.15). After the first pin is placed, the fixator template is locked onto the screw guide. The template is aligned with the axis of the proximal fragment, and the second pin is inserted. In the very large thigh in which the femoral shaft cannot be felt, it can be helpful to probe with a small Kirschner wire to locate the bone.

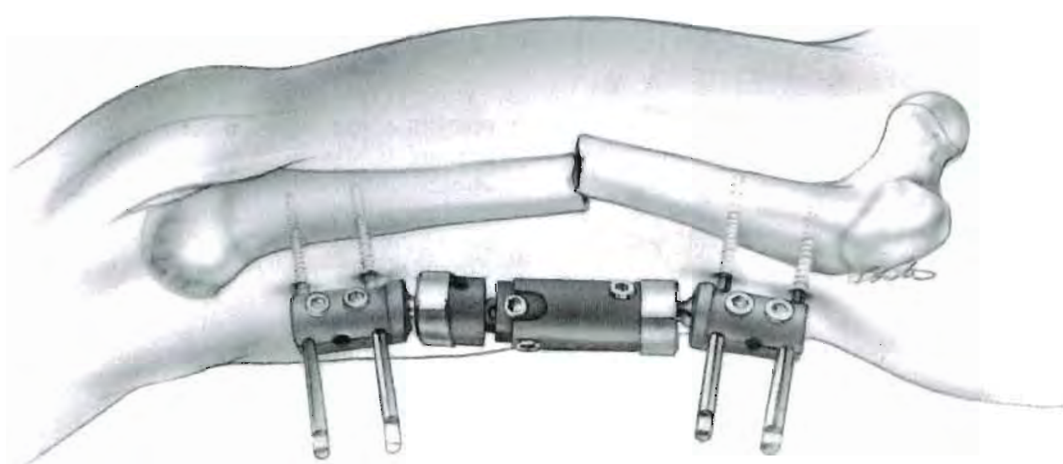


FIGURE 4-102. With the template locked on the proximal screw guides and screws, the distal screw template is aligned with the distal fragment, and two screws are inserted. If the fracture is displaced markedly, it is helpful to pull on the leg to gain approximate alignment.

The template and screw guides are removed, the pins are wiped clean, and the ball joint fixator is locked onto the screws. The fixator should be applied so that the tightening nuts are easily accessed. The screw clamps are tightened firmly on the screws, but the ball joints and the lengthening slide are left loose. A small dressing is applied to each pin site, and the sterile drapes are removed.

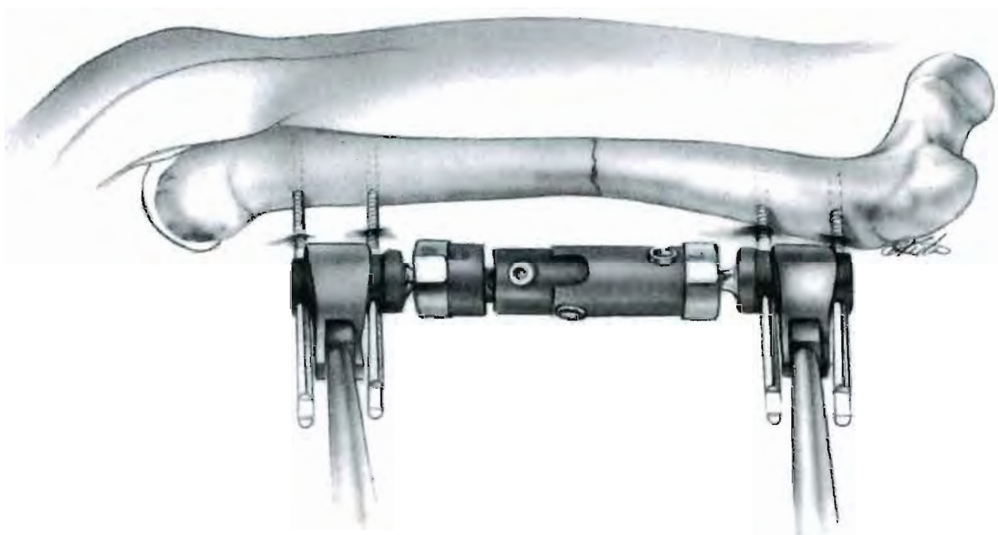
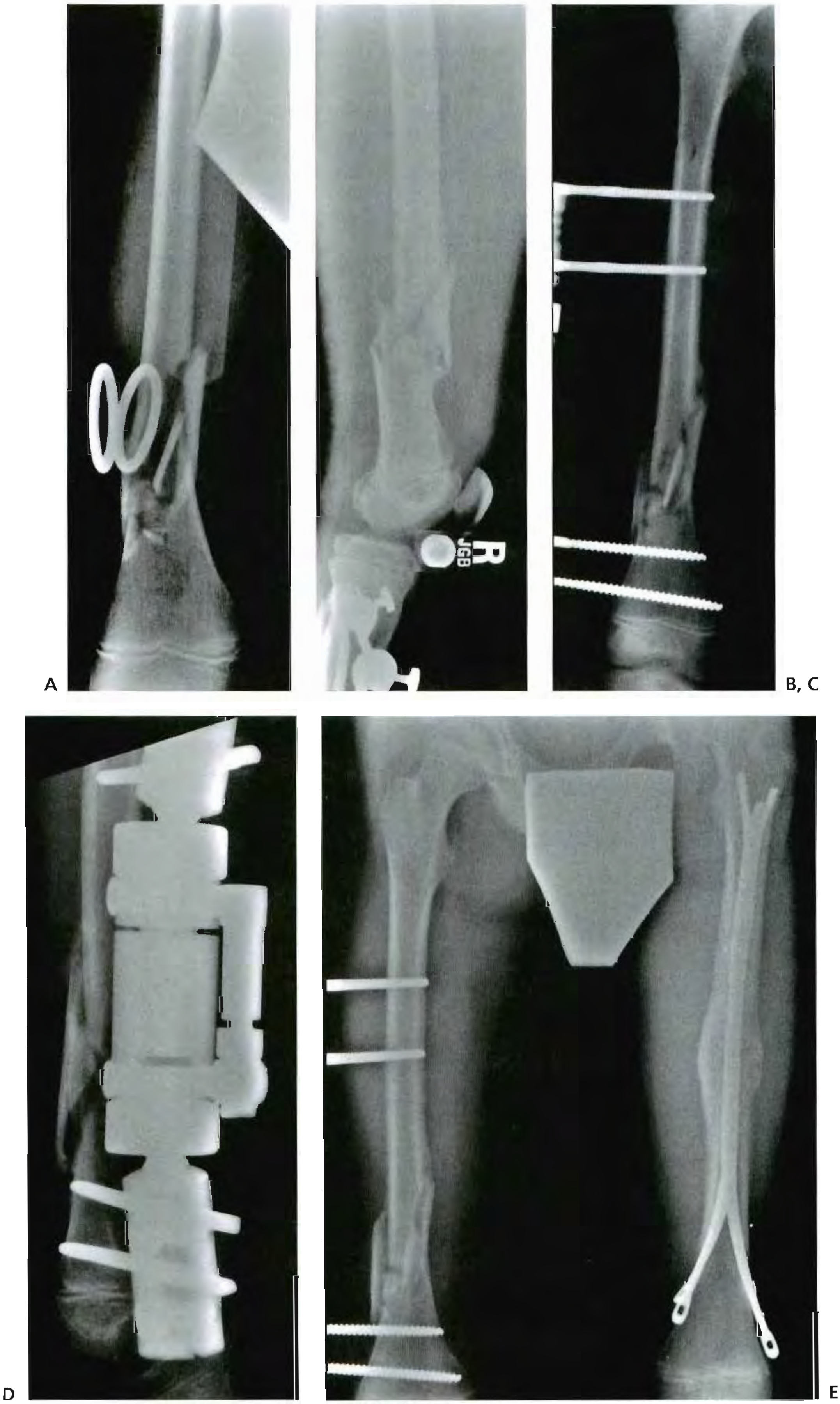


FIGURE 4-103. The fracture reduction clamps are applied, and the image intensifier is positioned beneath the fracture site. The fracture is reduced, the lengthening nut and the ball joints are locked using fracture clamps and, if necessary, traction is applied by an assistant. This completes the procedure.

FIGURE 4-104. As soon as early callus is seen, it is wise to begin thinking about dynamization, especially if the fracture is transverse. This can be accomplished by applying the Orthofix dynamic locking collar and moving the fixator as far from the thigh as possible. This allows increased bending of the pins, which allows increased motion at the fracture site.

FIGURE 4-105. A, B: Anteroposterior and lateral radiographs of the right femur of a 12-year-old boy who sustained bilateral femur fractures in an automobile accident. He was transferred to the Scottish Rite Children's Medical Center in bilateral skeletal traction. It was elected to treat this fracture with an external fixator, while the other femur fracture was treated with flexible intramedullary rods. This plan was designed to use the best method of fixation for the type of fracture. **C, D:** Results 4 weeks after fracture. **E:** Ten weeks after fracture, the amount of healing in both fractures is seen. ▶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4.15 LENGTHENING OF THE FEMUR WITH ROTATIONAL AND ANGULAR CORRECTION WITH THE ORTHOFIX LIMB RECONSTRUCTION SYSTEM

With most lengthening devices, the name of the device also describes or is associated with unique biologic principles. The Orthofix lengthener is a monolateral fixator developed by De Bastiani and colleagues to be used with the principle of callotasis (1). The device has certain advantages and disadvantages compared with other external fixators. It is better tolerated than the Ilizarov apparatus and is easier to use for the surgeon. The template for insertion of the screws makes their precise alignment easier, and the lengthener permits up to three screws to be used at each end of the osteotomy, which helps avoid angulation during lengthening. Angular adjustment is possible without loosening the hold on the screws if the limb reconstruction system is used in place of the lengtheners. Although the swiveling clamps allow up to 50 degrees of angular correction, this must be done acutely. Rotational correction is achieved at the time of the screw insertion and is not adjustable.

Because this is a monolateral fixator, it is easily tolerated by the patient and can be placed proximally or distally depending on where the surgeon wishes to perform the lengthening. If there are no compelling reasons for distal placement, such as correction of angular deformity at the knee, the osteotomy is best performed proximally. This keeps the screws away from the fascia lata at the knee, where they tend to make knee motion more difficult.

In the treatment of a congenitally short femur, there are two factors to weigh when planning where to perform the lengthening. These femurs have two intrinsic deformities: femoral retroversion and a smaller lateral femoral condyle that creates a valgus and an external rotation deformity at the knee. The former may predispose to dislocation of the hip during or even after lengthening, whereas the latter may leave a significant valgus deformity at the knee and possibly predispose to subluxation of the knee during lengthening.

Which of these factors is the most important in the particular case determines where the lengthening is done. If femoral retroversion is severe, that is, 45 degrees or greater, the fixation is applied proximally and the rotation is corrected at the time of application. If angular correction is necessary, the osteotomy is done distally, and angular correction is obtained at the time of osteotomy. If both are required, they can be achieved by a double osteotomy, which requires three sets of screws and three clamps, as are used for bone transport (Figs. 4-106 to 4-122).

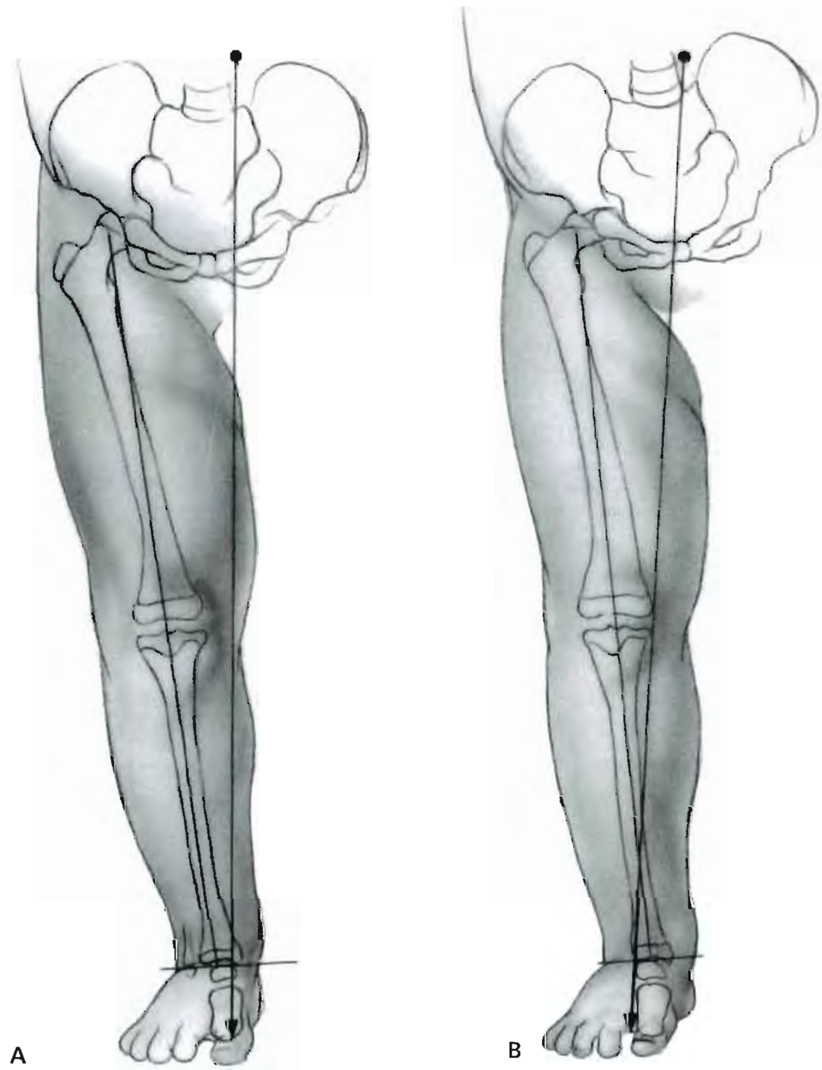


FIGURE 4-106. The anatomic axis of the leg and the mechanical axis of the leg are illustrated. The anatomic axis changes with the angulation of the bones. The weight-bearing axis changes with the position of the limbs and the center of gravity, which is constantly shifting during gait. Note the difference in the weight-bearing axis when the body is in static single-leg stance **(A)** and how this shifts with the transverse movement of the pelvis during dynamic gait **(B)**. Under conditions of normal anatomy, the normal anatomic axis probably is ideal for resisting the forces on the joints produced by the shifting weight-bearing axis (2). (*continued*)

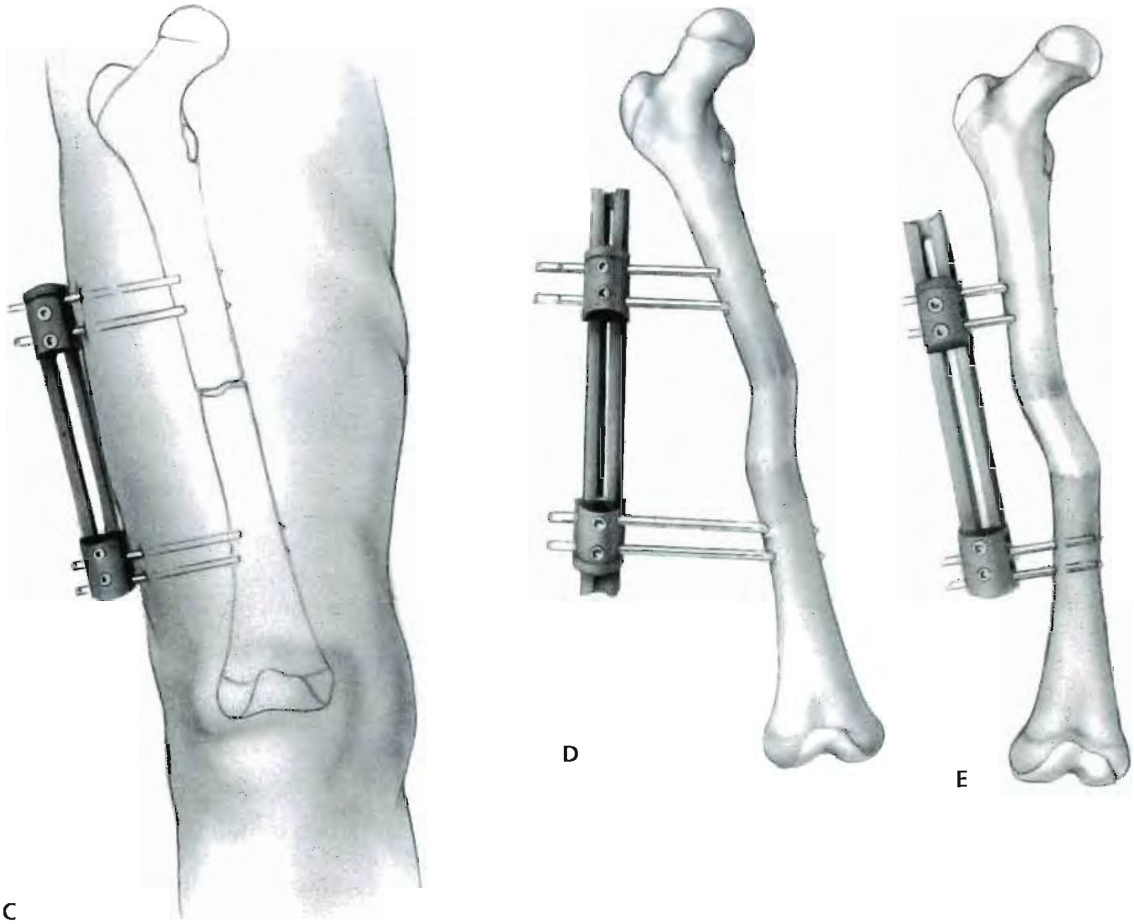


FIGURE 4-106. ***(Continued)*** With the use of monolateral fixators for lengthening, however, the surgeon is able to shift the distal fragment medially or laterally during lengthening. If the screws are placed perpendicular to the axis of the bone, the axis of the bone remains unchanged during lengthening **(C)**. If, however, the screws are other than perpendicular, the axis of the distal fragment is translated medially or laterally to the axis of the proximal fragment **(D, E)**.

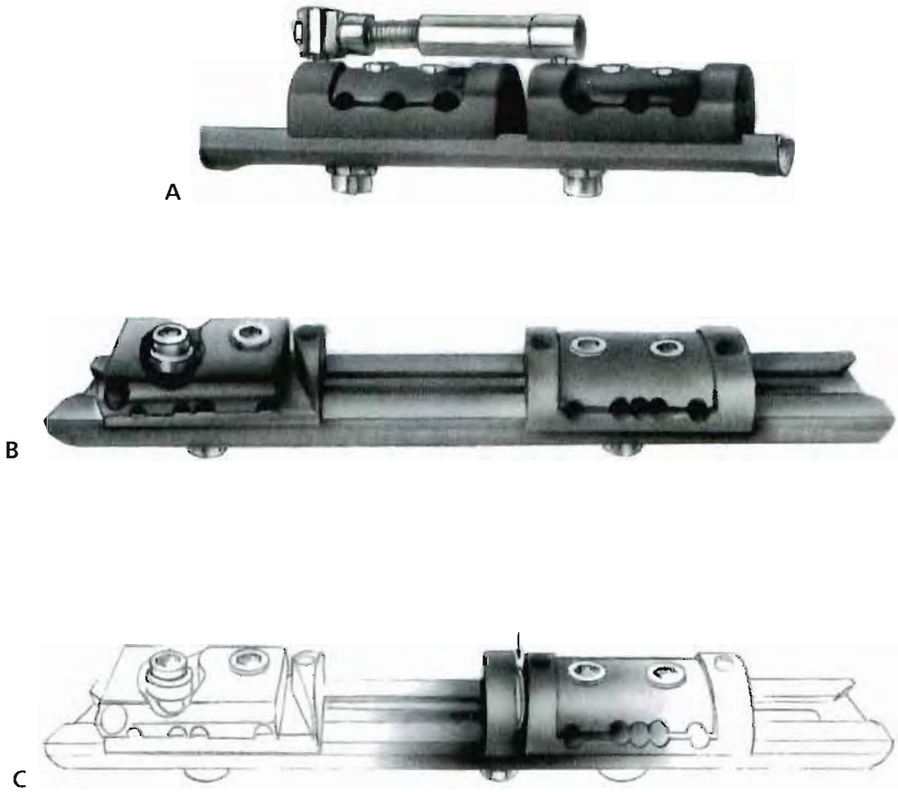


FIGURE 4-107. For limb lengthening, the limb reconstruction system is used **(A)**. This is a rigid sled on which the screw clamps slide. Three screw clamps can be put on the sled at the same time, permitting double osteotomy and bone transport. One type of clamp is rigid and not adjustable; the swivel clamp has 50 degrees of adjustability **(B)**. As with the other Orthofix fixators, there is a clamp that allows the screw clamp to be dynamized **(C)**. There is a template system for insertion of the screws.

FIGURE 4-108. The Orthofix screws differ from the Schantz screws used on the Wagner device and others in their thread design: they are tapered. This is thought to give them a more secure fit in the bone. The standard cortical screw **(A)** tapers from 6 mm at the base of the thread to 5 mm at the tip (6/5 mm). Smaller screws of 4.5/3.5 mm are also available (to be used in bones with a diaphyseal diameter less than 15 mm), as are 6/5 mm cancellous screws **(B)**. For leg lengthening, these screws are available with a cutting edge **(C)** to minimize the tissue trauma at the leading edge of the screw during lengthening.

It is generally best to use all cortical screws for their stiffness as compared with the cancellous screws. In most average-sized adolescents and adults, three screws above and below the osteotomy are used, again for increased resistance to bending.

FIGURE 4-109. The patient is positioned in the supine position on a translucent operating table with an image intensifier opposite the surgeon. After the entire leg is prepared, a large, soft roll is placed under the knee to flex the hip and knee. Because the leg tends to fall into external rotation, it is also helpful to place a large roll under the buttocks.

Before beginning the procedure, it is helpful to locate the lesser trochanter and the distal femoral physis with the image intensifier and mark them on the skin with a line that is perpendicular to the shaft of the femur.

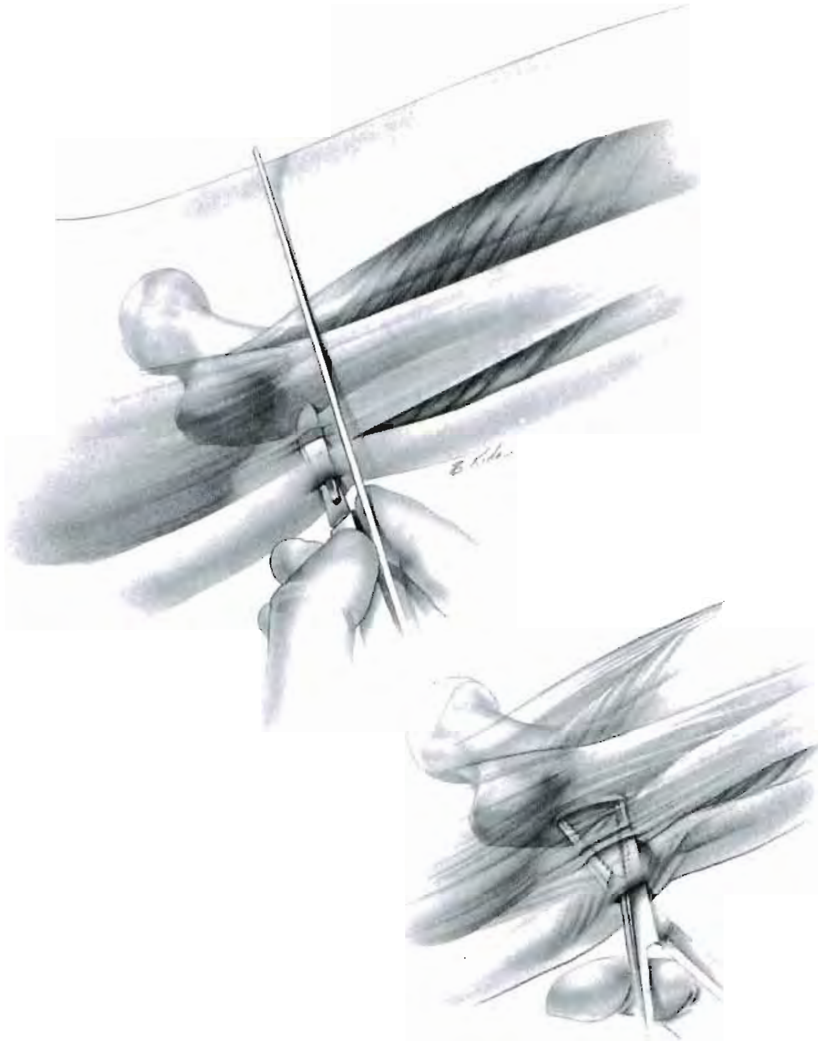


FIGURE 4-110. In performing a proximal osteotomy, the most proximal screw is placed first. It should be placed just proximal to the lesser trochanter. Although it is possible to place this even higher in the femoral neck region to keep the osteotomy more proximal, this is not really necessary. After identifying the correct area by means of the image intensifier and a small Kirschner wire held over the thigh, a stab wound is made through the skin and the fascia lata. This wound is then spread widely down to the bone with a large hemostat or scissors. The tendency is not to cut and spread as deeply or as widely as necessary. To prevent necrosis and subsequent infection, this wound should be large enough that the screw does not put any pressure on the skin, the muscle, or the fascia.

FIGURE 4-111. A screw guide of appropriate length with the trocar inserted through it is passed down to the bone, and the center of the bone is found. The trocar is struck with a mallet to start the hole for the drill. The trocar is then removed, and the screw guide is struck with the mallet to drive its teeth into the bone and secure it.

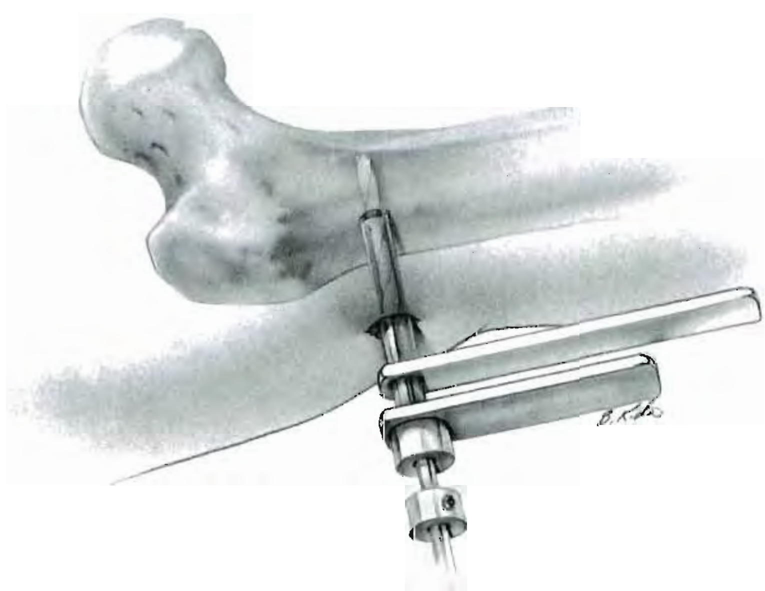


FIGURE 4-112. The drill guide of appropriate diameter and length is now passed through the screw guide. This aligns the drill precisely within the screw guide. For the use of the 6/5-mm cortical screws, a 4.8-mm drill is used to make a hole through both cortices. A drill stop can be used to avoid overpenetration of the far cortex. The lateral cortex is penetrated, and the drill is advanced until the opposite cortex is encountered. The drill stop is then adjusted to allow the drill to advance another 5 mm and penetrate the other cortex.

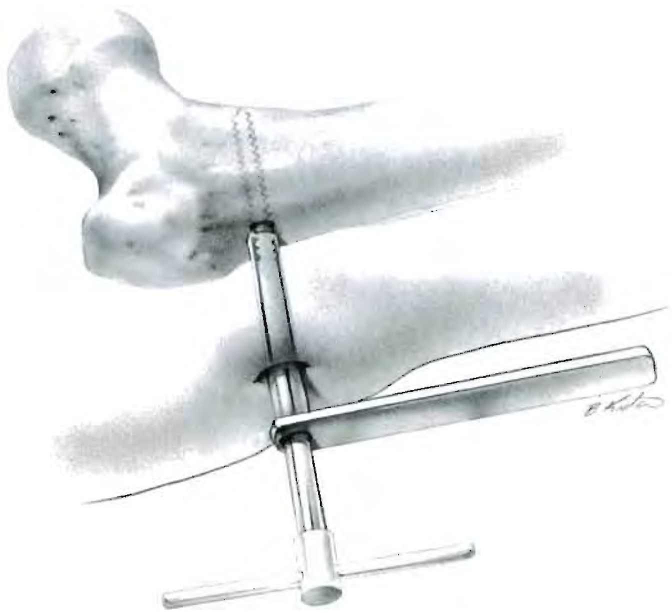


FIGURE 4-113. The drill and the drill guide are removed, and the proper length of screw is inserted using the T wrench. Although a cancellous screw can be used in this most proximal location, it is more flexible than the cortical screw and does not appear to offer better purchase than a cortical screw, which penetrates both cortices. Therefore, it is preferable to use a cortical screw here for its increased rigidity. After the far cortex is engaged, 6 to 8 half turns usually result in two threads projecting through the opposite cortex, which is what is desired. There will be less resistance encountered with these screws, however, than with those the surgeon is accustomed to using. In addition, caution must be used not to advance these screws too far because backing the screw out will result in loosening. Use of the image intensifier is helpful at this point. The screw guide is left in place because the template is designed to fit tightly around this guide.

FIGURE 4-114. The desired size of sled is selected, and the screw clamp templates are placed on it. They are adjusted and locked on the sled to be in the desired position and distance apart. If the lengthening is proximal, the proximal screw clamp will be near the end of the sled so that the sled will not project past the buttocks, making sitting difficult. If a distal osteotomy is performed, the distal screw clamp will be near the distal end of the sled so that it will not project beyond the knee when the knee is bent.

The most proximal slot on the template is secured to the screw guide over the screw that was just placed. The template is now aligned with the femoral shaft, and the site for the most distal screw is marked. This is done accurately by passing a screw guide through the slot in the template and pushing it firmly against the skin to mark the area for the incision. The most distal screw in the femur should be the second screw placed to ensure correct alignment.

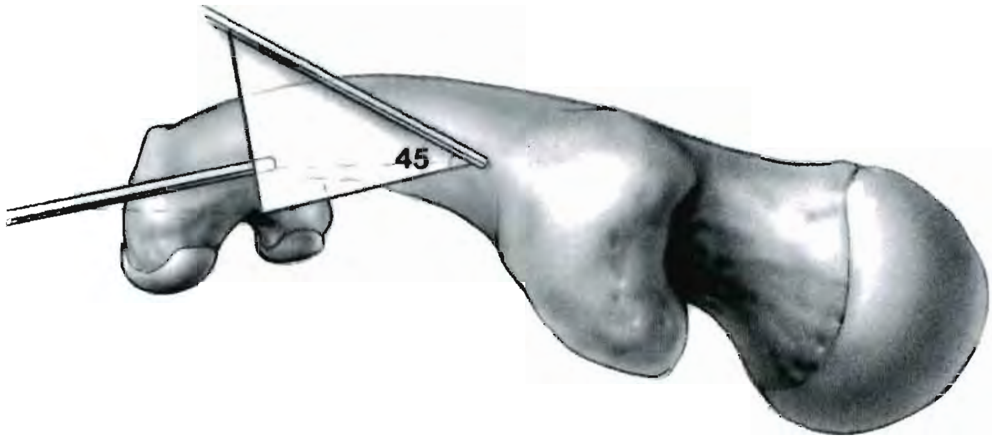


FIGURE 4-115. If rotational correction is desired, this second screw is placed in a different plane than the first. If retroversion of the femur is to be compensated for, the distal fragment will be rotated internally on the proximal fragment. Therefore, the distal screws will be placed more posterior. The desired amount of correction is estimated, and the starting point of the second screw is rotated posteriorly around the femur so that when it is brought coaxial to the first screw, the desired amount of rotation will be achieved. This estimation of the amount of angulation can be done by using an angular template, such as that used in calculating bone wedges to be removed in correction of angular deformity. Straight lines drawn on the skin keep the axial alignment of the screw clamps. This is important because there is no adjustment for this, as there is with the ball joint fixator, with the limb reconstruction system. The skin is pulled posteriorly so that after rotation, there will be no tension on the skin.

There is a jig available that attaches to the limb reconstruction sled that allows the screws to be placed accurately in various degrees of rotation. The rotation is performed acutely.

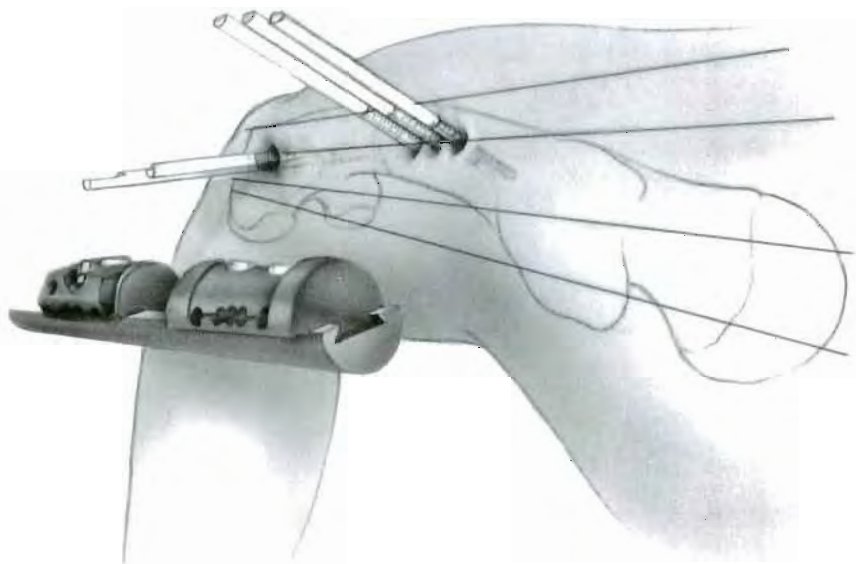


FIGURE 4-116. The other screws are placed, as previously described. If no rotational correction is needed, the sled is attached to the two screws in place, and the others are placed in the remaining holes. As illustrated previously, the screw guide is passed through the template and then the drill guide through the screw guide. After each screw is placed, the screw guide is left in place to provide a tight fit with the template and maintain precise alignment. In larger children, adolescents, and adults, three screws should be used proximally. In smaller children or for short lengthening, two screws at each end may be sufficient.

To achieve rotational correction, it is not possible to apply the sled at this point unless the osteotomy is performed and the rotational correction is obtained and held with the two screws. In this method, the remaining screws are then inserted. It is also possible to apply all of the screws simply by using the templates. If this is done, the surgeon must be confident that he or she has maintained parallel alignment between the proximal and distal screws because the sled does not permit adjustment in this plane. In such cases, parallel lines drawn the length of the thigh are helpful.

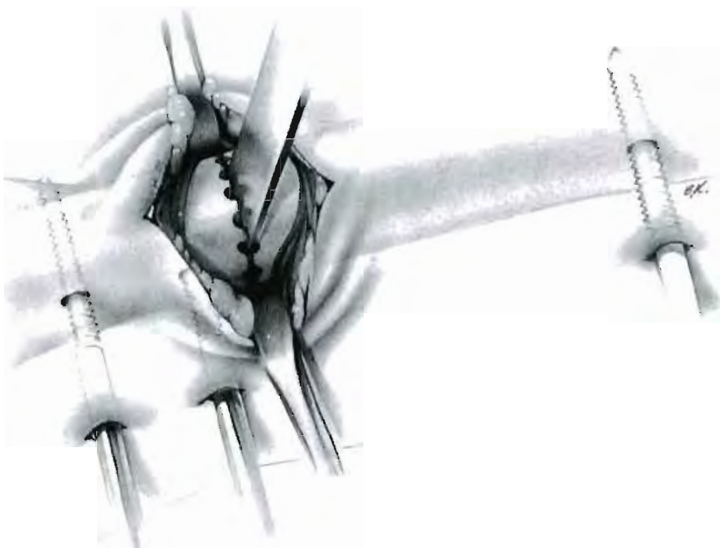


FIGURE 4-117. After all of the screws are placed, the template is removed, and the osteotomy is performed. It should be about 1 cm below the most distal of the proximal screws. This is accomplished through a small, 4-cm incision placed on the anterolateral aspect of the thigh over the interval between the sartorius and tensor fascia muscles. In smaller children, the location of the osteotomy is lower than this anatomic interval, and in this situation, the fibers of the tensor can be split, allowing excellent access to the bone.

A longitudinal incision is made in the periosteum and is elevated circumferentially. Multiple drill holes are made in the bone. Although importance initially was attached to maintaining the intramedullary circulation, there has been no difference noted in bone healing when the posterior cortex is drilled by passing from the anterior cortex through the medullary canal with the drill. This greatly simplifies (and demystifies) the osteotomy and avoids the complication of a fracture propagating from the osteotomy into the nearest screw hole, which can occur when the posterior cortex is divided with an osteotome without drilling. To avoid excessive penetration of the posterior cortex, particularly the posterior medial cortex where the deep femoral artery runs close to the bone, the drill stop can be used as previously described. After multiple drill holes are made, they are connected with an osteotome. A power saw should not be used to make the osteotomy.

To be certain that the osteotomy is completed, the proximal and distal screws are grasped and rotated while observing the osteotomy. (An alternative method is to attach the lengthener to the screws, place the lengthener under slight distraction, perform the osteotomy, and verify the completeness of the osteotomy with the image intensifier.)

The osteotomy is now complete. The periosteum can be approximated, and the wound is closed. Some surgeons believe that the hematoma actually aids in the callus formation and prefer not to use a drain.

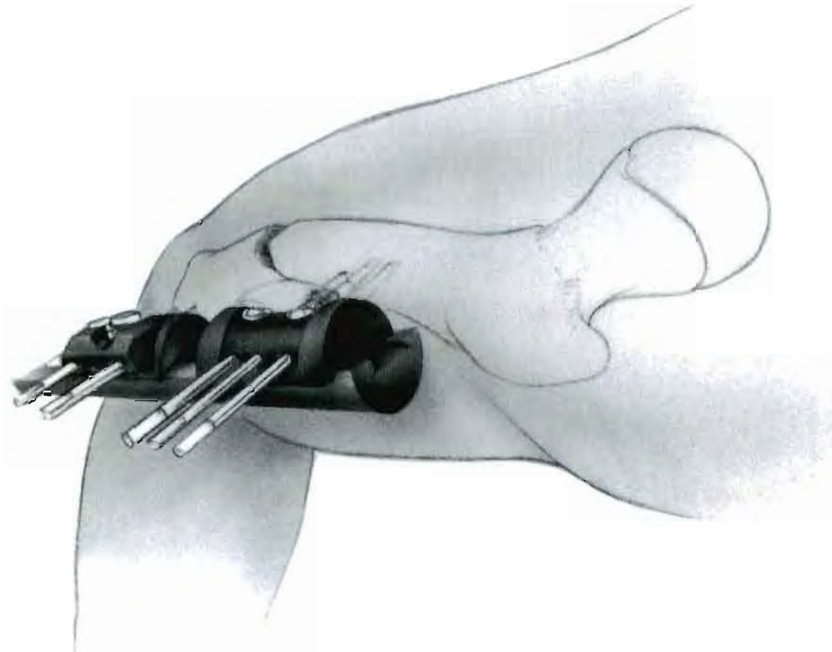


FIGURE 4-118. The sled with the screw clamps is now attached to the screws. This achieves the rotational correction. The distraction and compression bar is placed. The sled is positioned, and the proximal screw clamp is locked to the sled. The distraction compression bar is compressed until the osteotomy site is compressed. The distal screw clamp is now locked onto the sled, and the bar is reversed to produce distraction. Because both clamps are locked, distraction will not occur, but this will ensure that when lengthening begins, the first turns of the distractor bar will produce distraction.

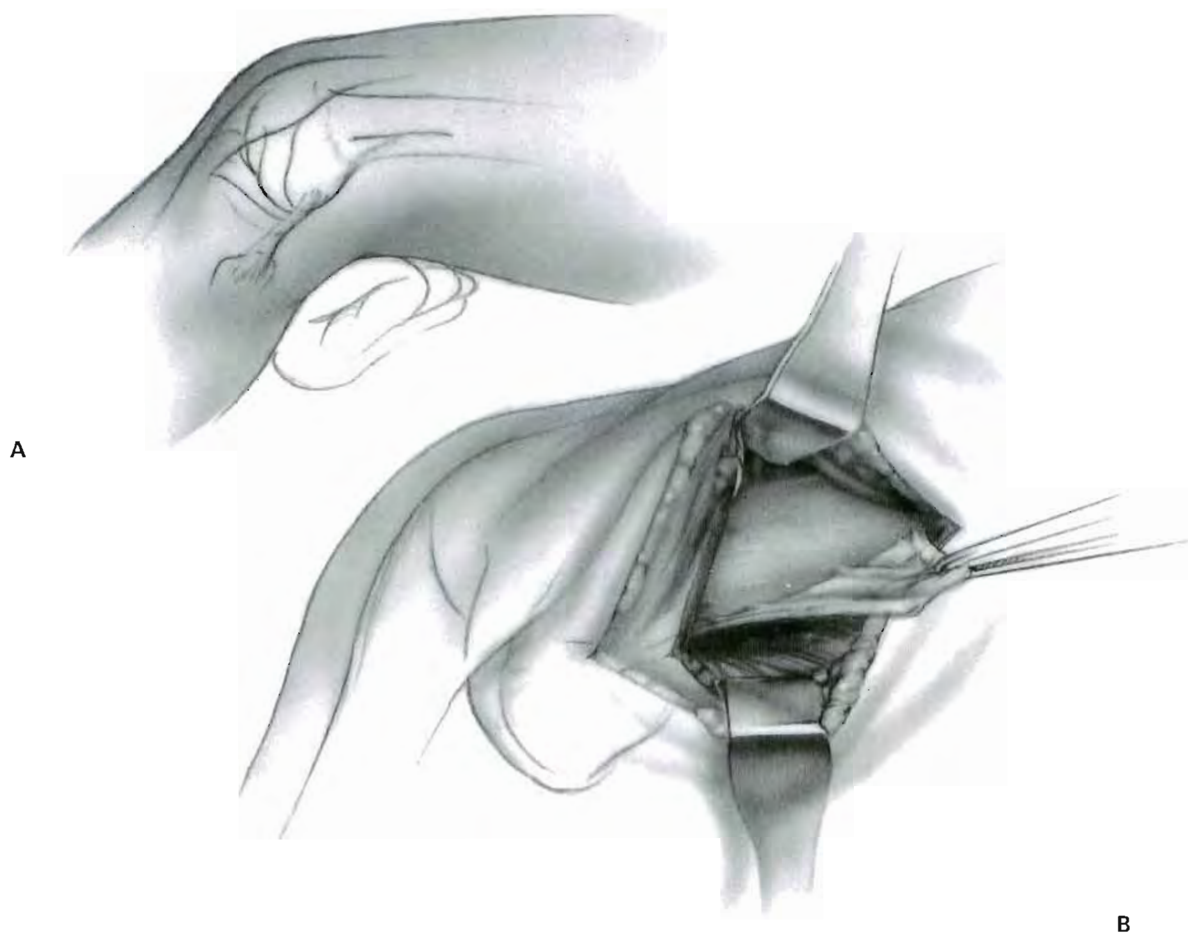


FIGURE 4-119. If the osteotomy is performed distally to correct angular deformity, a lateral incision is made that spans the site of the distal screws **(A)**. The fascia lata is released in an oblique manner from posterior distal to anterior proximal and includes the interosseous membrane **(B)**. This releases one of the biggest deforming forces on the knee during lengthening. If the valgus is severe, it may also be desirable to lengthen the biceps muscle at the same time.

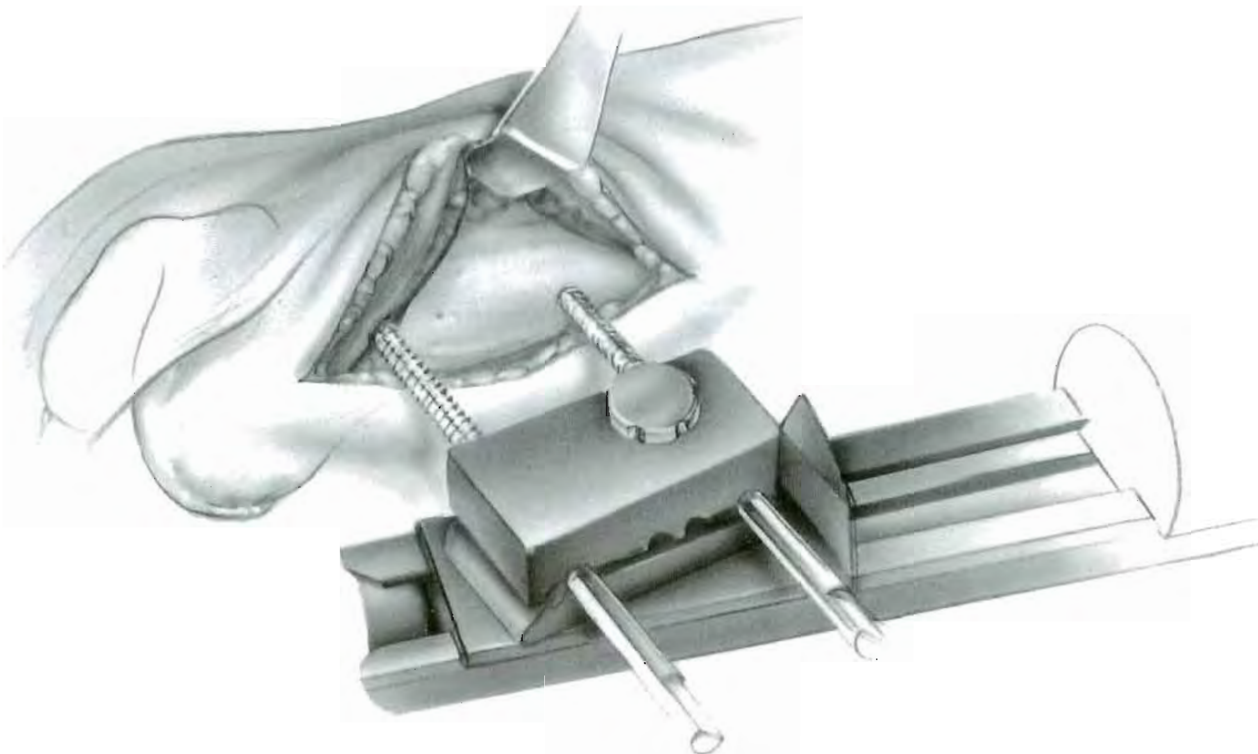


FIGURE 4-120. After the proximal screw is inserted, the distal screws can be inserted through the incision. Under image intensifier control, the first distal screw is placed 1 cm proximal to the distal femoral physis and parallel to the joint line. An adjustable screw clamp template is applied to the sled distally (one may also be used proximally to increase the adjustability), and the sled is attached to the proximal and distal screw. The remaining screws are placed proximally and distally, with the distal screws placed through the incision.

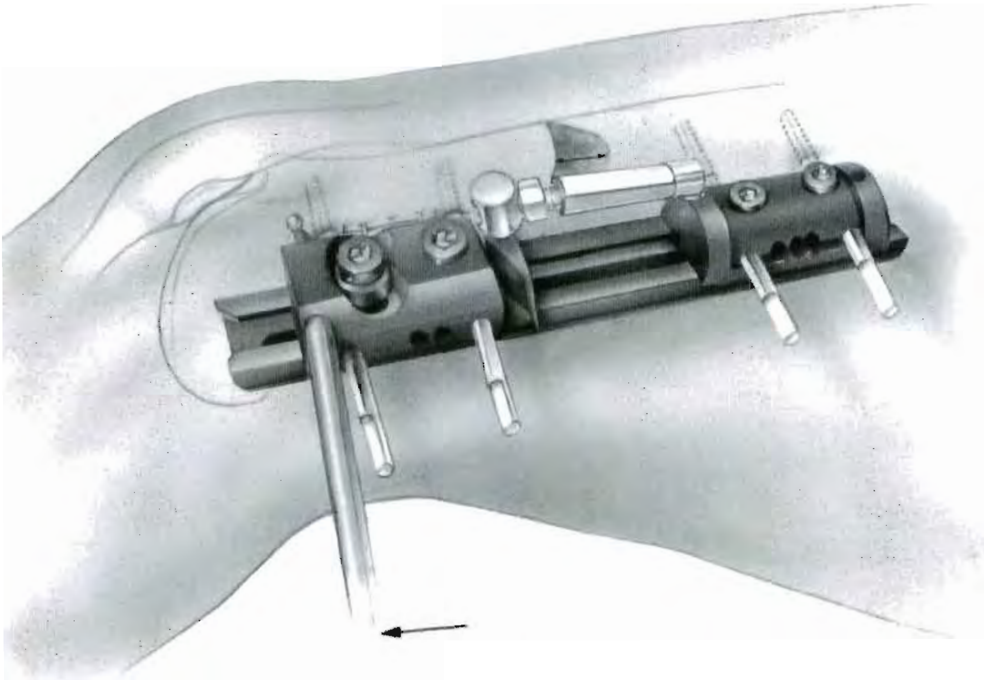
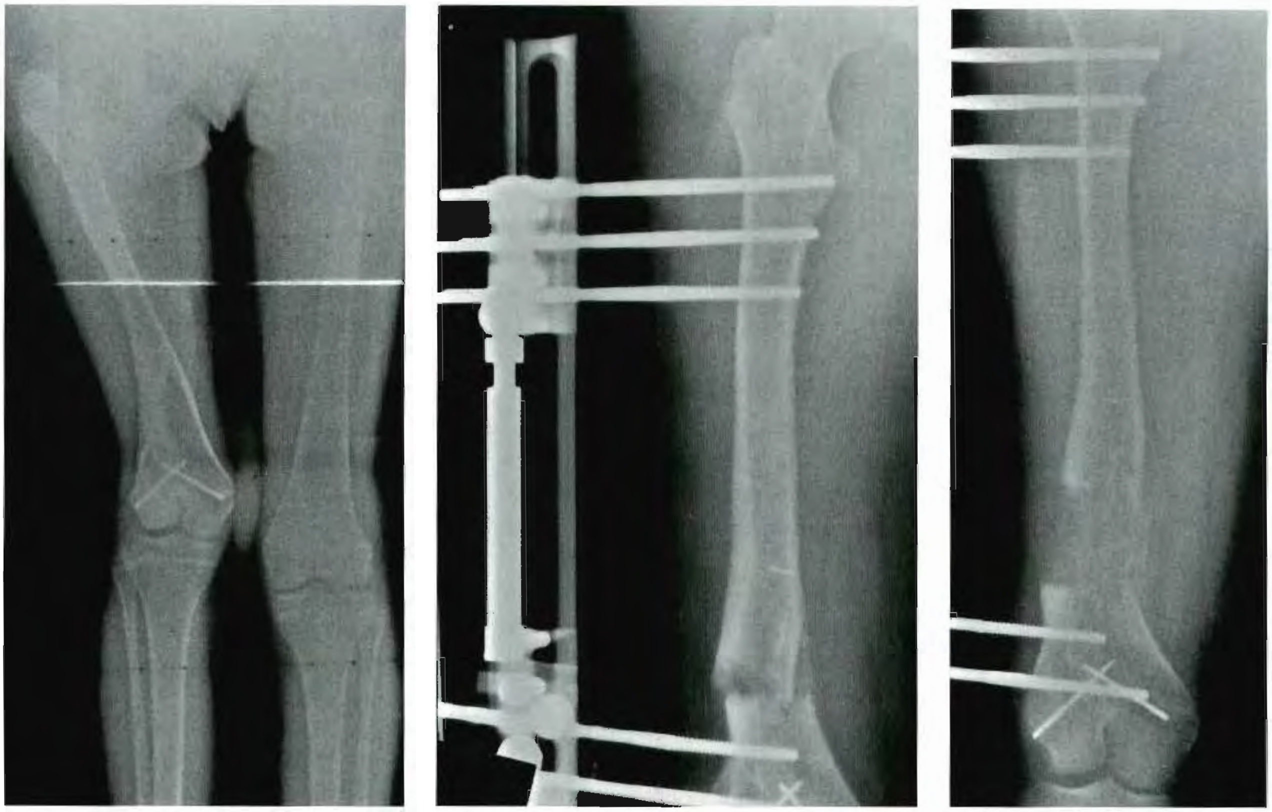
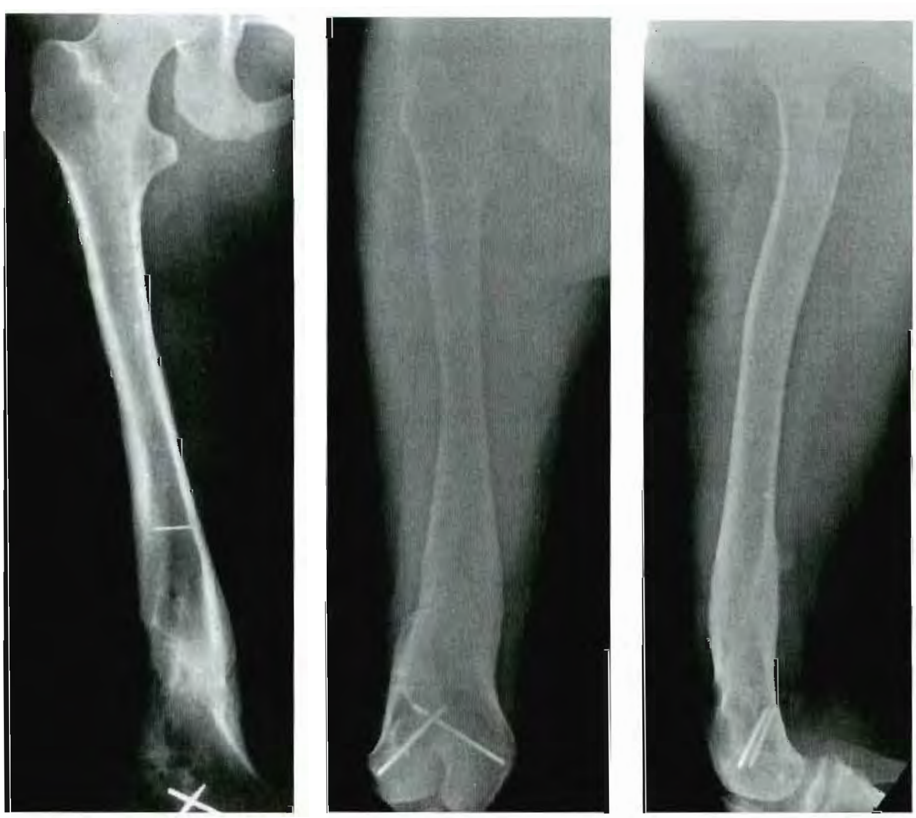


FIGURE 4-121. The fixator is removed, and the osteotomy is performed. This can also be accomplished through the same incision by pulling the wound proximally and anteriorly and approaching the femur through the thin area of muscle between the vastus lateralis and rectus muscles. The wound is closed carefully around the screws, and the axial lengthener is attached to the screws. Under image intensifier control, the desired angular correction is obtained, and the clamps are locked in place. A screwdriver in the hole on the adjustable screw clamp provides the necessary leverage and control to adjust the screw clamp.

FIGURE 4-122. A: Anteroposterior radiograph of a 14-year-old girl who sustained an epiphyseal fracture of the distal femur at 8 years of age with subsequent growth arrest. Attempts to resect the bar were unsuccessful, and when seen, she had a 6-cm discrepancy and a severe valgus deformity. **B:** Acute angular correction was gained at the time of surgery and is seen here 3 weeks after surgery and 2 weeks after lengthening was started. **C:** During the lengthening, the formation of bone in the distraction gap can be seen. Note the deficiency of bone on the side in which the osteotomy was opened to correct the valgus deformity. This usually does not prove to be a problem. **D:** A slight deficiency of bone is still seen 9 months after surgery and 6 months after removal of the fixator. **E, F:** At 1 year, however, the deficiency has disappeared, and remodeling has progressed. ▶

A,B  C

D,E  F

POSTOPERATIVE CARE

Before leaving the operating room, the anesthesiologist may insert a catheter for a continuous epidural anesthetic. This produces excellent pain relief without the side effects of intravenous or intramuscular narcotics. This, in turn, allows physical therapy and ambulation with crutches (if the epidural anesthetic is titrated correctly) to begin on the day of or the morning after surgery.

Teaching of screw care to the patient and parents begins on the first postoperative day. The philosophy and methods of screw care vary so widely and involve such rigidly held beliefs that it is difficult to make any recommendations. That not withstanding, it is important to clean the skin and the screws daily with half-strength hydrogen peroxide only, avoiding any ointments or disinfectants, which tend to build up around the screws. The principle is to keep the local environment clean so that the tissues remain healthy. For the first few weeks, dressings are applied in a manner that minimizes the motion of the skin around the screws.

Distraction usually begins about 7 days after surgery. If an opening wedge osteotomy is performed acutely, it may be wise to delay a few days longer. To begin lengthening, the bolt holding the screw clamp that is to slide is removed while the other remains securely locked on the body of the fixator. This bolt is saved for later use, when lengthening is completed. The patient distracts the leg 1 mm/day by four one-quarter turns of the distraction and compression bar each day.

It is important to monitor the distraction of the callus. An anteroposterior radiograph of the osteotomy site is taken after 1 week and then every 2 to 4 weeks as deemed necessary. It is important to maintain continuity of the callus. If a break in the callus is observed, distraction should be stopped while awaiting callus formation. It may be necessary, in some cases, to reverse the distraction and apply compression. Distraction is then resumed when radiographs demonstrate continuity of the callus. It is also necessary to be cautious of premature consolidation, a more unusual problem. If this occurs, distraction can be increased to 1.5 mm/day.

When the desired lengthening is achieved, the bolt is used to lock the mobile screw clamp. A period of consolidation begins. When the callus shows good consolidation, the bolt is again removed from one of the screw clamps, and the period of dynamic loading is begun. This can begin sooner and can be safer if the dynamic locking collar is used (see Fig. 4-104). This ring locks rigidly to the lengthener. It is placed directly against the mobile screw clamp. This permits the device to collapse a few millimeters, placing stress on the bone, but prevents any more collapse of the callus than that. Dynamization can also be done by removing some screws. Leaving one screw distal and one proximal while moving the fixator as far from the bone as possible increases the axial loading on the bone and may actually be the most effective method of dynamization. When cortical bone formation is observed, the device is ready for removal. This can usually be accomplished in the office.

The time to healing is expressed by the healing index, which is the number of days of total treatment required to obtain 1 cm of lengthening. It is calculated by dividing the total treatment days by the number of centimeters of lengthening. For the femur, the healing index is 36 days/cm (1).

References

1. De Bastiani G, Aldegheri R, Renzi-Brivio L, et al. Limb lengthening by callus distraction (callotasis). J Pediatr Orthop 1987;7:129.
2. Horster G. Principles of the surgical correction of posttraumatic deformities of the lower extremities. In: Hierholzer G, Muller KH, eds. Corrective osteotomies of the lower extremity after trauma. Berlin: Springer-Verlag, 1985:128.

4.16 ILIZAROV TECHNIQUE OF FEMORAL LENGTHENING

The Ilizarov apparatus is a complex circular frame that is connected to the bone by a combination of rigid pins and wires that transfix the bone in multiple planes. There are many components that can be used in constructing a frame; although there is considerable latitude in the details, there should be no variation from the principles. Because of the complex nature of this apparatus and its varied applications, it is beyond the scope of this book to do more than describe its principles by illustrating a case of simple femoral lengthening. The details of erecting a frame and attaching the wires to the frame are described in more detail in the description of Ilizarov lengthening of the tibia (see Chapter 6, Procedure 6.9).

As with any device, there are potential advantages and disadvantages to the use of the Ilizarov device in lengthening of the femur. The greatest advantage that the Ilizarov device has over other methods of lengthening is its ability to correct angular and rotational deformities at the same time. The trade-off for the bulky frame proximally that interferes with daily functions is that proximal pin fixation can be obtained in more than two planes at right angles to one another as opposed to the unilateral frames. This means secure fixation of the bone fragments and thus less deformity during lengthening (Figs. 4-123 to 4-127).

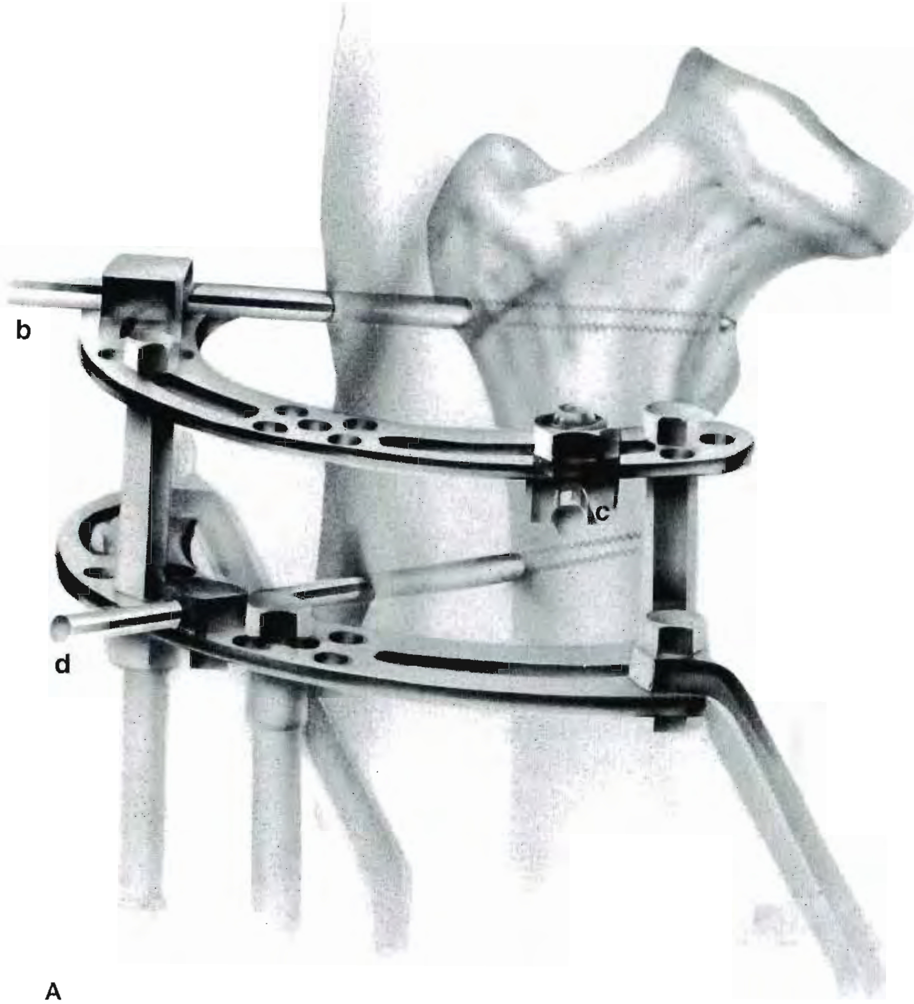
◀ **FIGURE 4-123.** For general guidelines in assembling the frames and a description of the various parts of the frame, see the discussion on Ilizarov lengthening of the tibia (see Chap. 6, Ilizarov procedure).

As much as possible, the assembly of the frame should occur before the surgery. The exact construction of the frame depends in large part on the size of the patient. The proximal part of the frame can be made with two arches (90 or 120 degrees, small or large), or in the case of a small child, one arch and a "dropped pin" that is attached to a multiple-pin fixation clamp. This provides two levels of fixation of the proximal fragment in the horizontal or transverse plane. To achieve fixation in the coronal and sagittal planes, additional pins are used to transfix the bone in these planes and attach to the frame.

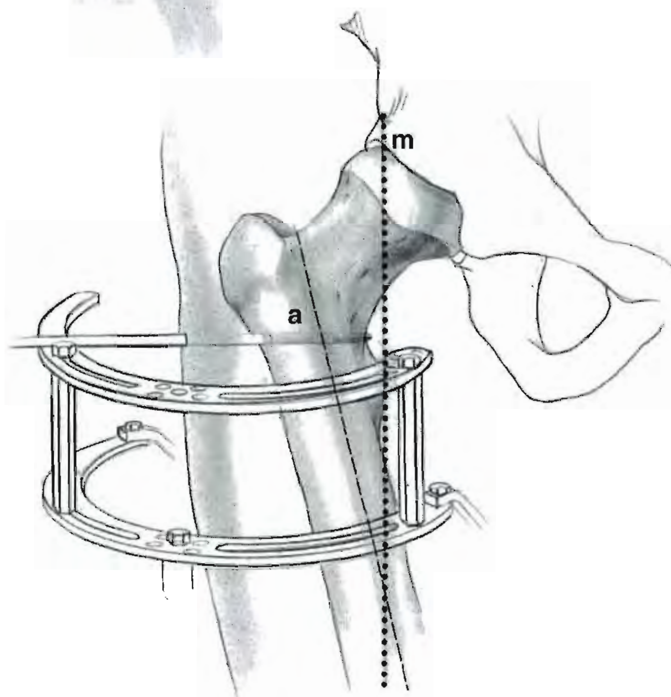
The distal frame consists of two complete rings joined in the usual manner by connectors. Again, the principle is to achieve fixation of the distal fragment in two different horizontal planes. The distal ring supports two transfixion wires, and the proximal ring supports one or two transfixion wires, depending on the need for stability. If the child is too small to permit the use of two rings, a "dropped wire" can be used. If there is fear that the distal ring will block knee flexion, a 5/8-ring can be used as the distal ring.

Between the 120-degree arch and the distal rings is a "dead ring." This ring is not attached to the bone. The proximal frame is connected to the dead ring by two oblique supports and two rigid rods. The dead ring will be connected to the more proximal of the distal rings with lengtheners or hinges that will be used to lengthen or correct the angular deformity. When initially constructed, the frame will conform to the deformity. This concept of the dead ring greatly simplifies the construction of the frame when it is used for angular correction.

The parts of the apparatus that are preassembled—the distal rings and the dead ring—are attached to the femur by the most distal transverse wire (see Fig. 4-125**A**). With the apparatus attached to the bone through this wire, the frame can be adjusted to permit sufficient space between the rings and the skin, and the remainder of the frame can be assembled to fit the proximal thigh.



A



B

◀ **FIGURE 4-124. A:** With the assembly of the frame completed and adjusted, the proximal half-pins are placed as illustrated. These can be either 4- or 5-mm pins depending on the size of the patient. The first pin (b) placed is the lateral pin, which is placed directly distal to the greater trochanter (b). **B:** It is important that this pin be perpendicular to the mechanical axis (m) of the femur, which passes from the center of the femoral head through the center of the knee to the center of the ankle, not the anatomic axis. This half-pin is then attached to the ring, and the frame is further adjusted on the thigh. The apparatus is now fixed in position. Next, the anterior pin (c) is placed at 90 degrees to the lateral pin and is attached to the proximal arch. The third pin (d) is placed at a 45-degree angle to these two pins and attached to the lower arch. In a large patient, a fourth pin can be placed and attached to the lower arch.

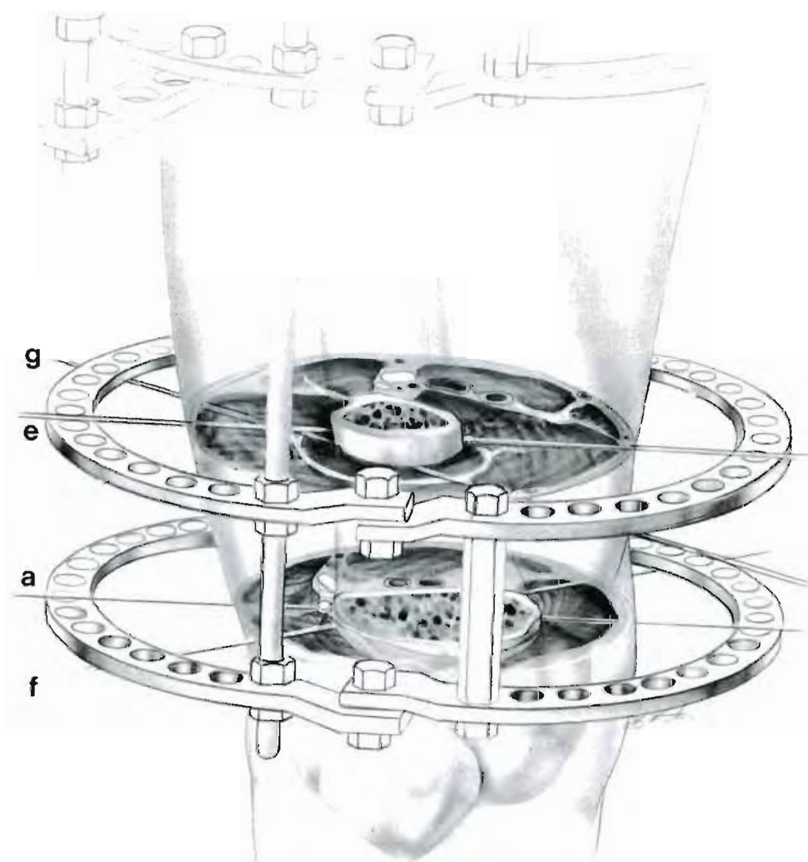


FIGURE 4-125. The distal wires are inserted in the following manner. The transverse pin on the distal ring is the first pin inserted (a). This pin should have an "olive" laterally. This first transverse pin should be placed parallel to the axis of the knee joint. The knee should be flexed when this pin is inserted to avoid fixing the quadriceps muscle in an extended position, thus blocking flexion.

A second transverse wire with an olive medially is attached to the more proximal ring (e). Two additional pins are needed. One of these should begin anterolaterally (f) and another anteromedially (g) so that they tend to be at 90 degrees to each other. When the wire is passing through the quadriceps, the knee should be flexed, and when the wire is exiting posteriorly and passing through the hamstring muscles, the knee should be extended.

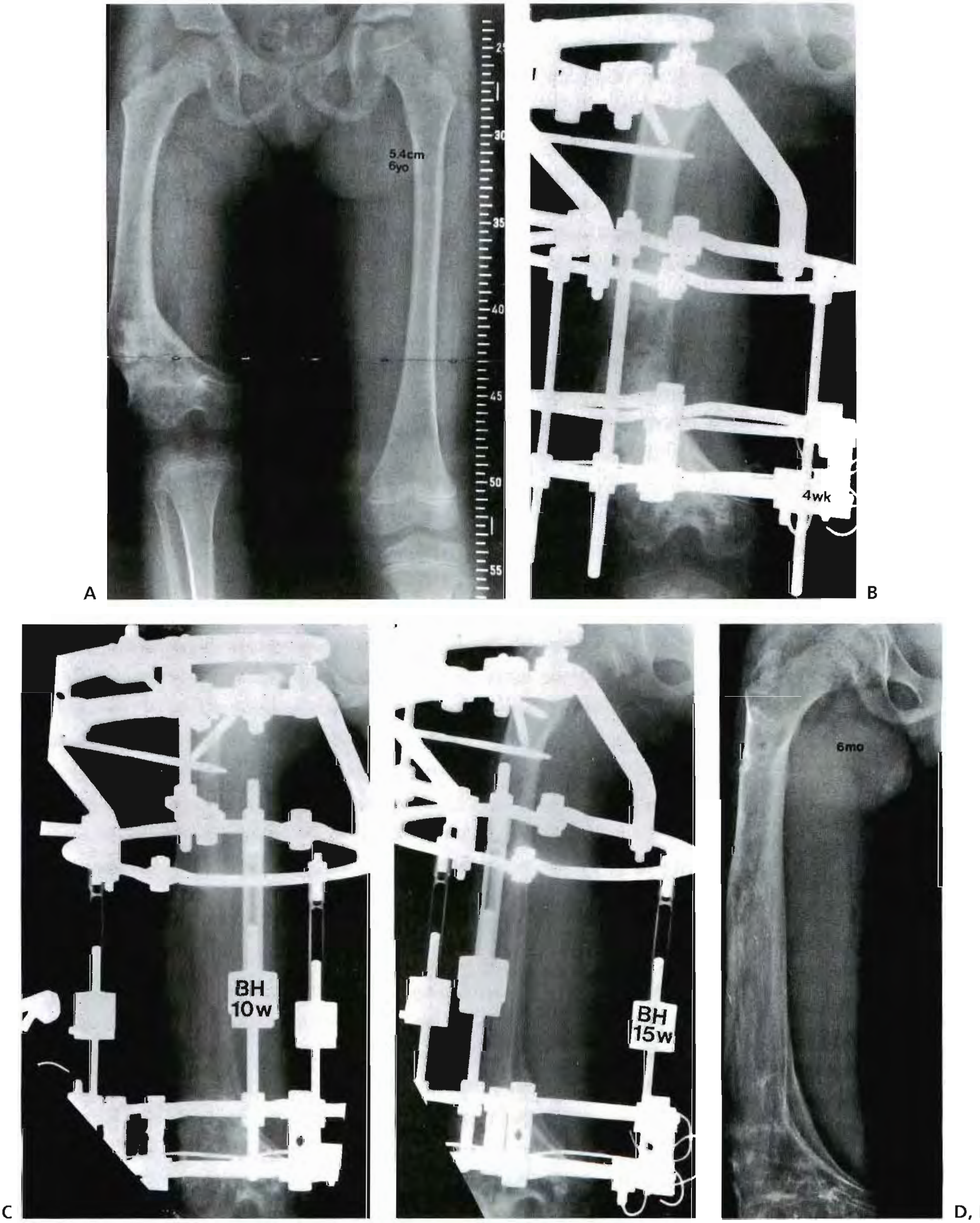
FIGURE 4-126. With the frame now attached to the leg, the connectors between the distal rings and the dead ring are removed in preparation for the osteotomy. The principles of the osteotomy and the technical aspects of its performance are described in the procedure for tibial lengthening with the Ilizarov technique (see Chap. 6, Ilizarov tibia lengthening). The osteotomy is performed in the distal femur about 1 cm proximal to the most proximal of the distal pins. This can be done through a lateral incision.

FIGURE 4-127. BH is a 6-year, 6-month-old girl who sustained destruction of the distal femoral epiphysis secondary to sepsis as an infant. She has undergone several previous osteotomies, and her projected leg-length discrepancy is 15 cm **(A)**. The plan is to gain as much length as possible, recognizing that further lengthening will be necessary in the future. It is anticipated that the translational deformity will be corrected during a future lengthening. Notice that despite the poor mechanical axis of the femur, her knee joint is parallel to the floor throughout the lengthening.

The progression of the callus distraction is illustrated at 4, 10, and 15 weeks **(B, C, D)**.

The results are seen 6 months after removal of the apparatus **(E)**. (Courtesy of Peter Armstrong, M.D., Shriners' Hospital for Crippled Children, Salt Lake City, UT.)

▶


5.4cm
6yo
25
30
35
40
45
50
55
4wk
BH
10w
BH
15w
6mo
A
B
C
D, E

POSTOPERATIVE CARE

The lengthening begins 3 to 10 days after the application of the device and osteotomy of the bone. In most children, lengthening is started at 5 days. Lengthening is done at the rate of 1 mm/day in four stages. If the lengtheners are used, the patient's task is simplified because each click equals 0.25 mm. If threaded rods are used, the patient must adjust all of the nuts on all of the rods four times per day. During this period of lengthening, weight bearing is encouraged, and physical therapy to maintain joint motion is done several times per day.

The lengthening is monitored radiographically to be certain that continuity of the callus is maintained. Remember that 1 mm/day is a guide and that circumstances (e.g., disruption of the callus, premature consolidation) may call for either an increase or a decrease in the rate of lengthening. The apparatus should not be removed until cortical bone is present in the distraction callus. Because the structure of the frame provides enough flexibility for mechanical loading of the bone, this cortex should develop without loosening the distraction, as is done during the period of consolidation in the Orthofix technique. Nevertheless, fracture is a problem with all leg lengthening procedures, and the patient should be protected with a brace, crutches, or both, as the circumstances dictate.

4.17 DISTAL ANGULAR FEMORAL OSTEOTOMY

Many deformities in children can result in a growth disturbance of the distal femur. Among the most common are infection, injury, and systemic growth disturbances (e.g., rickets). In many cases, especially those that destroy a segment of the growth plate, varus or valgus may be combined with anterior or posterior angulation, affecting predominantly one condyle. These combined deformities create a plane of motion at the knee that is not in the mechanical or anatomic axis of the limb, and they require careful preoperative planning to correct each component of the deformity.

There is a particular risk in correcting valgus deformity, especially when severe and of long duration or when contemplating an opening wedge osteotomy. That risk is damage to the peroneal nerve. When this risk is foreseen, releasing the peroneal nerve from the tight overlying fascia distally past the fibular head is advised.

Fixation around the knee (i.e., the distal femur or proximal tibia) is often difficult in children because of the open growth plates. Crossed smooth Steinmann pins have been used but have the disadvantage of being less rigid than desirable, necessitating a cast, and risking infection if the pins are left outside of the skin. Rigid internal fixation with blade plates can be done in the usual manner if the growth plate is closed, but if it is open, the blade must be inserted above the growth plate and the side plate recontoured. A contoured AO dynamic compression plate may also be used. These last two methods require that the osteotomy be higher than might be desirable. Often, in smaller children, the smaller right-angled blade plates can be used. Careful preoperative planning, considering the location of the osteotomy and the type of plate, its length, and its off-set, is required. A third alternative is the use of external fixation.

The osteotomy is performed and fixed from the lateral approach, although a severe valgus deformity can be corrected from a medial approach. When a valgus deformity is corrected from a lateral approach, the blade plate is used as a buttress plate. If an opening osteotomy is used in this region, it is usually not necessary to add bone graft. Curetting bone from the metaphysis into the defect usually results in prompt healing.

Limb length is also a consideration in angular deformities of the distal femur and should be accounted for in the preoperative planning. In addition to the projected discrepancy at the end of growth secondary to growth plate damage, there are two factors regarding the limb length that should be considered in the planning. These factors are discussed in relation to tibial osteotomies by Canale and Harper (1) (Figs. 4-128 to 4-139).

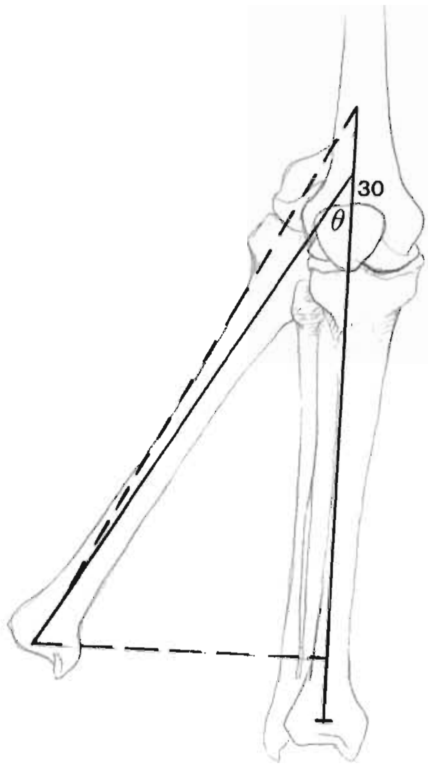


FIGURE 4-128. The first factor to consider in terms of length is that any angular deformity will produce a functional shortening of the limb, and correction of this angulation will produce a gain in length. The amount of length that can be gained (independent of the type of osteotomy performed) is dependent on the length of the limb below the osteotomy site and the degree of angulation. The amount of length to be gained can be derived from analysis of the geometry (1). It can be estimated more easily by drawing templates of the correction. If the deformity was created by a malunion and not a disturbance of growth, there is little value in this calculation because correction of the angulation will restore normal length. The calculation of this factor is of importance when correction is planned of a large angular deformity caused by a disturbance in the overall longitudinal growth of the limb.

FIGURE 4-129. The second factor to consider in the planning of the osteotomy is how much length will be gained or lost by an opening or closing wedge. Geometric analysis shows that the amount of length gained or lost is equal to the height at the center of the wedge (1). This can be calculated either geometrically or from templates before surgery and measured directly at the time of surgery. Small corrections of length in the range of 1 to 2 cm are usually possible, but the surgeon should not expect to gain larger corrections by the osteotomy alone.

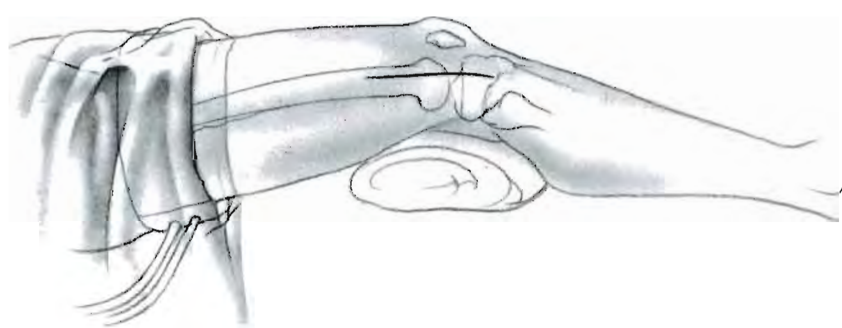


FIGURE 4-130. The patient is positioned supine on a translucent table. A sandbag is placed under the hip to compensate for the tendency of the leg to rotate externally, and a soft roll is placed under the knee to relax the muscles. The leg is draped free so that it can be moved. A sterile tourniquet can be used around the proximal thigh except in small children. The incision extends from the level of the knee joint proximally along a line that connects the midportion of the lateral femoral condyle and the greater trochanter.

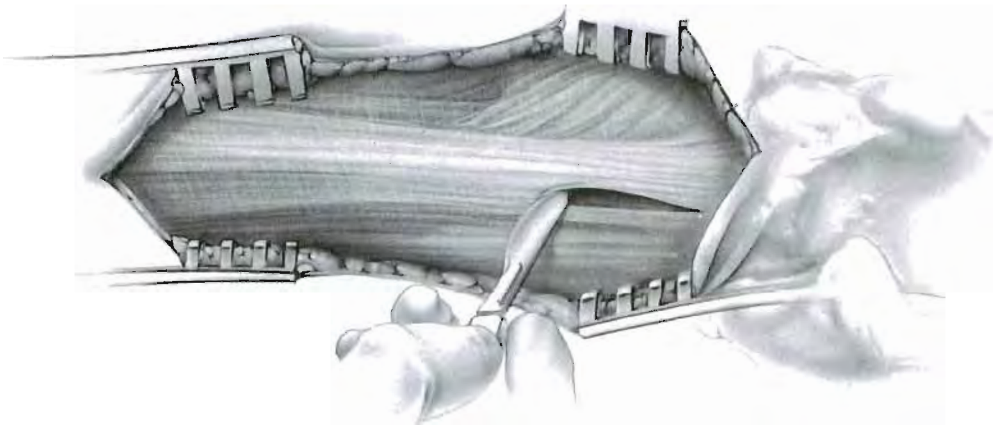


FIGURE 4-131. The iliotibial band is identified after the subcutaneous tissue is divided. A divergence of the fibers distally can be identified: the fibers to the patellar retinaculum going anteriorly and the insertion of the iliotibial band into Gerdes' tubercle continuing distally. The iliotibial band is divided beginning in this interval.

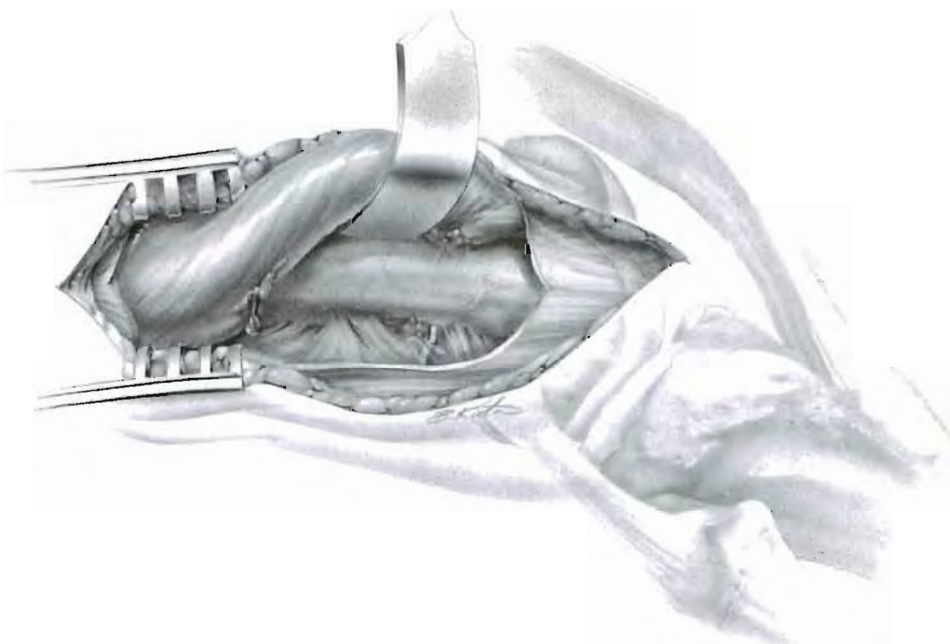


FIGURE 4-132. The posterior edge of the vastus lateralis muscle is identified in the distal part of the exposure and is elevated anteriorly. After a short distance, the vastus lateralis will be attached to the intermuscular septum, from which it must be freed. This is done with a periosteal elevator. The muscle can be followed back to its insertion into the femur, from which it also must be freed. This would be a simple matter were it not for the superior geniculate artery crossing the flare of the lateral femoral condyle and the perforating branches supplying the vastus lateralis muscle that come through the intermuscular septum close to the bone to enter the muscle. As the bone is approached, these vessels can usually be identified and cauterized if care is taken in the dissection.

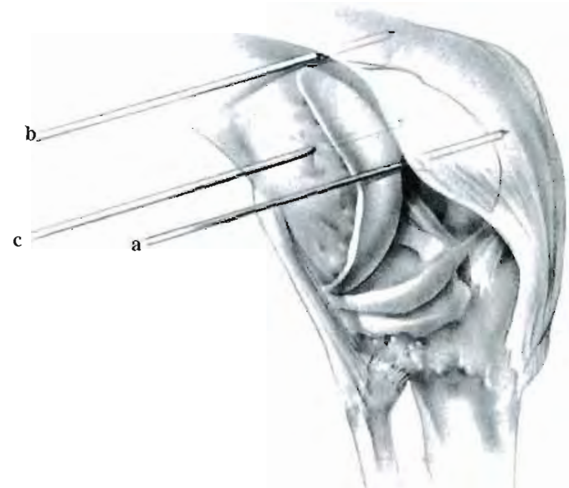


FIGURE 4-133. Because there will be a deformity, the condylar guide cannot be used as it is for fracture fixation. The correction of the deformity, however, is dependent on the blade being placed in the distal fragment in exactly the correct position. This is usually parallel to the joint line. It is therefore best to identify the joint line by inserting a small, smooth Kirschner wire through the knee joint, passing over both femoral condyles (a). This is easiest to do with the knee flexed 90 degrees. This wire guides the insertion of the seating chisel in the frontal plane.

It is necessary, at this point, to determine the correct location and direction for the insertion of the seating chisel in the sagittal plane. A second smooth Kirschner wire can be passed over the anterior surface of the femoral condyles through the patellofemoral joint to determine the inclination (b). The correct starting point will be 1.5 cm proximal to the joint line and in line with the middle of the femoral shaft. Now a third Kirschner wire parallel to the joint line and at the proper inclination can be drilled into the femoral condyle 1 cm proximal to the joint; its location is confirmed on the image intensifier and then used as the guide for the seating chisel (c). The other two wires (a, b) can be removed.

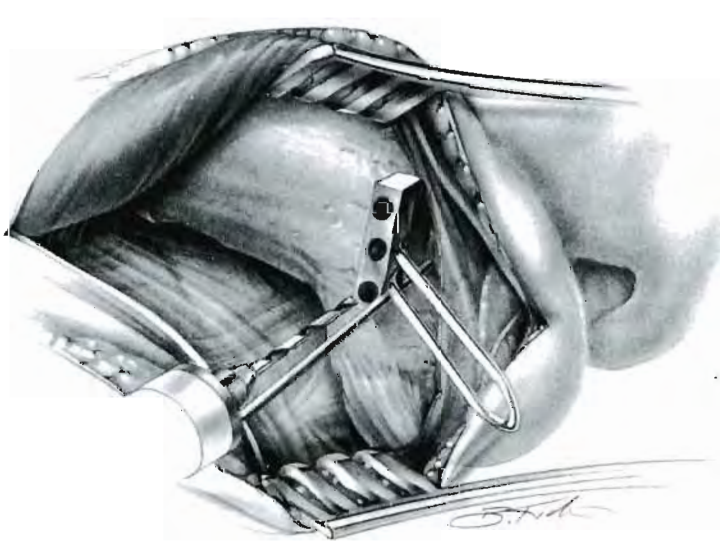


FIGURE 4-134. It is necessary to make an opening in the cortex before inserting the chisel so that its direction can be controlled. This can be performed with a small osteotome or by making three holes with the 4.5-mm drill and drill jig, which can be connected with a small rongeur.

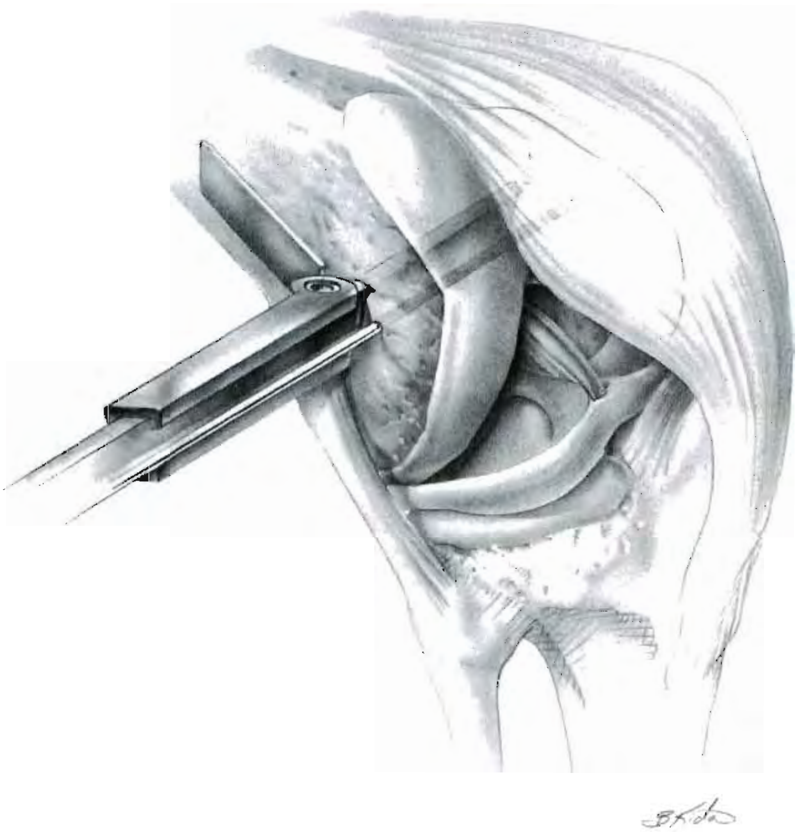


FIGURE 4-135. The seating chisel is driven into the femoral condyles. It is helpful to use the seating chisel guide and the slotted hammer to maintain the proper rotation of the blade during insertion. If this is not done, the plate will not contact the shaft of the femur.

FIGURE 4-136. If a valgus deformity is being corrected by an opening-wedge osteotomy to gain length, no further calculations are needed. A simple transverse osteotomy is made in the supracondylar region. When the side plate is brought in contact with the femoral shaft, the alignment of the distal femur should be brought to normal.

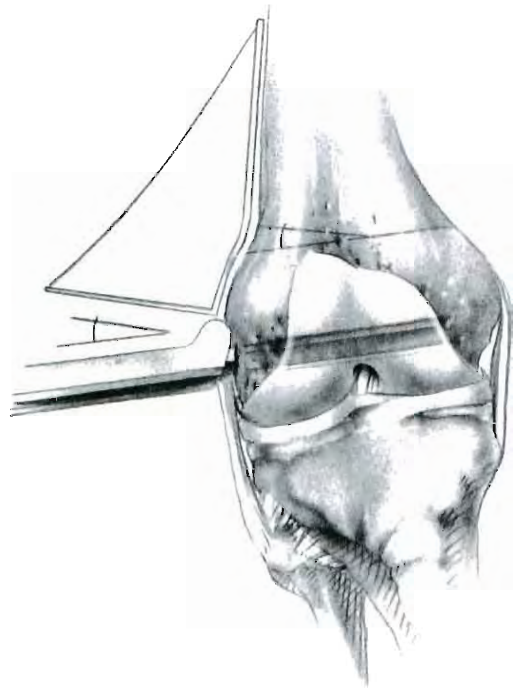


FIGURE 4-137. When a varus deformity is being corrected by a closing-wedge osteotomy, the size of the wedge needs to be determined. This should be done preoperatively but can be confirmed by noting the angle formed by the seating chisel and the bottom of the condylar guide. A transverse osteotomy is made in the supracondylar region, and the appropriate-sized wedge is then removed from the lateral half of the proximal fragment if varus is being corrected or from the medial half if valgus is being corrected without the need for additional length.

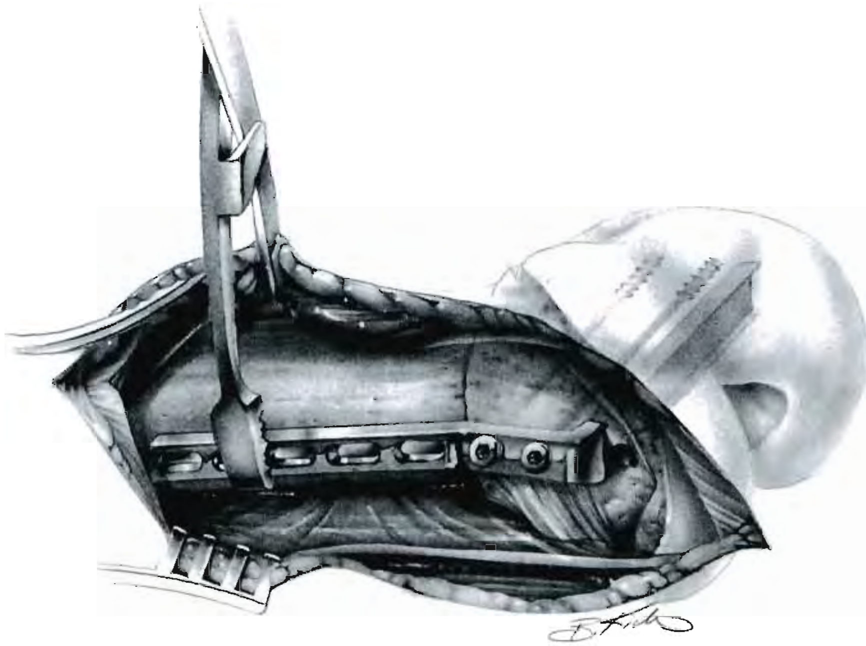
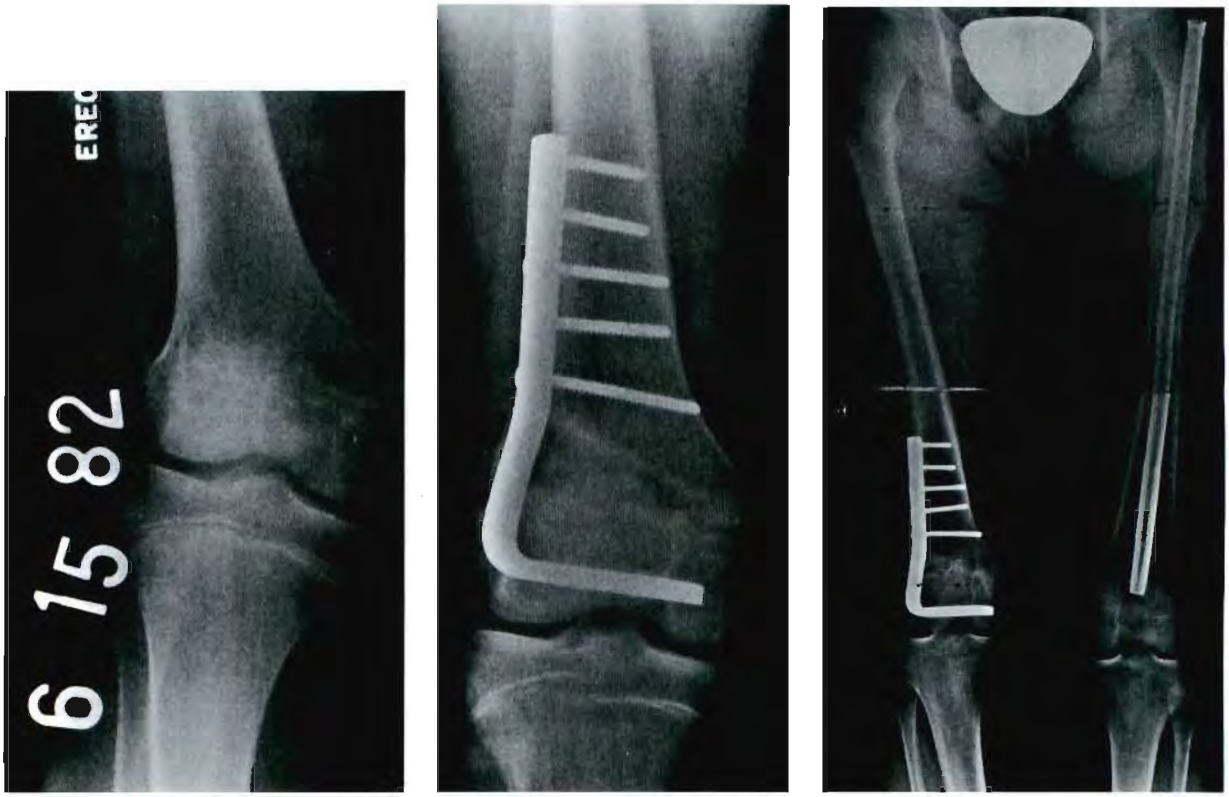


FIGURE 4-138. The two distal holes in the condylar plate are for the use of cancellous screws to provide for additional fixation of the distal fragment. After they are secured, the plate is held to the femoral shaft with a clamp and secured with screws. It is advisable in this osteotomy to use the compression device to obtain compression rather than relying on the compression obtained through the dynamic compression of the plate and screws alone.

The wound is drained and closure started at the iliotibial band.

A, B



C

FIGURE 4-139. JT sustained a Salter II fracture of the distal femoral physis at 12 years of age, with subsequent growth arrest of the lateral half of the growth plate. When seen at 16 years of age, he had a significant valgus deformity and 4.5 cm of shortening of the femur as compared with the opposite side **(A)**. It was calculated that an opening-wedge osteotomy of the distal femur would produce 1.5-cm gain in length of the leg, leaving a 3-cm discrepancy. An opening-wedge osteotomy was performed using a condylar blade plate **(B)**. At the same operative session, the patient also underwent a closed intramedullary shortening of the opposite femur to produce equalization of his limb lengths **(C)**. Lengthening with angular correction, using either the Ilizarov or Orthofix device, would be another alternative to this treatment plan.

POSTOPERATIVE CARE

No immobilization is necessary postoperatively. The patient is started on active-assisted range-of-motion exercises the day after surgery and progressed to protected crutch weight-bearing in a few days. As pain subsides, the patient begins active exercises to maintain quadriceps and hamstring strength. Healing of the osteotomy is monitored with radiographs, and full weight bearing is permitted when union is evident, usually within 6 to 8 weeks.

Reference

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4.18 DISTAL ROTATIONAL FEMORAL OSTEOTOMY USING EXTERNAL FIXATION

Rotational malalignment in the femur can be corrected by osteotomy at any point in the bone. The rapid healing that occurs in the metaphyses, however, favors correction in either the intertrochanteric or supracondylar region. Although many surgeons recommend that correction be done in the intertrochanteric region at any age, some prefer to perform the osteotomy in the supramalleolar region for children younger than 9 years of age (1,2). The indications for rotational osteotomy for excessive and persistent femoral anteversion have been given (1–3). Because surgery is usually not indicated or necessary before 8 years of age and this technique is not recommended for children older than 9 years of age, there is limited use for this indication.

The procedure initially was conceived on two principles: it does not matter where the rotational correction is achieved, and it is a smaller and simpler operation when performed in the supracondylar region, leaving only a small scar and not requiring the removal of internal fixation. As originally performed, the procedure required no fixation other than a double-hip spica cast. After experiencing loss of position, some surgeons began to place Steinmann pins into the bone and incorporate these into the cast. With the evolution of external fixation, it was logical that external fixation without a cast would be an additional option for treatment.

In addition to the potential loss of position if no fixation other than casting is used, medial overgrowth of the distal femur requiring reoperation has been reported (4). The reason was not apparent but was likened to the valgus deformity that is seen after an incomplete proximal tibial fracture in a growing child.

The advantages of using this approach need to be individualized to each patient. Using external fixation with distal rotational osteotomy carries its own drawbacks and benefits. With most fixators, there is some adjustability if needed after the patient is evaluated awake. This should seldom be necessary after a careful evaluation on the operating table with the patient still under general anesthesia and the drapes removed. In general, patients do not like external fixation. For the surgeon, the same problems with delayed healing that are seen with transverse fractures are seen here (Figs. 4-140 to 4-144).

FIGURE 4-140. The patient is positioned flat on a radiolucent table. A sterile bolster beneath the knee facilitates placing the pins but must be removed when checking the rotation.

The appropriate-sized Orthofix fixator and its template are chosen. The body of the template should be extended 2 to 3 cm. This is to allow for the shortening of the device that will occur as the bone is rotated, bringing the two sets of pins closer together. Just as important, having the device extended permits dynamic loading of the osteotomy site to promote more rapid healing. The template is aligned with the femoral shaft, and the most proximal two pins are placed first, as described for lengthening.

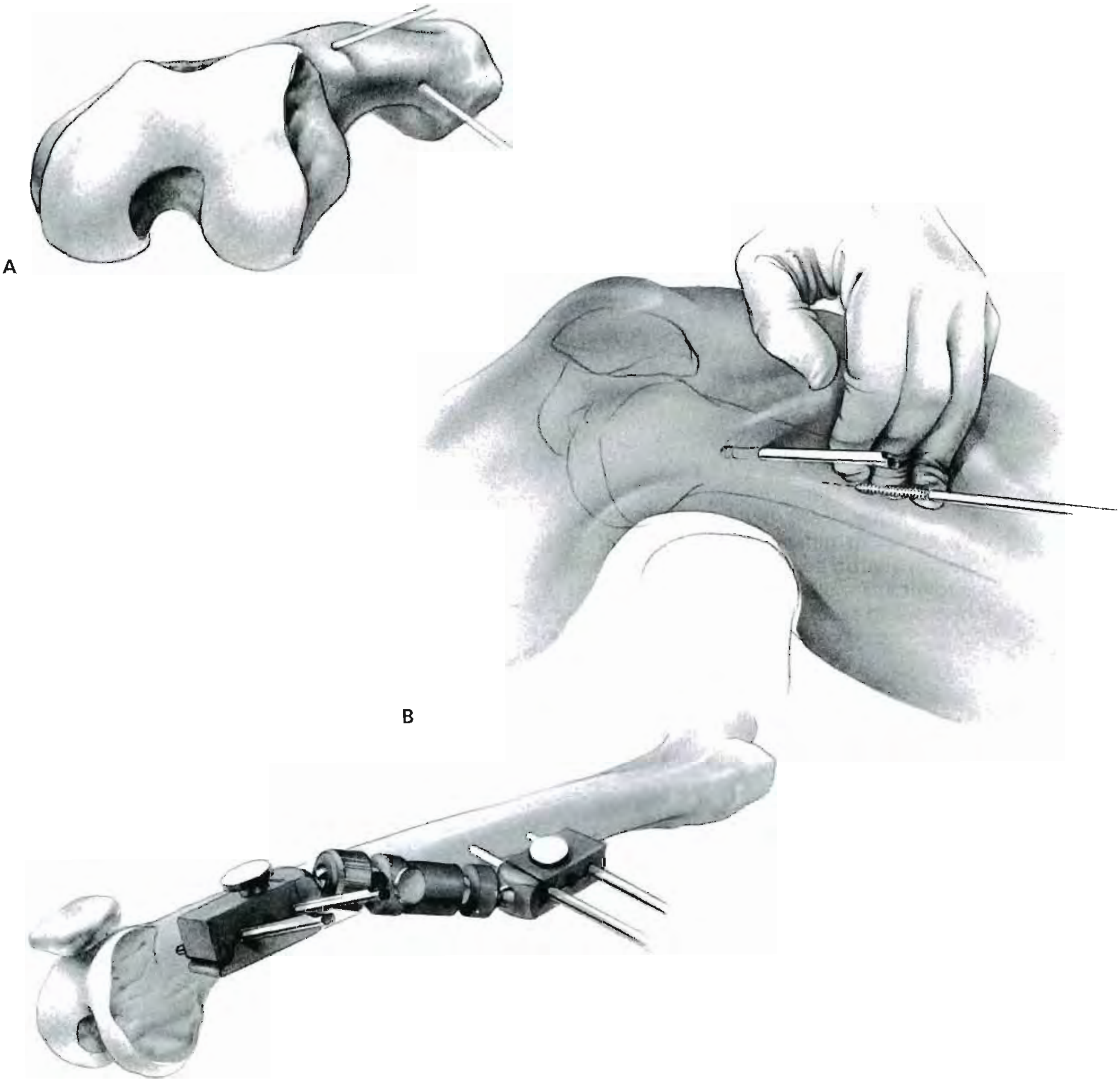

FIGURE 4-141. The most distal pins are placed next. Because the distal fragment will be rotated externally, however, these pins will not be placed in the same axis as the two proximal pins. Rather, they will be placed at an angle to the proximal two pins that approximates the degree of correction that is desired. These distal pins should not simply start at a different angle in the same longitudinal axis as the other two pins but actually should start on that surface of the bone that will lie in the axis of the proximal pins after the rotational correction is achieved **(A)**.

If these distal pins are placed straight through the skin, they will produce severe pressure and subsequent necrosis of the skin after they are rotated to produce the correction. To avoid this, the skin of the distal thigh is rotated anteriorly and held there while these distal pins are inserted **(B)**. The ball joints of the template are rotated to permit the insertion of these pins in a different axis but parallel to the femur **(C)**. They are inserted in the manner previously described for the Orthofix device with one addition. Because these pins rotate through the muscle and particularly the fascia lata, the incision in the fascia lata is made in a T configuration posteriorly, and the hemostat is spread in both a longitudinal and transverse direction.

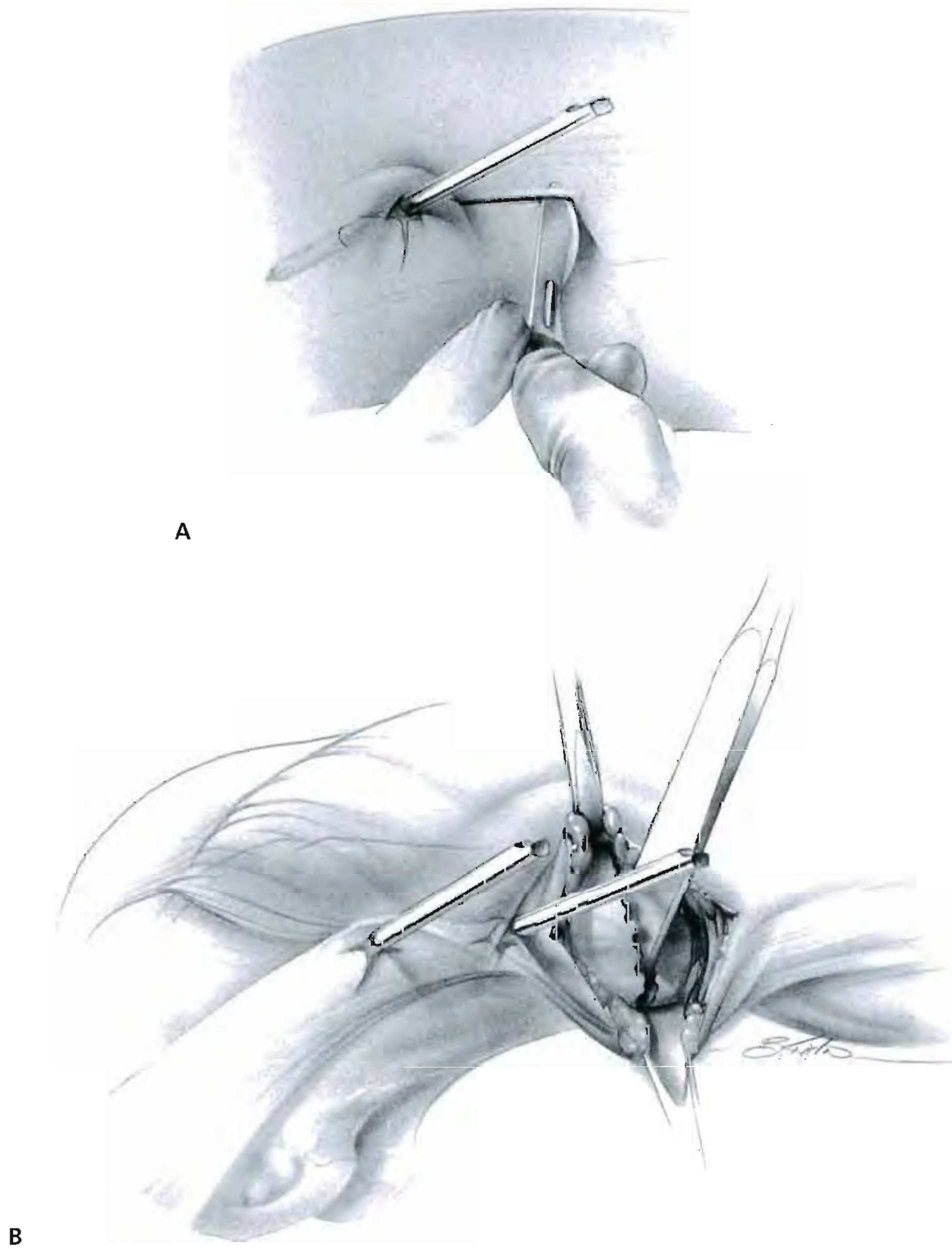

FIGURE 4-142. After the pins are inserted, the template is removed, and a small incision is made posterolaterally, extending proximally about 2 cm from the level of the most proximal of the distal two pins **(A)**.

The vastus lateralis is elevated off the intermuscular septum and followed to the bone. A longitudinal incision is made in the periosteum, which is elevated circumferentially. Multiple drill holes are made in the bone, extending through the opposite cortex. The drill stop can be used to avoid overpenetration on the medial side. The osteotomy is completed with a small osteotome **(B)**. The pins are grasped and twisted to be certain that the osteotomy has been completed and that there is sufficient mobility between the two fragments. The wound is then closed over a drain.

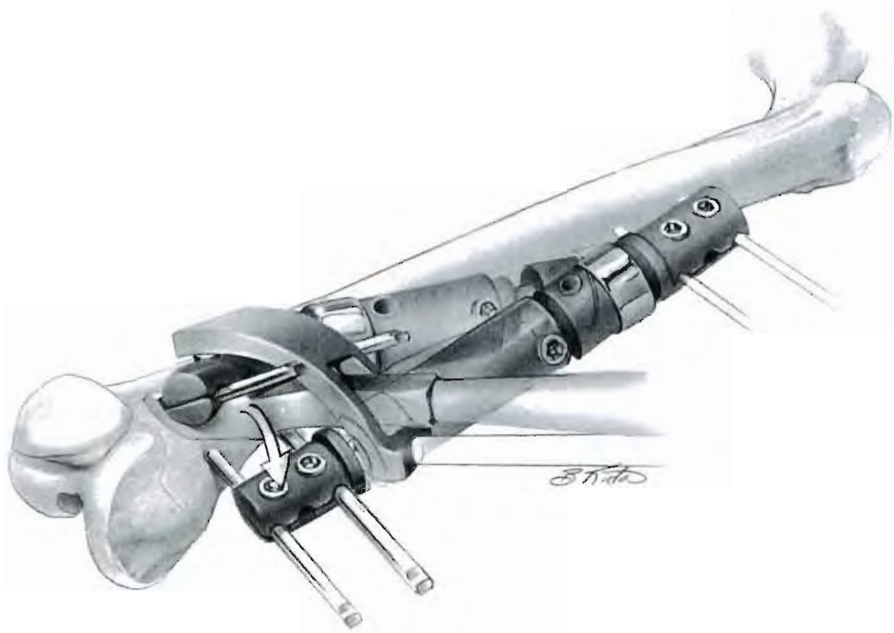

FIGURE 4-143. The fixator is applied to the pins, and the fracture reduction clamps are applied (only one clamp is shown for clarity). With the bolster removed and the leg flat on the table, the rotational correction is accomplished. The ball joints are locked with the torque wrench. The compressor-distractor is now applied and the osteotomy site compressed. The body-locking nut is tightened. The knee is flexed past 90 degrees to ensure that the pins are loose enough in the muscle to permit knee motion.

After the second leg is done, the drapes are removed, and the rotation of the two is compared. If any adjustments are necessary, they can be accomplished before the patient emerges from the anesthetic.

A

B

C

FIGURE 4-144. Immediate postoperative anteroposterior radiographs of an 11-year-old girl after a bilateral distal rotational femoral osteotomy **(A)**. The Synthes external fixator was used for fixation. The osteotomies were done higher than necessary but healed sufficiently in 8 weeks to allow removal of the fixators. The lateral radiograph of the right femur **(B)** demonstrates the displacement that occurs when the linea aspera is not stripped for a long distance: it acts as a tether at one point on the radius of the bone, causing one fragment to rotate out of the axis of the other fragment. This is illustrated in the technique of proximal rotational femoral osteotomy. The result at 8 weeks is shown **(C)**.

POSTOPERATIVE CARE

The drains can usually be removed on the first postoperative day. Range-of-motion exercises are also started on the first postoperative day. By the second day, the patient is out of bed and may progress to four-point crutch gait as tolerated. At 3 to 4 weeks, the body-locking nut is loosened, and the compressor-distractor is removed. Healing should be sufficient to prevent distraction at the osteotomy site, and pain should be minimal so that dynamic compression of the osteotomy site can begin. When the osteotomy is healed, the fixator and the pins can be removed.

References

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4.19 DISTAL FEMORAL EPIPHYSIODESIS, PHEMISTER TECHNIQUE

There are two indications to perform an epiphysiodesis. One is to slow the growth in one limb to allow the other to catch up in length, and the other is to correct an angular deformity. When used for the purpose of equalizing leg lengths, the growth of the entire physis is arrested to slow the growth of that segment relative to the opposite limb.

There are three methods by which arrest of the physeal growth may be accomplished: the open technique originally proposed by Phemister (1), the staple technique originally popularized by Blount and Clarke (2), and the percutaneous technique popularized by Timperlake and colleagues (3) and Canale and Christian (4).

The original concept proposed by Blount and Clarke (2) was to staple the physis while there were several years of growth remaining, usually after 8 years of age, then removing the staples when the correction had been achieved. Other surgeons, unsure of the reliability of the physis to resume growth, began to use the procedure of stapling nearer the end of growth (5,6). Today, emphasis is placed on calculating the correct time to arrest the growth so that when growth ceases, the limbs will be of equal length. Phemister's technique was developed with this concept in mind, that is, to stop the growth with an open destruction of the physis at the correct time to achieve equal limbs at the end of growth.

Although seemingly a simple procedure, open epiphysiodesis can have a high complication rate without careful planning and technique. Failure to achieve the desired correction and subsequent deformity due to incomplete arrest of growth are the main complications occurring in up to 10% of patients (7–9). Inadequate correction can be obviated by proper timing, and angular deformity can be avoided by adequate physeal arrest.

The Phemister technique of open epiphysiodesis has been the standard technique for epiphysiodesis but is rapidly being replaced by the percutaneous method. In the previous edition of this atlas (10), one of these authors mentioned abandoning this technique because of the soft tissue bleeding from the bone that delayed rehabilitation of the knee. This not uncommon occurrence is minimized by using a small drill and curette in the technique described here. The postoperative course after percutaneous epiphysiodesis is almost as benign as that after stapling.

Although it might be assumed that incomplete growth arrest and resulting angular deformity would be greater after percutaneous epiphysiodesis because of the lack of direct visualization, early reports with small numbers of patients do not bear that out. Two separate series reported no angular deformity and few minor complications (3,11), whereas a third (12) showed no difference between open and percutaneous procedures (11) (Figs. 4-145 to 4-151).

FIGURE 4-145. The patient is first positioned for surgery on the lateral side with a sandbag under the buttocks. When surgery is completed, the sandbag can be removed easily, allowing the patient to roll flat, facilitating the medial approach. A tourniquet is used. An incision about 3 cm in length is centered over the physeal plate. This incision is often made unnecessarily large, resulting in an unsightly scar. Remember that the exposure only needs to be large enough to excise the block of bone; the remainder of the surgery is performed through the resulting hole in the bone. If the surgeon is not able to identify the region of the epiphyseal plate by the external anatomic landmarks, an image intensifier can be used.

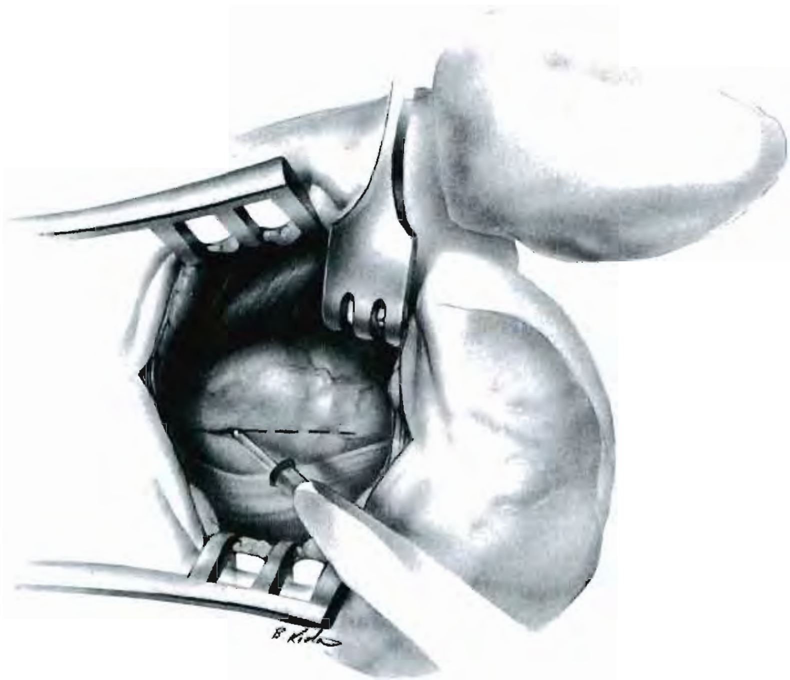
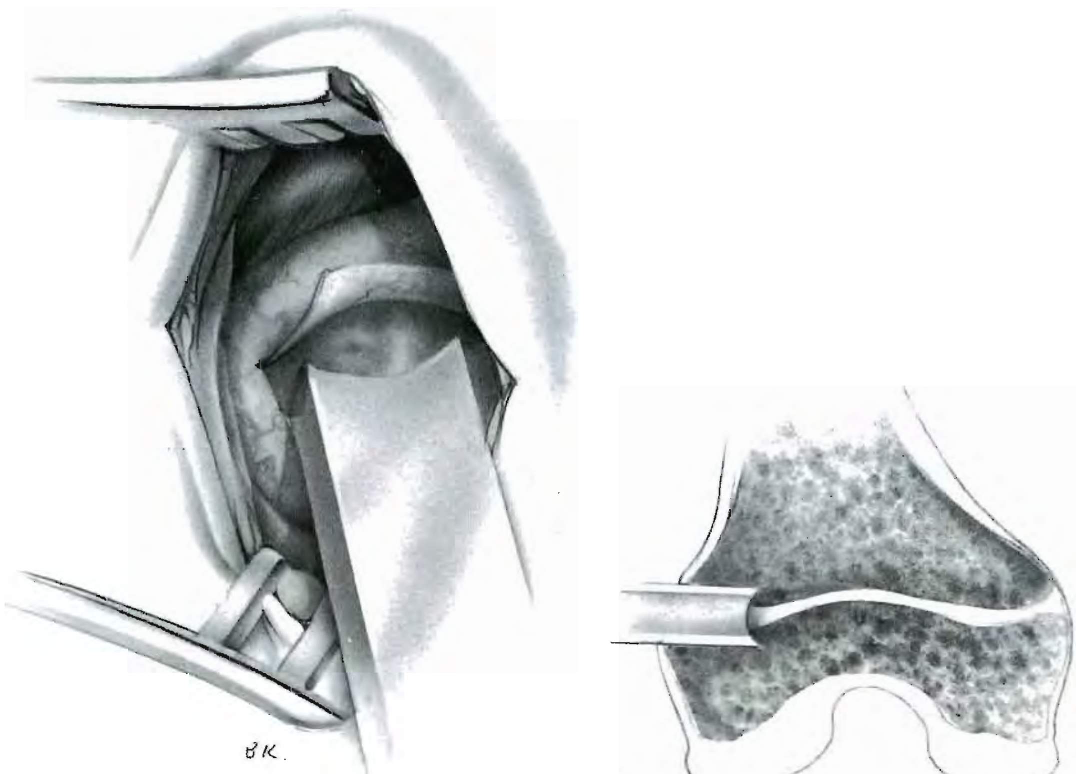


FIGURE 4-146. The incision is deepened through the fascia lata, and the posterior border of the vastus lateralis is identified, freed, and retracted anteriorly. This exposes the periosteum, which is incised, creating two flaps that are elevated with a periosteal elevator. These flaps can be cut in the periosteum with a coagulation current to cauterize the numerous vessels that cross this operative site. This helps prevent excessive bleeding and swelling after the tourniquet is removed. The physeal plate is easily identified if exposed by elevating the periosteum. The exposure can be enhanced by incising the periosteum directly over the plate at 90 degrees to the first incision, producing a cruciate incision. It is more difficult to secure a tight closure with this cruciate incision. It is not necessary to perform excessive periosteal stripping and expose large areas of the physeal plate. Only an area sufficiently large to permit removal of a block of bone no larger than 3/4 to 1 inch square is necessary. This block of bone will create a bony bridge across the plate, whereas the hole it makes will allow access for the destruction of most of the physeal plate.



A B

FIGURE 4-147. The next step is to remove a square or rectangular piece of bone, which includes the physeal plate. This can be accomplished with ordinary osteotomes or a mortising chisel **(A)**, as described by White and Stubbins (13). If osteotomes are used, a 5/8- to 3/4-inch osteotome is a good size. This block of bone should be removed to a depth of about 1 inch or more if the size of the femur permits. This makes removal of the surrounding physeal plate easier. This block of bone should be kept intact so that when it is replaced it will seal off the bleeding from the cancellous bone, which is a significant cause of postoperative swelling resulting in knee stiffness.

In removing the bone block, attention should be given to the anteroposterior radiograph of the distal femoral physis. If this is not done, it is easy to miss most of the physeal plate in the bone block because the plate undulates and is not straight across **(B)**.

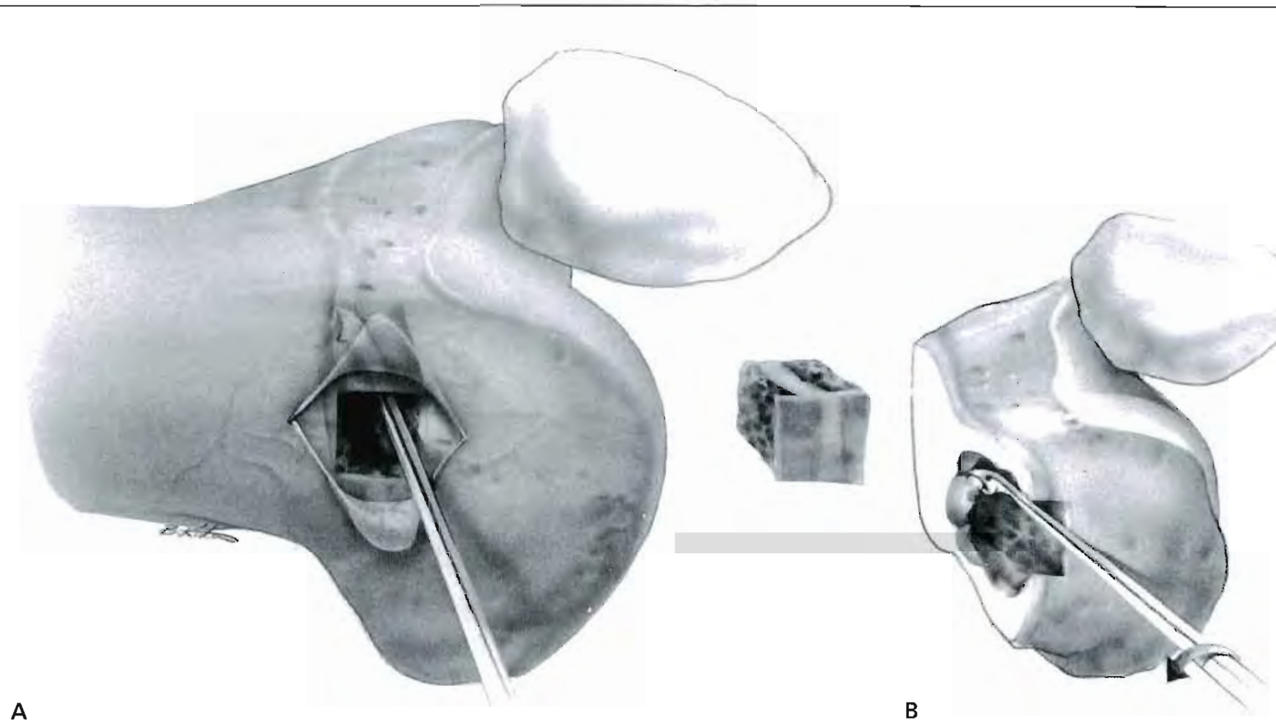


FIGURE 4-148. After the bone block is removed, it is necessary to curette out a large portion of the remaining physeal plate **(A)**. This is not as easy as it first appears. The undulating physeal plate has a way of disappearing, and it proves resistant to quick and effortless removal. Techniques have been described using drills and other power tools; in our experience, however, the soft and resilient cartilage of the plate proves much more resistant to removal by these means than the surrounding cancellous bone. Visualization is important, and some surgeons find a headlight to be useful.

The most reliable tool is a sharp curette, which is used to remove the physeal cartilage by rotating the curette into the plate **(B)**. Frequent irrigation and suctioning is necessary to see the plate. It is not necessary to destroy the most peripheral parts of the physeal plate; indeed, this would cause unnecessary instability and bleeding into the joint. When the surgeon judges the lateral half of the plate to be sufficiently destroyed, a moist sponge is placed in the wound, the sandbag is removed, and the procedure is repeated on the medial side of the leg.

FIGURE 4-149. The incision on the medial side is identical to the lateral incision; it is about 3 cm in length and centered over the physeal plate. After the bone block is removed, curettement of the plate proceeds toward the opposite side until it joins the curetted area on the lateral side. This is advisable because it is easy to assume that more of the physeal plate has been removed than actually has been. After this, removal of the plate occurs in a centrifugal manner until the surgeon again judges that sufficient plate has been destroyed.

FIGURE 4-150. To complete the operation, the bone blocks are now reinserted into the area from which they were removed. In doing this, however, they are rotated: 90 degrees if a square block was removed, and 180 degrees if a rectangular block was removed. The periosteal flaps are closed as tightly as possible, and the remainder of the wound is closed. Drains are not effective because they never drain more than a few milliliters of blood. If the surgeon is unsure of the completeness of the epiphysiodesis, anteroposterior and lateral radiographs can be obtained before wound closure. Interpretation of this radiograph must be done, however, recognizing its limitations as a two-dimensional image in reflecting a three-dimensional problem—the depth of the curettement.

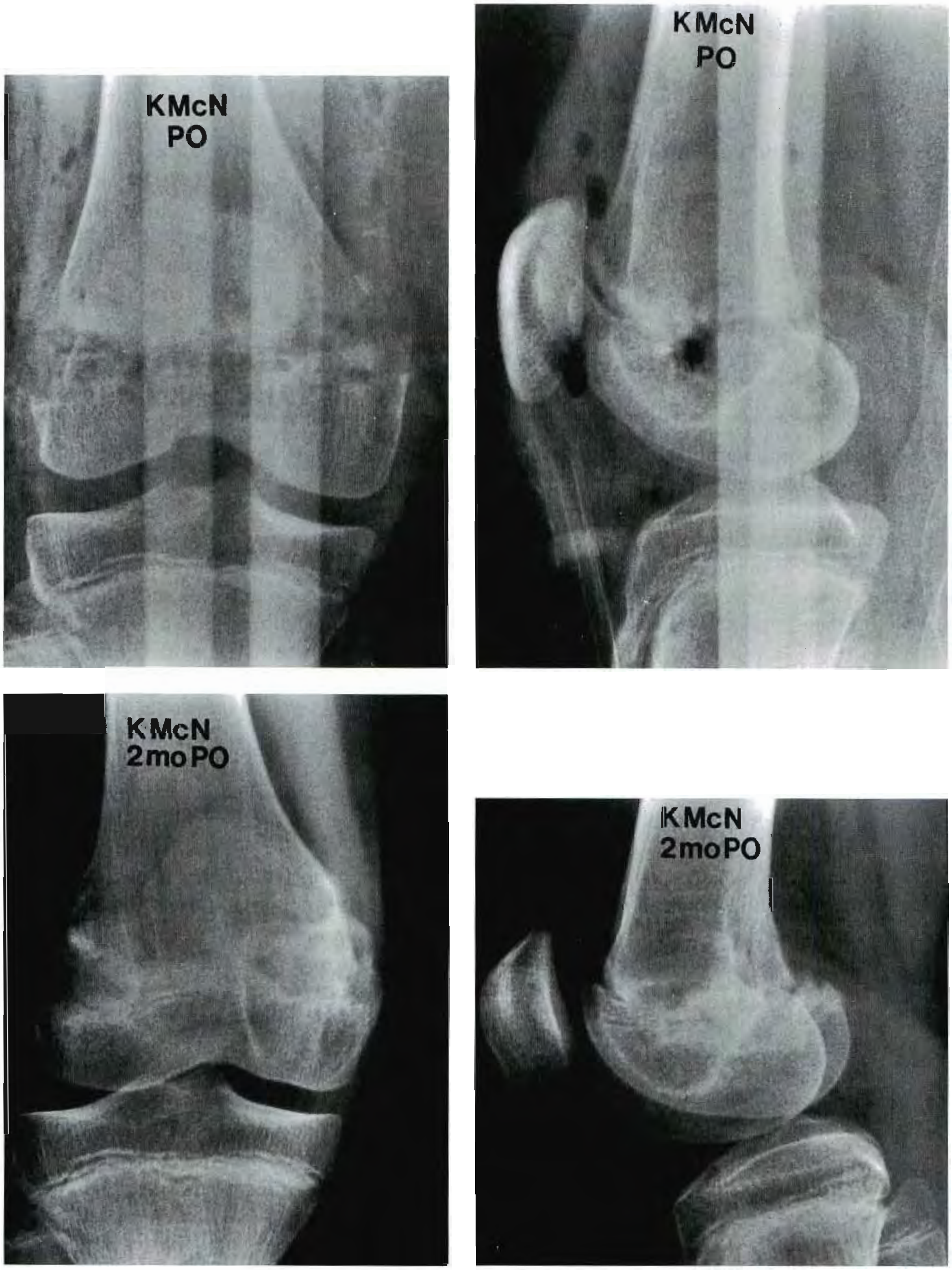


FIGURE 4-151. Radiographs taken immediately after surgery demonstrate adequate destruction of the physeal plate **(A, B)**. Two months later, radiographs confirm complete closure of the plate **(C, D)**.

POSTOPERATIVE CARE

At the completion of surgery, the patient is placed in a Velcro-fastening knee immobilizer. On the first postoperative day, a three-point partial weight-bearing crutch gait is begun, along with quadriceps-setting exercises and active-assisted range of motion. The patient usually can be discharged by the second postoperative day. Physical therapy is continued at home with supervision as necessary. If the patient is reliable on crutches, the immobilizer can usually be discontinued by 4 to 6 weeks. Crutches are continued until radiographic evidence of bone union is seen. This is preferable to discontinuing the crutches and maintaining the immobilizer or a cast because it permits earlier rehabilitation of the knee.

Radiographs at 6 to 12 weeks should demonstrate the areas of bone fusion across the physeal plate. This should be assessed so that the potential of developing angular deformity from an inadequate area of fusion is not ignored. The patient should be examined clinically for leg-length discrepancy every 4 to 6 months to be certain that correction is occurring and that the proper correction is obtained. Periodic scanograms for length or radiographs to assess the adequacy of plate closure may be necessary and depend on the clinical situation.

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4.20 PERCUTANEOUS DISTAL FEMORAL EPIPHYSIODESIS

Percutaneous epiphysiodesis is now a standard technique. In the previous edition of this atlas (1), one of these authors mentioned abandoning this technique because of the soft tissue bleeding from the bone that delayed rehabilitation of the knee. This not uncommon occurrence is largely avoided by using a small drill and curette in the technique described here. The postoperative course after percutaneous epiphysiodesis is as or more benign as that after stapling.

Although it might be assumed that incomplete growth arrest and resulting angular deformity would be greater after percutaneous epiphysiodesis because of the lack of direct visualization, early reports with small numbers of patients do not bear that out. Two separate series reported no angular deformity and few minor complications (2), whereas a third showed no difference between open and percutaneous procedures (3) (Figs. 4-152 to 4-154).

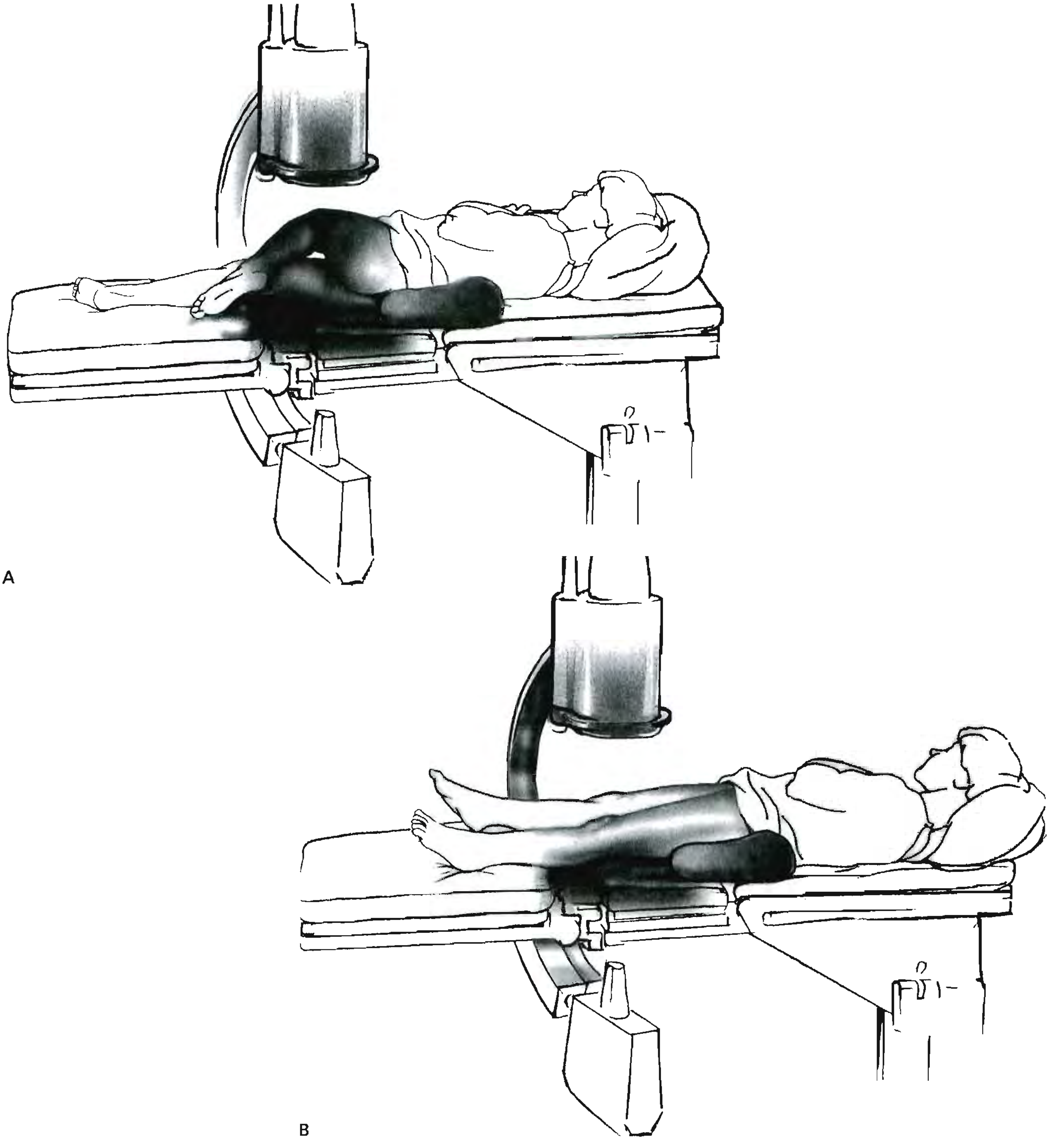
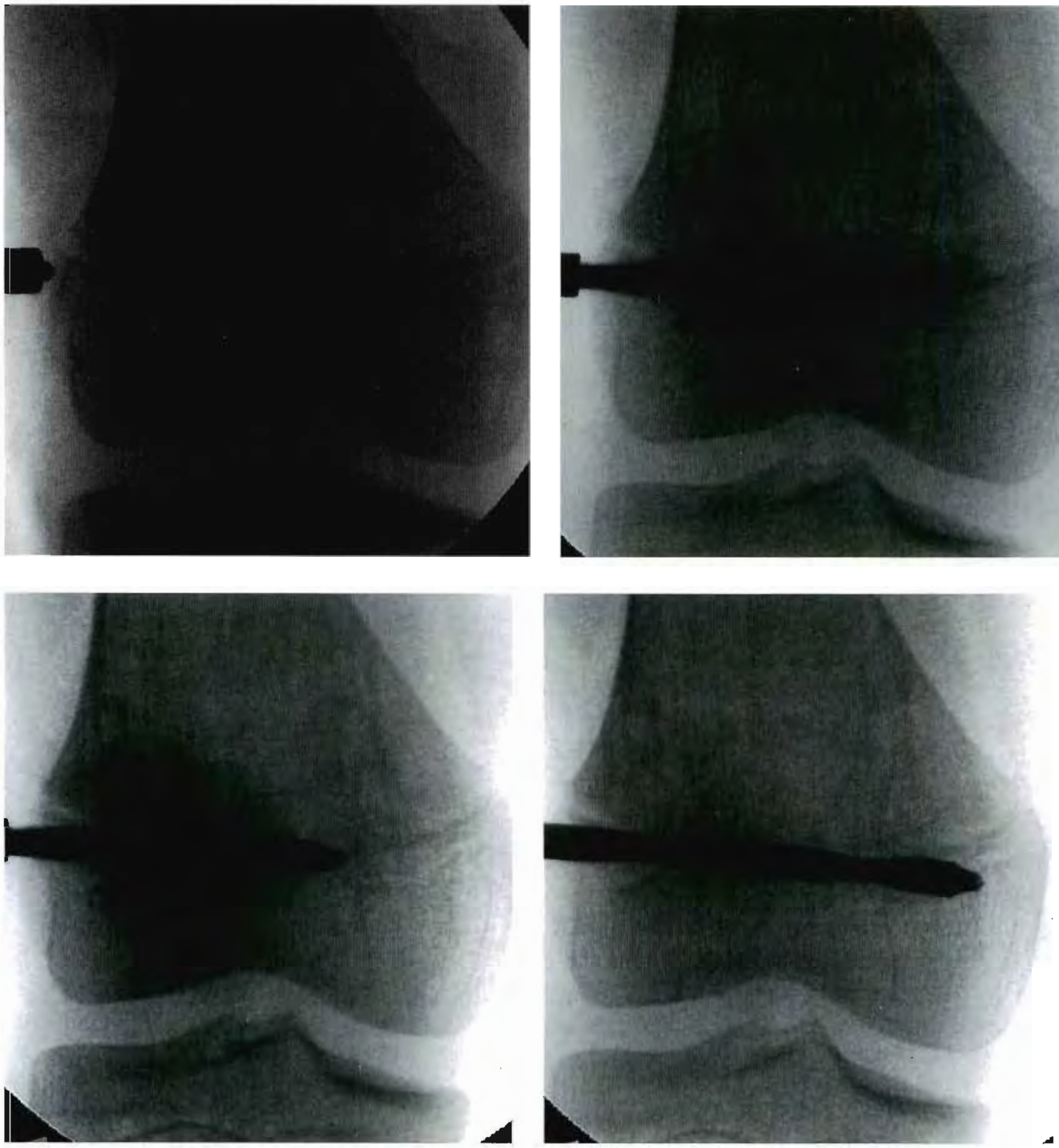


FIGURE 4-152. The patient is positioned supine on a translucent operating table. The epiphysiodesis can usually be completed from either a single portal (usually lateral is easier) or a combination of medial and lateral portals. The patient should be positioned so that an anteroposterior and lateral view of the physis can be obtained on the image intensifier. Given the normal arc of motion in the hip, this is best accomplished with a bolster under the buttocks. This allows sufficient internal rotation to obtain a lateral view **(A)** as well as making the lateral approach easier. When the anteroposterior view is needed, the patient is allowed to roll back, and the leg is externally rotated **(B)**.



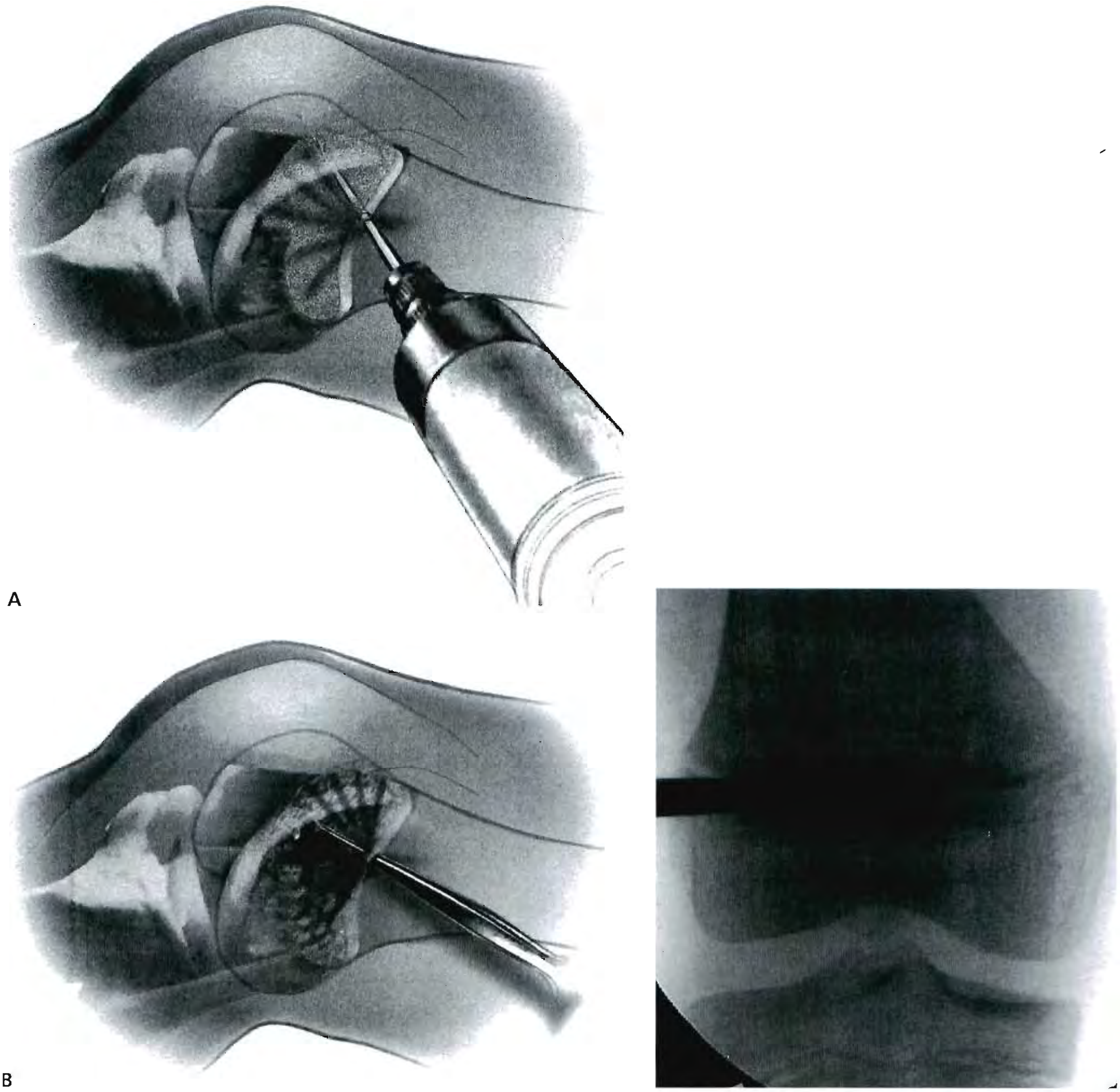
A B C D

FIGURE 4-153. Using the image intensifier position, with the distal femur in the correct amount of flexion and extension, the physeal plate is seen as a single rather than a double line. Next, the exact starting point is identified. A sharp drill with a tissue protector should be used; the drill must be long enough to reach to the opposite side of the bone. A good choice for this is the drill and drill guide used for predrilling pins for the monolateral fixators.

Notice that the physis undulates; however, most of the central portion is in a straight line. Thus, plan to enter the bone, not where the physis is seen at the lateral extent of the bone, but rather slightly inferior, missing the periphery of the plate, but passing through the central portion of the plate. **A:** Placing the other hand on the opposite side of the knee at the point where the drill is aimed aids in guiding the drill.

Advance the drill slowly, checking on the path frequently with the image intensifier. **B, C:** As the far side of the plate is reached, the drill may leave the physis. **D:** Either the drill will need to be redirected slightly, or the plate will need to be approached from the opposite side. After the first pass is completed, reaching the opposite cortex, withdraw the drill back to the starting point; then, angling slightly anterior or posterior, advance the drill again, frequently checking with the image intensifier. Several passes are made in this manner. It is during this time that the surgeon may find it helpful to see the femur in a lateral view. Leaving the drill in place can also help determine how far anterior or posterior the drill has gone. After some experience, it is easier to complete the procedure and then check on the amount of bone removed in the lateral projection.

The surgeon needs to have a firm grasp of the three-dimensional anatomy of the femur at this level to avoid passing the drill through the cortex, and potentially causing damage to any surrounding structures.



A

B

C

FIGURE 4-154. The surgeon has cut a series of holes in the physeal plate **(A).** It is now necessary to connect them while at the same time removing the remaining epiphysis between the holes. A curette is passed through the hole and used to break the septa of bone that remain between the drill holes. After this is done, the curette is used to remove additional cartilage **(B, C)**.

It is helpful to use the largest curette that will fit. Thorough removal obliterates the usual dense subchondral line of bone seen on both sides of the physis and is a good indication of adequate removal in the anteroposterior plane. Remember that those cells responsible for growth are on the epiphyseal side. On the lateral view, the amount of anterior and posterior removal can be assessed, but with the limitations of assessing three dimensions with a two-dimensional picture.

The puncture wound is closed with a single subcuticular absorbable suture. Two 4 × 4 dressings are folded and placed directly over the wound and bone portal and held under compression with an ace bandage. A Cryo-Cuff (e.g., that used after anterior cruciate ligament repair) is then applied. No knee immobilizer is used.

POSTOPERATIVE CARE

The surgery is performed on an outpatient basis. The patient is instructed in the use of the Cryo-Cuff for 24 to 48 hours, which appears to be effective in controlling the swelling. Instructions should also be given for loosening the elastic bandage in case distal swelling of the limb develops. The patient continues with a three-point partial weight-bearing gait as instructed preoperatively for 1 week. The patient is also instructed in straight-leg raising and quadriceps-setting exercises, which can be done during the first week. As soon as the patient can flex 90 degrees and fully extend the knee, he or she may discontinue the crutches. This is usually within the first 7 to 10 days after surgery. Bone healing is probably complete within 6 to 8 weeks.

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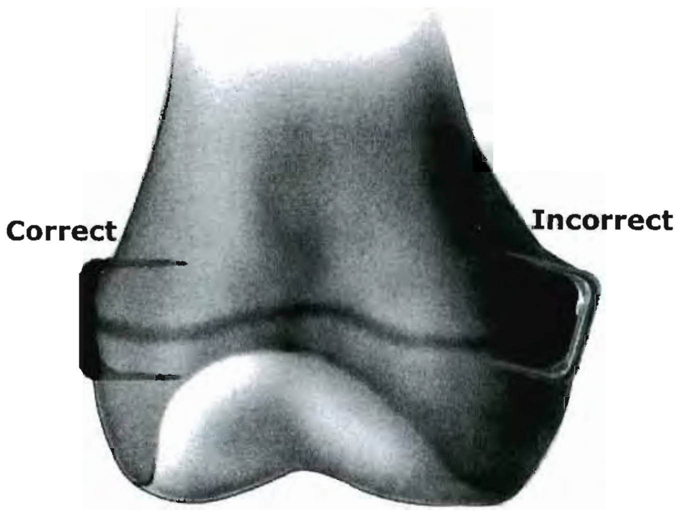
4.21 HEMIEPIPHYSIODESIS BY STAPLING TO CORRECT GENU VALGUM

When used to correct an angular deformity, a partial physeal arrest, either permanent or temporary, is the goal (1–3). A partial epiphysiodesis or hemiepiphysiodesis tethers one side, allowing the opposite side to grow. Just as limb-length equalization depends on the growth of the opposite limb, so does angular correction depend on the growth of physis opposite that which has been arrested. A partial epiphysiodesis can be either permanent (done near the end of growth) or temporary. In the latter indication, staples are used and then removed, allowing normal growth to resume. This was the original concept of Blount and Clarke (4). Careful planning is necessary for successful angular correction (1,4,5) (Figs. 4-155 to 4-158).

FIGURE 4-155. The patient is positioned as for Phemister open epiphysiodesis, and the incisions are similar. After exposing the area of the physis, it is necessary to identify the physis without stripping the periosteum. This is best done with the use of the image intensifier. This is important because the staples must be inserted correctly to prevent their backing out or creating a deformity.

The staples chosen must be the strong heavy staples with the reinforced corners. Anything less will bend with growth of the physis and lead to continued growth or extrusion.



A


B

FIGURE 4-156. Blount gives strict guidelines about how the staples should be inserted to avoid either extrusion or deformity as a result of incomplete growth arrest (6). First, the cross-piece of the staple should be perpendicular to the physis, the limbs of the staples should be parallel to the physis, and each limb should lie perpendicular to and be an equal distance from the physis **(A)**. Second, the staples should point toward the axis of the bone **(B)**. Staples inserted incorrectly are apt to extrude or even permit partial growth. Special care should be taken with the posterior staple to be sure that the superior limb is in bone and not in the soft tissue above the sloping condyle.

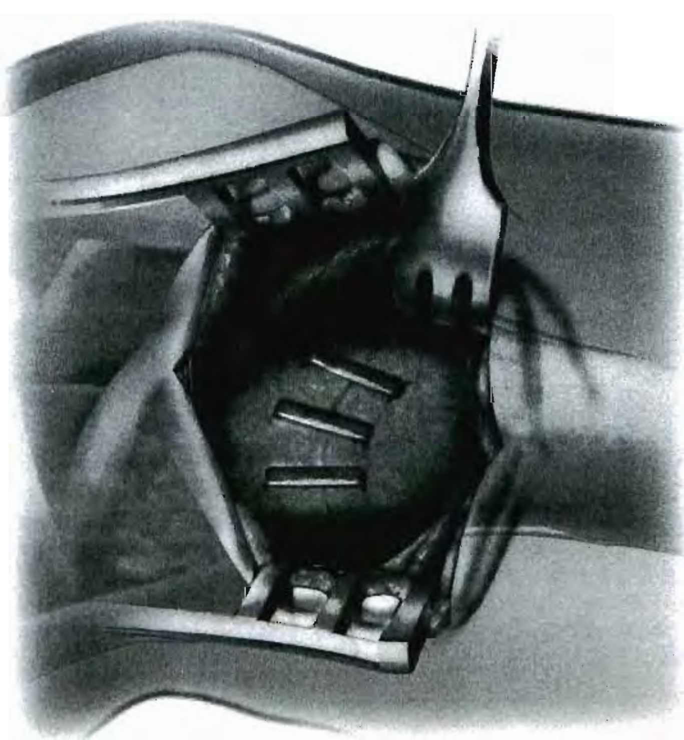


FIGURE 4-157. The final result will be three staples equally spaced and correctly inserted, lying above the intact periosteum. The position of the staples must be verified in both the anteroposterior and lateral projections on the image intensifier to be certain of their position. The wound is closed in a routine manner.

FIGURE 4-158. **A:** Anteroposterior standing view of the leg of a 13-year-old girl with significant clinical genu valgum. The condition was present bilaterally and was symmetric. At this time, the medial distal femoral physis was stapled. **B:** The same radiographic view 16 months later showing correction of the valgus from 160 to 80 degrees. The clinical improvement was dramatic. The staples were not removed because the patient's growth had ceased.

POSTOPERATIVE CARE

This procedure is performed on an outpatient basis. The patient may or may not need crutches, depending on comfort. Full activity is resumed as soon as the wounds are healed. The most important part of the care is the follow-up to observe correction of the deformity. Depending on the preoperative plan, it may be necessary to remove the staples after the correction has been obtained. If so, it is best to allow for slight overcorrection because a "rebound" phenomenon may result in an increased rate of growth for a short period. If stapling was done so that the correction was to coincide with the cessation of growth, careful observation is necessary to be certain that overcorrection does not occur. If it does, it may be necessary to arrest the growth on the opposite side of the physis.

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4.22 SURGICAL RESECTION OF PARTIAL GROWTH PLATE ARREST

Langenskiold (1) first reported on the correction of angular deformity after excision of a physeal bar in 1967, and Peterson (2) was the first to document longitudinal growth after resection of a bar in 1980. Since that time, excision of a partial growth arrest has become a standard procedure, and considerable progress has been made in the assessment of the bar and the selection of patients. Although there is a significant body of literature on physeal distraction, this chapter deals only with the surgical removal of the bony bar.

Several general principles relating to the selection of suitable patients and expected results are well accepted. There should be at least 2 years of growth or 2 cm of growth remaining to make the procedure worthwhile. Central bars generally do better than peripheral bars, although they are more difficult to remove. Physes injured by infection or vascular insult often do poorly, usually much worse than those bars created by fracture.

This leads to two crucial factors in planning a bar excision: determining the anatomic location and extent of the bar, and the more difficult problem of determining the health of the surrounding growth plate. The problem of determining the health of the growth plate remains unsolved and is especially important in partial growth arrests due to infection, vascular insult, and crushing Salter-Harris type V injuries. In these cases, the bar can be identified, but the surrounding growth plate may be narrowed and its potential for growth uncertain.

The standard technique for determining the anatomy of the bar was hypocycloidal tomography. The problems with this technique are moot because it is difficult to find a radiology department with this equipment still in use. Computed tomography (CT) has been used extensively and gives good images of the anatomy. However, the desired plane of the imaging is axial, not transverse, and it is often difficult to position the limb in the gantry for these views. Magnetic resonance imaging (MRI) has several advantages over CT. Scintigraphy does not have the resolution to aid in surgical planning, and there is no evidence that it will give reliable information about future growth of the surrounding physis. Thus, various imaging techniques and formatting options make MRI the method of choice.

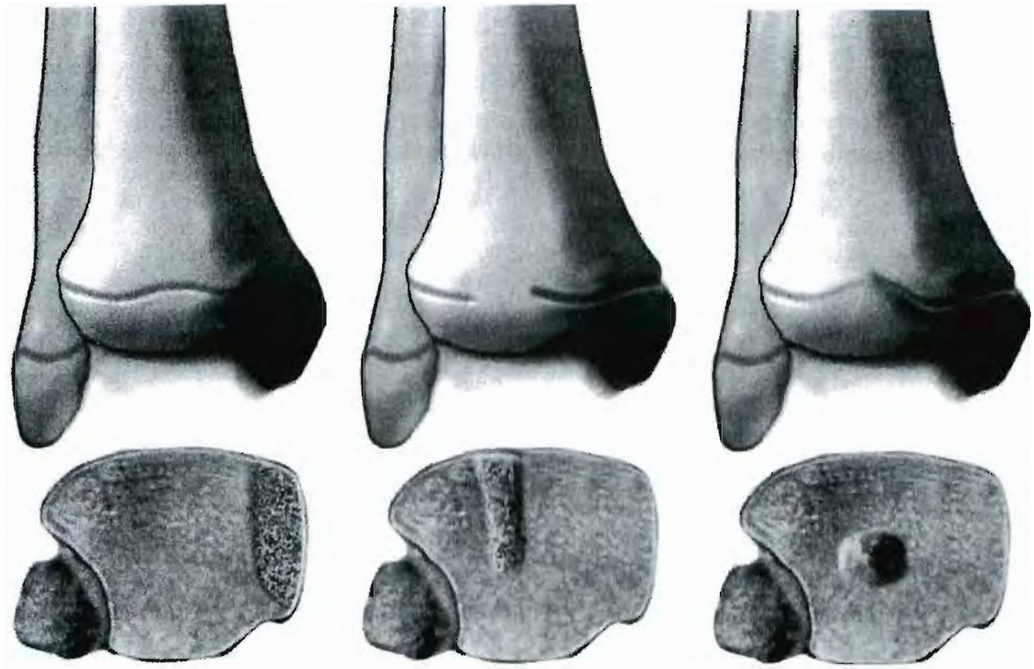
After acquisition of the necessary images, the surgeon must have a good three-dimensional concept of the bar to plan an approach. To do this requires a knowledge of the anatomy of the physis as well as the bar (3). If the imaging studies do not produce a map, it can be helpful for the surgeon to construct one on paper from the images (4).

The final decision the surgeon must make is the selection of the interposition material. The choices are between autogenous fat and methyl methacrylate. There is no evidence that one substance is better than the other. Fat is autogenous, whereas Cranioplast has been used since the 1940s without any deleterious effects noted (5). Fat may require a separate incision. Both are sterile and pose no risk for disease transmission. Fat tends to be more easily displaced from the cavity by bleeding, and closing the periosteum to keep the fat in place may predispose to new bar formation. Methyl methacrylate provides structural strength, whereas fat does not. Methyl methacrylate can conform to the shape of the cavity better than fat. Neither requires removal.

Resection of the bar requires a good three-dimensional understanding of the physis and the extent of the bar (6). The bony bar is excised with a high-speed bur. Locating the bar is aided by the knowledge that the bone that forms the bar is sclerotic and is surrounded by softer cancellous bone. Use of a curette until the bar is identified takes advantage of this fact.

Visualization of normal physis around the resection is necessary for a successful result. In all but the smaller peripheral bars, this can be difficult. In many situations, it is helpful to have a bur, with continuous irrigation at the tip of the bur. Use of a fiberoptic light source that can be placed in the cavity or a small arthroscope with a large angle of view can be helpful. An image intensifier is useful in orienting the surgeon to the location of the bur in the bone but usually does not demonstrate the physis and the bar in sufficient detail to add any more help.

After completion of the resection, it is best to insert metallic markers on either side of the physis to serve as a means to measure the subsequent growth. Small vascular clips, small Kirschner wires cut flush with the bone, or small bone anchors with the suture removed can all work. The important detail is to be sure there is not a foreign object that could migrate and cause problems in the future (Figs. 4-159 to 4-163).



A, B C

FIGURE 4-159. Peterson (6) described three types of bar. This classification uses descriptive terms that are easier to say, convey more information, and are less likely to lead to confusion than the type I, II, and III terminology. The three types of bars are peripheral **(A)**, elongated (linear or longitudinal) **(B)**, or central **(C)**. Small peripheral bars can be expected to do well, but large ones often do poorly because there is not enough surrounding physis to create the growth. Elongated or linear bars are unusual and are not described here. Central bars are more difficult to reach but tend to do better because of the surrounding physis.

Depending on the type of bar and its location, a different type of approach may be needed. Peripheral and longitudinal bars may be approached directly starting at the periphery of the bone, whereas central bars may be approached either through a metaphyseal window or more directly through the access created by a metaphyseal osteotomy adjacent to the bar.

FIGURE 4-160. It is desirable to maintain the interposition material in the epiphysis during subsequent growth because this is thought to produce the best long-term results. To achieve this, the cavity in the epiphysis is undercut while the metaphyseal defect is fashioned in such a way that is does not "capture" the methyl methacrylate and pull it out of the metaphysis with subsequent growth. Some surgeons have transfixed the methyl methacrylate in the epiphysis with a Kirschner wire to maintain it in the epiphysis.

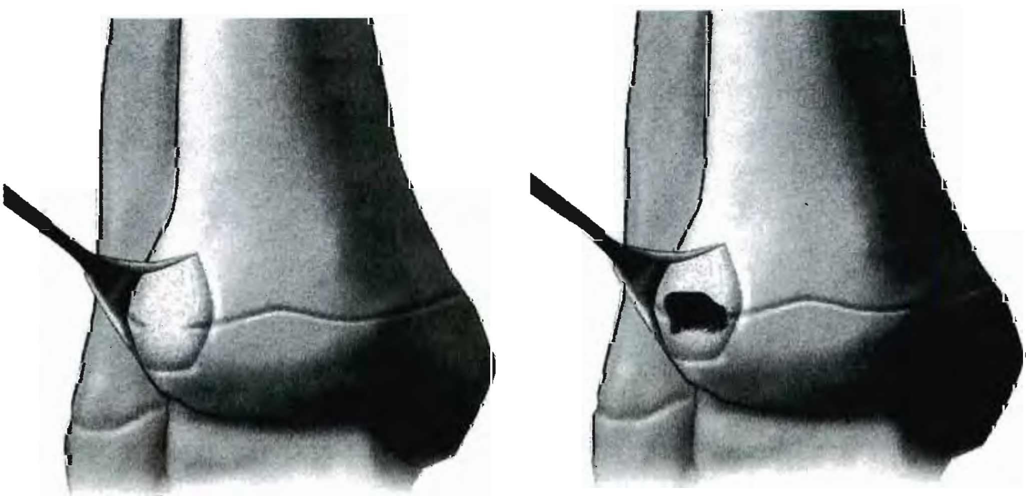
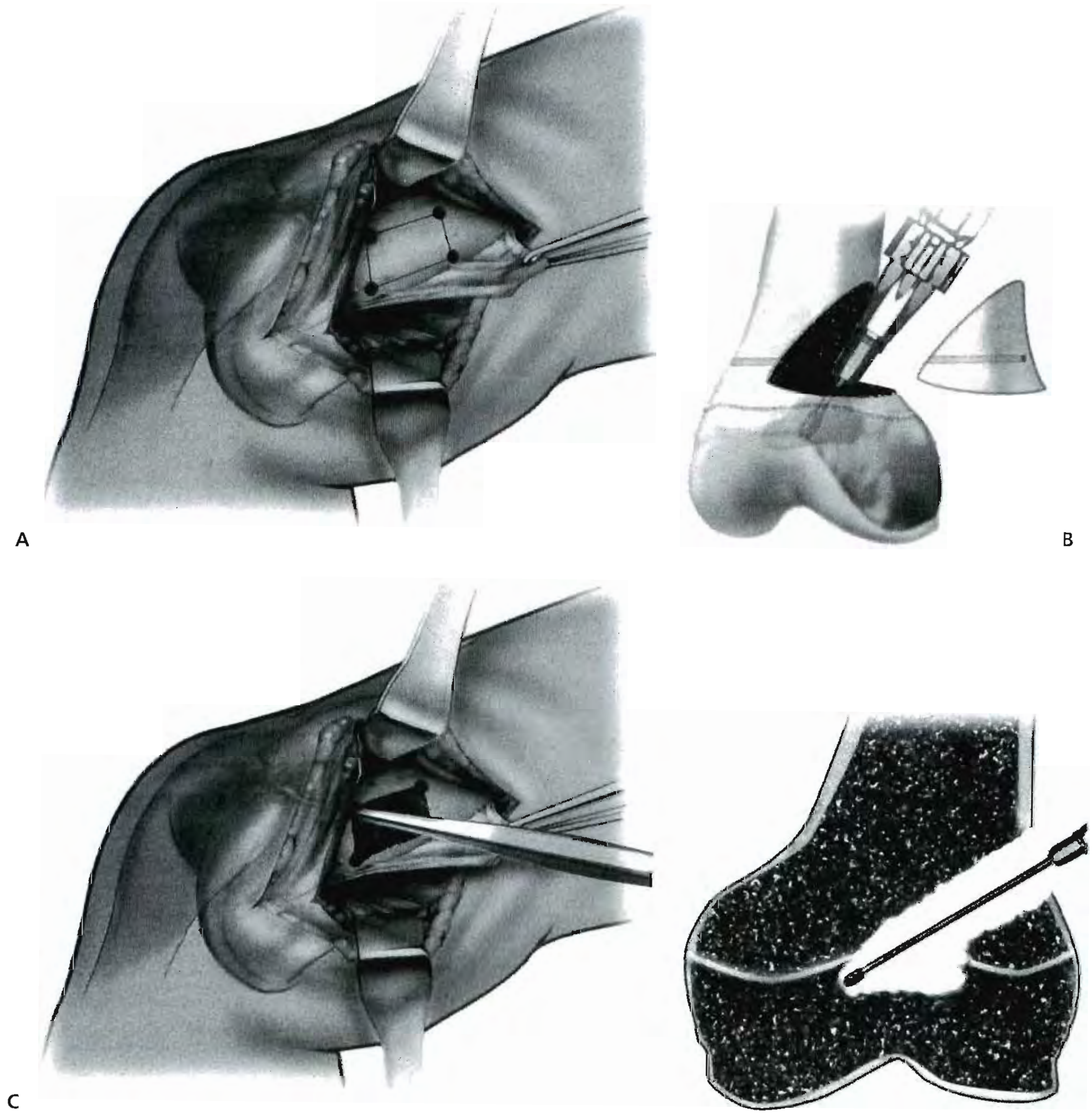


FIGURE 4-161. Peripheral bars can be of variable extent, and this is one of the most important factors in the success of the excision. A direct approach to the bar is made. The periosteum over the bar is excised. If fat is to be used as the interposition material, however, the periosteum should be elevated as a flap that can be sutured back in place to hold the fat in the cavity.

The periosteum is elevated and excised until normal physis is identified on both sides of the bar. A high-speed bur is then used to remove the bar until contiguous normal physis is seen. The interposition material is placed. If methyl methacrylate is used, the cavity should be undercut to hold it in place.

The wound is closed, and the patient is treated according to the circumstances.


A
B
C

◀ **FIGURE 4-162.** Central bars can be approached in one of two ways: a metaphyseal window or an osteotomy. The more common approach is through a metaphyseal window. These windows can range from a window to removal of a large portion of the metaphysis. A window leaves the continuity of the bone intact, simplifying the postoperative management. In cases in which an osteotomy is needed to correct an existing deformity, however, its use simplifies the resection.

After mapping the bar, the location of the metaphyseal window is planned to give the best access to the bar. This usually means that the bottom cut of the window will be at the apex of the physis. A cortical window may be all that is needed for a simple central bar **(A)**. If greater visualization is needed, removal of a section of the metaphysis that is equivalent to half of the width of the metaphysis just above the plate is removed **(B).** In this case, the future fragment is predrilled and tapped, so that when it is replaced, it is easily secured with a screw.

A curette is used to remove cancellous bone down to the area of the bar **(C)**. This bone should also be saved. The hard dense bone of the bar gives the surgeon the first clue about the location of the bar.

When the bar is located, the high-speed bur is used to remove it **(D)**. Again, irrigation on the end of the bur, fiberoptic light, and a high-angle-of-view arthroscope are all useful in visualizing the complete circumference of the cavity. After normal physis is seen around the entire circumference, the resection is complete. Undercut the epiphysis and taper the metaphysis so that the methyl methacrylate will remain in the epiphysis.

This is the ideal circumstance in which to use Cranioplast. Because it sets much slower than methyl methacrylate with barium, it can be placed in the cavity in a liquid state. This allows it to conform well to the cavity. The exothermic reaction of Cranioplast is minimal and not known to damage the normal physis. To put the Cranioplast into the desired location, it can be placed in a syringe with a 16-gauge blunt needle. It can then be injected into the cavity. Only an amount sufficient to cover the exposed physis with a small extension into the metaphysis should be used. The remainder of the cavity is filled with the cancellous bone that was removed during the exposure. This can be supplemented with bank allograft bone if it is thought that additional bone is needed. The cortical window is replaced, the screw inserted, and the periosteum and wound closed.

In cases in which an osteotomy is needed to correct an angular deformity, the bar resection can be performed at the same time with great advantage. This technique may also be used when exposure through a metaphyseal window is thought to be too difficult for adequate resection.

The osteotomy must be planned with two contradictory factors at work. The ideal location for the osteotomy is as close to the physis as possible. This makes fixation of the osteotomy difficult, however. It is therefore usually necessary to leave sufficient metaphysis for fixation.

A B C D

FIGURE 4-163. A: Anteroposterior radiograph from a scanogram shows the distal femur with a central growth arrest, which occurred as a result of neonatal sepsis. **B:** The pathoanatomy is better seen on the MRI. With images from the MRI in both planes, an accurate understanding of the extent and location of the bar can be gained. **C:** The block of bone and the cancellous bone were resected down to the hard cortical-like bone that identifies the bar. A bur was used to remove the bony bridge until normal physis could be seen completely around the resection. The curette was used to determine the depth of the resection. **D:** With the resection complete and the methyl methacrylate inserted, the bone block is reinserted and held with a predrilled and tapped screw.

POSTOPERATIVE CARE

The loss of structural integrity is what usually dictates the postoperative treatment in regard to weight bearing and motion. In small peripheral bars and some longitudinal bars where methyl methacrylate is used as the interposition material, immediate full weight bearing might be possible. When an osteotomy or large cortical window has been part of the approach, however, protection until bone healing is advisable. Most children do not have difficulty regaining joint motion.

Follow-up until the completion of growth is essential. Patients should be followed with scanograms to determine with accuracy the changing distance between the metallic markers. It is not unusual to have several years of normal or near-normal longitudinal growth only to have sudden growth slow considerably or cease altogether. Sometimes, this is associated with reformation of the bar, but at other times, it appears that the physis has simply "run out of gas." Reexcision of the bar is usually possible. If not, arrest of the opposite physis, planning for future epiphysiodesis, or limb lengthening are all options, depending on the circumstances and the patient and family's desire.

There is no need to remove the interposition material unless it is causing problems, which is a rare occurrence.

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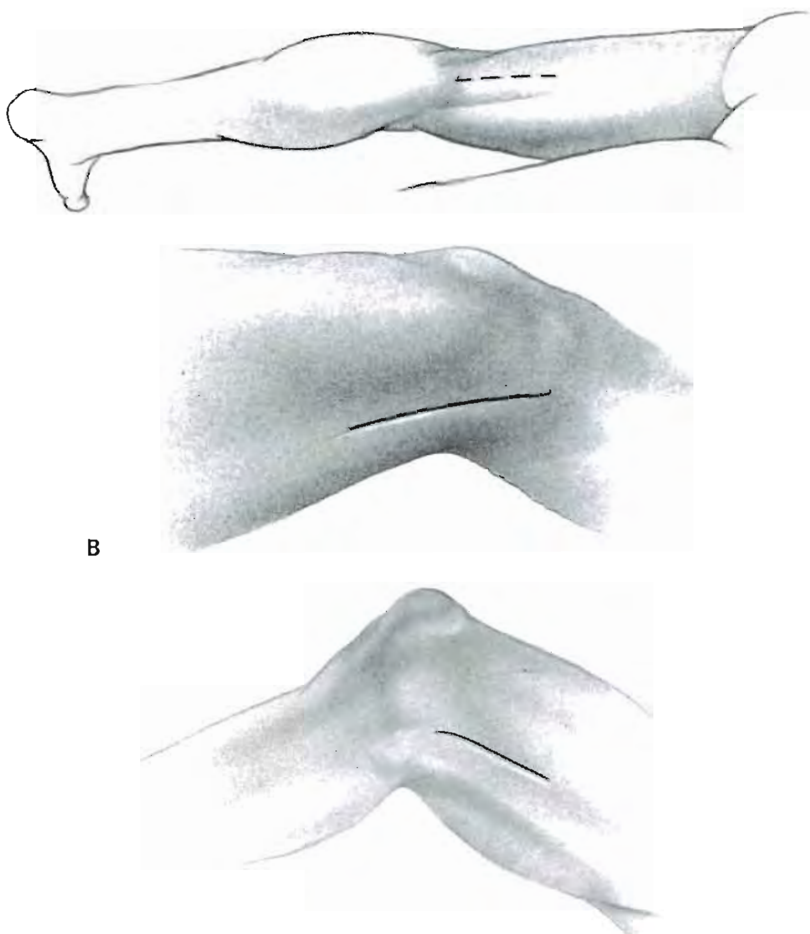
4.23 DISTAL HAMSTRING LENGTHENING AND POSTERIOR CAPSULOTOMY

Knee flexion contracture is one of the most common and most easily noticed of all the deformities in the patient with cerebral palsy. In addition, its correction is the most likely to produce worsening of the patient's functional abilities if the surgeon does not observe all of the prerequisites and indications. These are discussed by Rang (1), Bleck (2), and Renshaw (3). There are three hamstring muscles: the semimembranosus, the semitendinosus, and the biceps femoris. The gracilis muscle is often considered for lengthening during this operation, but care should be given to its inclusion because this is one of the muscles that initiates the swing phase of gait (2).

The technique of fractional lengthening of the hamstring tendons was first described by Green and McDermott (4) in 1942 and is still used by most surgeons (Figs. 4-164 to 4-169).



A B C

FIGURE 4-164. Distal hamstring lengthening can be performed in either the prone or supine position. Although it is a bit easier for the surgeon to have the patient in the prone position, this makes it impossible to perform any associated operations around the hip (e.g., adductor release) and does not permit testing of the lengthening by straight-leg raising. If the patient is prone, the incision can be a midline incision, which should extend from the popliteal crease proximally to the junction of the middle and distal one third of the thigh **(A)**. This length is necessary to allow exposure of both medial and lateral structures. An alternative is two incisions, one medial and one lateral, placed over the hamstring tendons **(B, C)**. These incisions can be used in either the prone or the supine position. These incisions are placed slightly anterior to the tight hamstring tendons, beginning just proximal to the knee joint and extending proximally for about 5 cm.

Posterior capsulotomy can be performed through either of these incisions. If posterior capsulotomy is done through the two incisions, all of the structures posterior to the capsule are bluntly dissected free and retracted posteriorly, allowing the origins of the gastrocnemius muscle and the capsule to be divided. This approach, although seeming more difficult at first, is actually easier because dissection of the popliteal space is avoided.

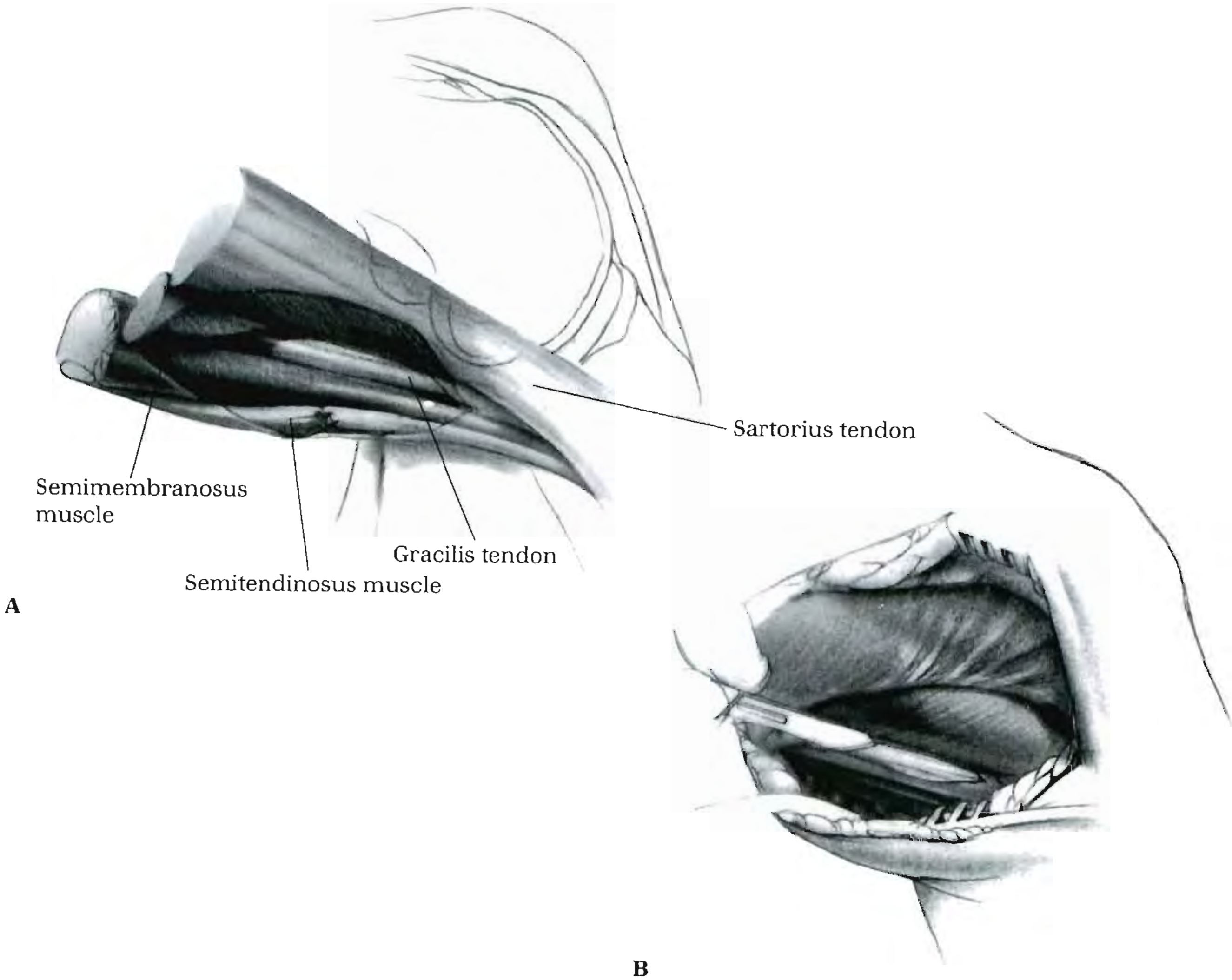


FIGURE 4-165. The leg is flexed at the hip and rotated externally. The medial incision is made between the palpable tendons of the gracilis anterior and the semitendinosus posterior muscles. The tendons of these two muscles usually stand out clearly with the knee extended and can be identified before the incision is made. If there is a question, abduction of the hip with the knee extended will identify the gracilis because it will become tight in abduction.

A: The arrangement of the tendons on the medial side of the knee. The sartorius muscle is the most superficial and anterior. It is not easily confused with the hamstring tendons. Deep and posterior to the sartorius muscle is the tendon of the gracilis muscle. It is a small round tendon at this location. A second small round tendon, that of the semitendinosus muscle, can be identified posteriorly to the gracilis muscle tendon. It is larger than the gracilis muscle tendon. It is shown here sutured together after a Z lengthening. At this location, it is crossing over the posterior aspects of the broad musculotendinous portion of the semimembranosus muscle, coming to lie laterally to it. The semimembranous muscle is not easily confused with any other muscle because in this location, it has a broad muscle belly that is transitioning into a thick tendinous aponeurosis.

After the subcutaneous fat is divided, the semitendinosus tendon is identified easily by palpation but is not seen easily because it is enclosed in a sheath. Cutting down on the tendon with a sharp knife will open this sheath **(B)**. A scissors is then used to expose a sufficient length of this tendon to perform a Z lengthening. This is often difficult in small children. Bleck (2) reports no noticeable difference between Z lengthening and release of this tendon. If the surgeon wishes to lengthen the gracilis, it is exposed in the same manner.

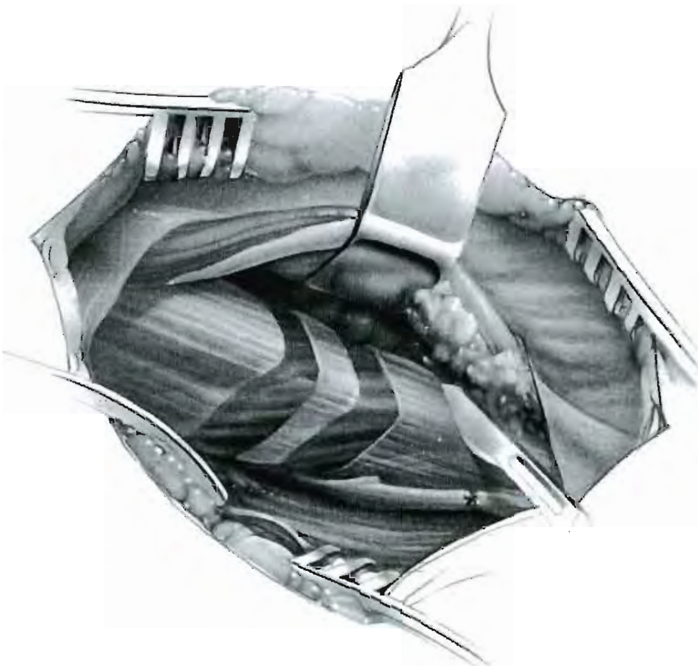


FIGURE 4-166. The semimembranosus muscle is relatively easy to identify deep to the semitendinosus. As mentioned, it has a broad aponeurosis that is thick, surrounds the muscle in the proximal part of the wound, and fans out into a more tendinous structure distally. This muscle and the biceps femoris do not lend themselves to a Z lengthening because of their thick and muscular insertions. They will be lengthened by division of their surrounding aponeurosis.

After the muscle and its aponeurosis are identified, they should be exposed completely on all sides so that part of the aponeurosis is not missed and left intact. The aponeurosis is now incised with two or three chevron cuts. These should not extend into the muscle and must include all of the aponeurosis. Because the goal is to leave the muscle in continuity, these cuts should not be made too distally. Straight-leg raising is performed gently to stretch the muscle. The aponeurosis will be observed to spread apart. Great force should not be used for two reasons: the sciatic nerve is tight and can be injured, and the muscle should not be disrupted.

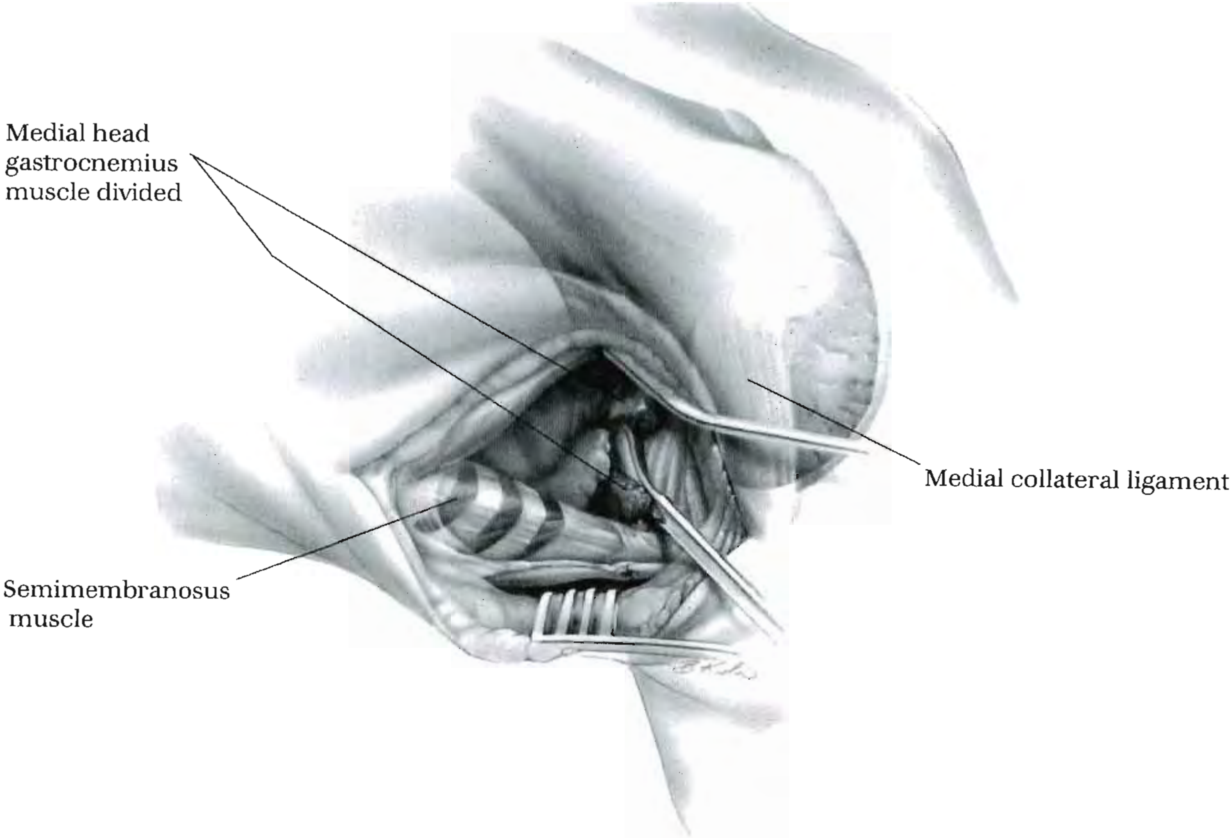


FIGURE 4-167. If posterior capsulotomy will be performed, the medial side of the posterior capsule is exposed and divided. Starting at the posteromedial corner of the femoral condyle, all of the soft tissues are reflected posteriorly off the gastrocnemius muscle and the posterior aspect of the knee capsule. This includes the hamstring tendons and the neurovascular structures. This is accomplished by dissecting the tissue with a broad periosteal elevator. It will be necessary first to work anteriorly, exposing the capsule up to the medial collateral ligament. The dissection is then carried posteriorly around the insertion of the medial head of the gastrocnemius muscle. Care is taken to stay close to the capsule between it and the fat that surrounds the structures in the popliteal space. The medial head of the gastrocnemius, which inserts on the posterior aspect of the femoral condyle, covers the posterior capsule. After dividing this medial head, it is reflected distally to expose the capsule. Opening of the capsule can wait until the lateral side has been exposed and the surgeon is certain that all of the vital structures are safely out of the way.

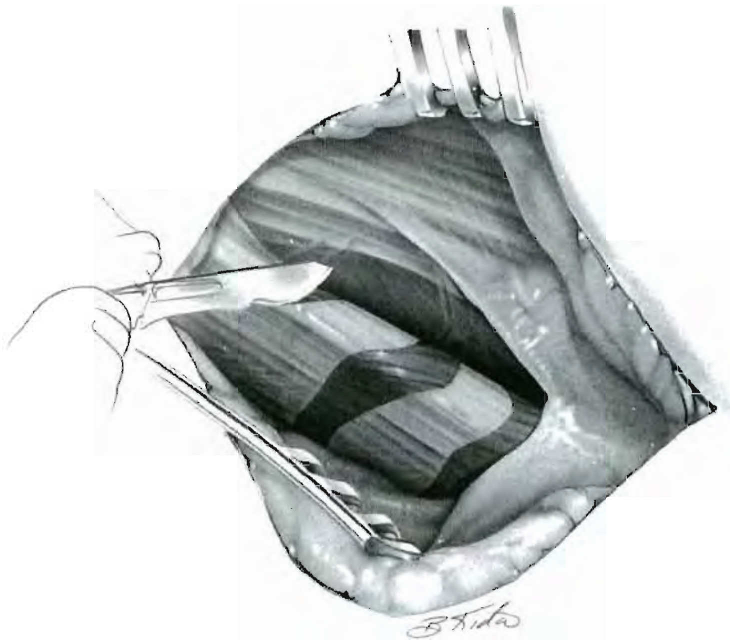


FIGURE 4-168. The hip is rotated internally, and the lateral incision is made just anterior to the taut biceps femoris tendon. The aponeurosis of this tendon is exposed, and two or three chevron cuts are made in it, as was done for the semimembranosus muscle.

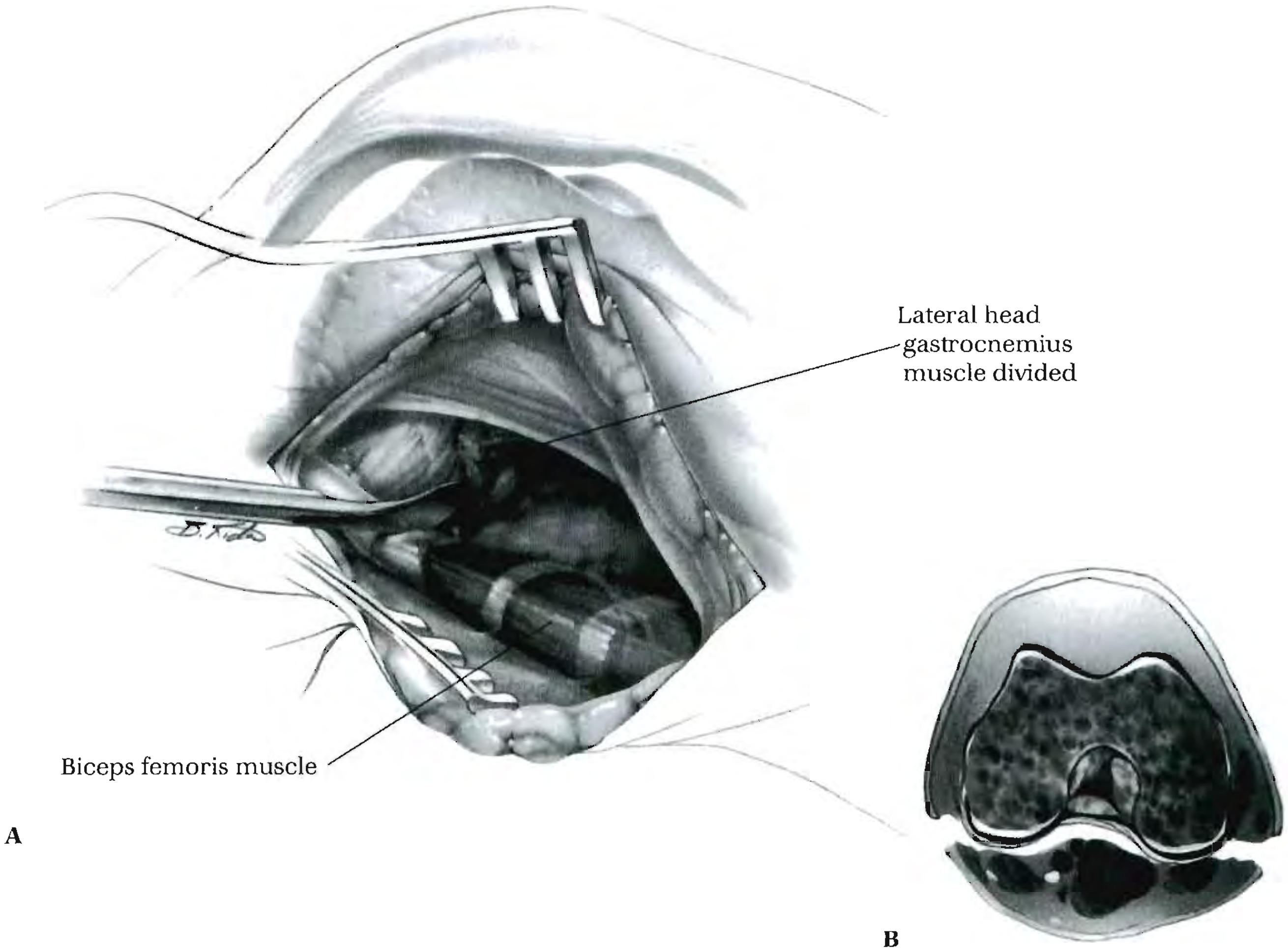


FIGURE 4-169. The soft tissues are reflected off the lateral head of the gastrocnemius and the posterior aspect of the knee, as on the medial side **(A)**. This dissection should join that of the medial side, ensuring that all vital structures are retracted posteriorly. The gastrocnemius head is divided and reflected distally to expose the underlying capsule.

A moist 4 × 4 sponge is passed through the exposure and is used to retract the hamstrings and the neurovascular structures posteriorly **(B)**. The lateral capsule is incised, and the joint is identified. There is a tendency to make this incision too proximally. It should be started at the most prominent part of the femoral condyles or it will be difficult to divide the midportion of the capsule. After the joint is identified, a curved Mayo scissors is used to divide the capsule as far medially as possible. The division also should be done moving anteriorly, stopping just before reaching the lateral collateral ligament. The division of the capsule can be completed through the medial incision, again extending as far anteriorly as the medial collateral ligament.

A closed-suction drain is placed in the wound. The deep fascia, the subcutaneous fascia, and the skin are closed.

POSTOPERATIVE CARE

If posterior capsulotomy was necessary, it is unlikely that the knee will straighten completely without force. Therefore, to avoid stretching the sciatic nerve, a cast should be applied to the leg in the amount of extension that can be obtained without force. The cast should be applied and padded, with the plan to wedge it into more extension during the postoperative period. Shortly before discharge, 3 to 4 days after surgery, the cast is wedged. This can be repeated at weekly intervals until correction is satisfactory. An alternate approach is to remove the anterior half of the cast from a point above the patella distal. Stretching is then done several times a day. As further extension is gained, a new cast is applied, the anterior half is removed, and the entire process is repeated until correction is achieved.

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4.24 RECTUS FEMORIS TRANSFER

Distal rectus femoris transfer is a commonly performed operation in children with cerebral palsy with a crouched or stiff knee gait. Normally, the rectus femoris begins to fire at terminal swing along with the other quadriceps muscles to prepare the limb for acceptance of weight (1–3). In children with cerebral palsy, continuous rectus femoris activity throughout the swing phase (and in some, throughout the entire gait cycle) severely limits knee flexion in swing and subsequent foot clearance (1,2,4).

In theory, transferring the distal rectus posterior to the axis of the knee into either the gracilis, the stump of the gracilis, or semitendinosus enhances knee flexion in the swing phase, compensating for decreased momentum of hip flexion (2,5). Recent studies by Chambers and colleagues (3) demonstrated no difference between transfers to the gracilis or semitendinosus.

Chambers and colleagues (3) also compared the results of distal rectus transfers versus distal rectus releases. Patients with rectus transfer had improved knee flexion in swing phase, with swing phase peak knee flexion improving so that gait was more efficient and foot clearance was improved. When the rectus was merely released, peak knee flexion deteriorated slightly (5).

Distal rectus transfer is generally combined with hamstring lengthening (see Procedure 4.23). Preoperative gait assessment is advocated by many authorities, whereas others feel the indications can be made by pattern recognition (6). Distal rectus transfer can also be combined with other surgical release and lengthening procedures, such as those around the hip and the ankle, as well as with various osteotomies to correct rotational deformities (Figs. 4-170 to 4-174).

FIGURE 4-170. A longitudinal incision is made in the middistal thigh region extending from the superior pole of the patellar proximally about 6 to 10 cm, depending on the size of the child. Dissection is carried down through the subcutaneous tissues to the deep fascia of the thigh, which is incised sharply.

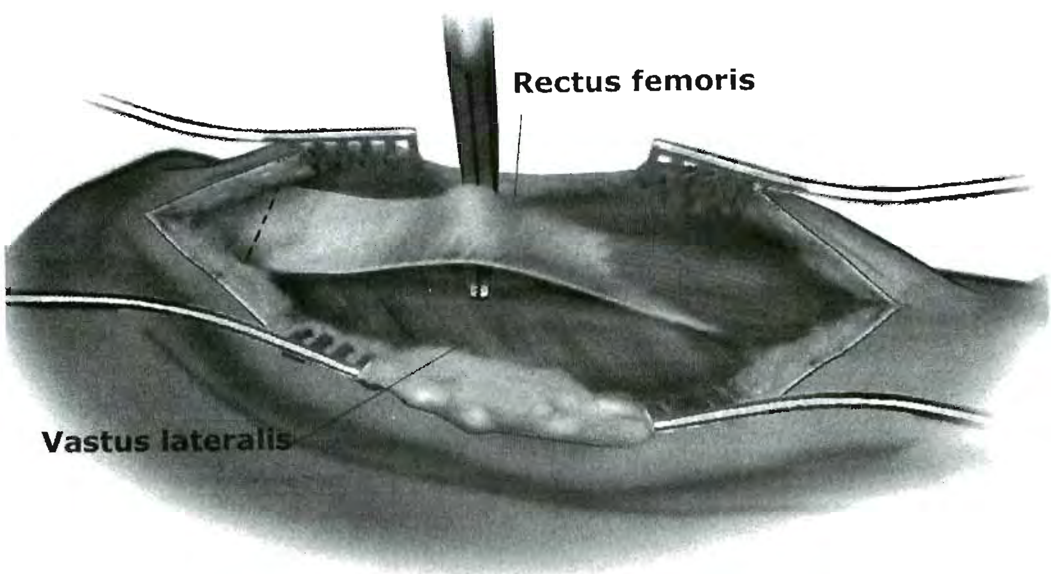


FIGURE 4-171. The rectus femoris tendon is isolated from the underlying vastus intermedius by making a small incision at the medial and lateral border of the rectus tendon and inserting a blunt instrument under the rectus tendon. This plane is then developed both proximally and distally. Distally, the tendon is freed to the patellar insertion, taking great care to avoid entering the knee joint. This is generally done with dissecting scissors and knife dissection. If the knee joint is entered, the capsule should be repaired.

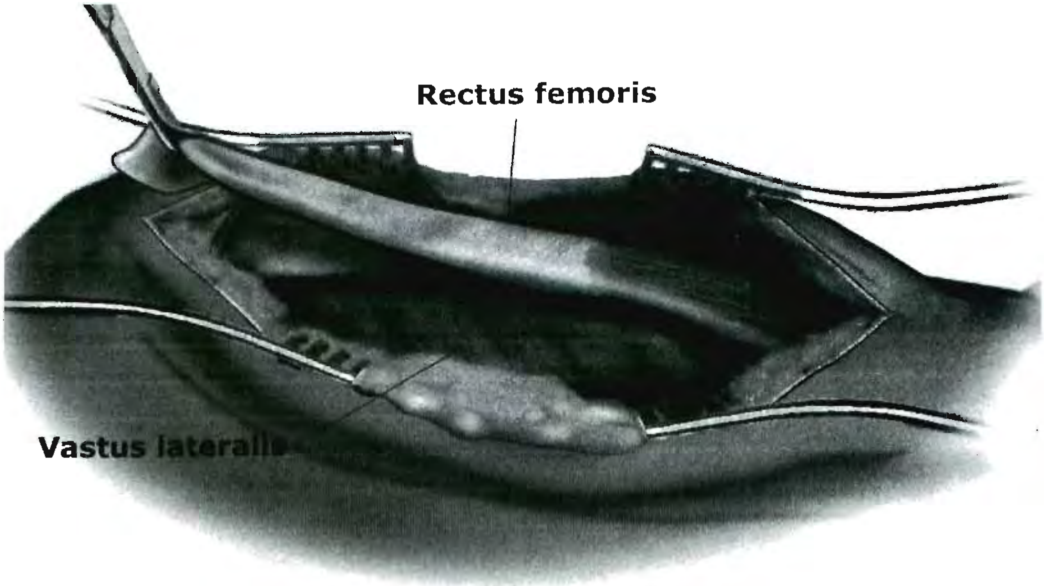


FIGURE 4-172. After the tendon is freed distally, dissection is carried proximally, and the tendon is dissected free from the underlying quadriceps muscle. The tendon and proximal musculotendinous junction must be freed so that there is complete free excursion of the rectus tendon from the underlying quadriceps muscle. Hamstring-lengthening procedures are then performed.

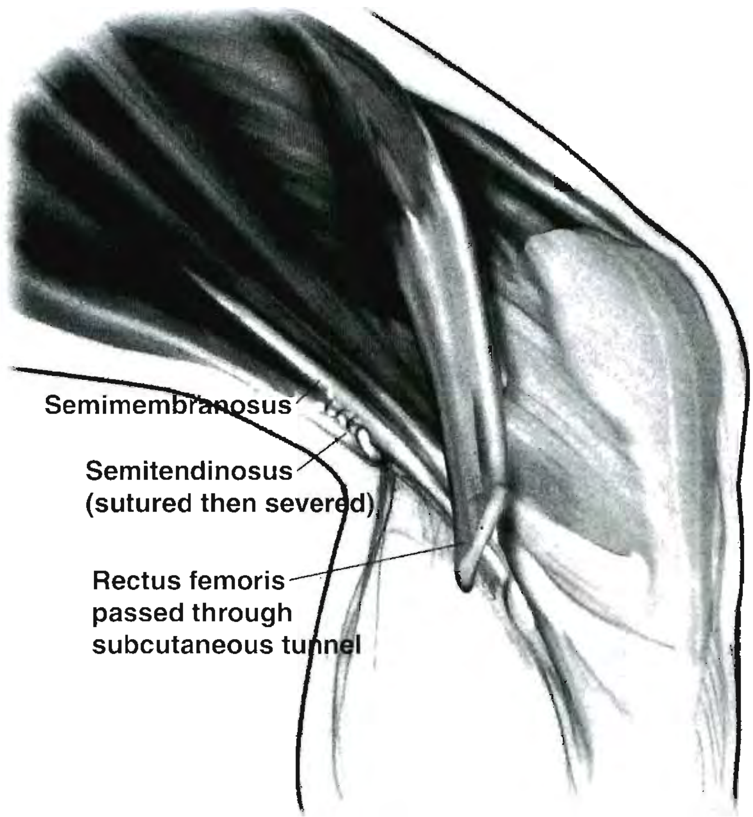
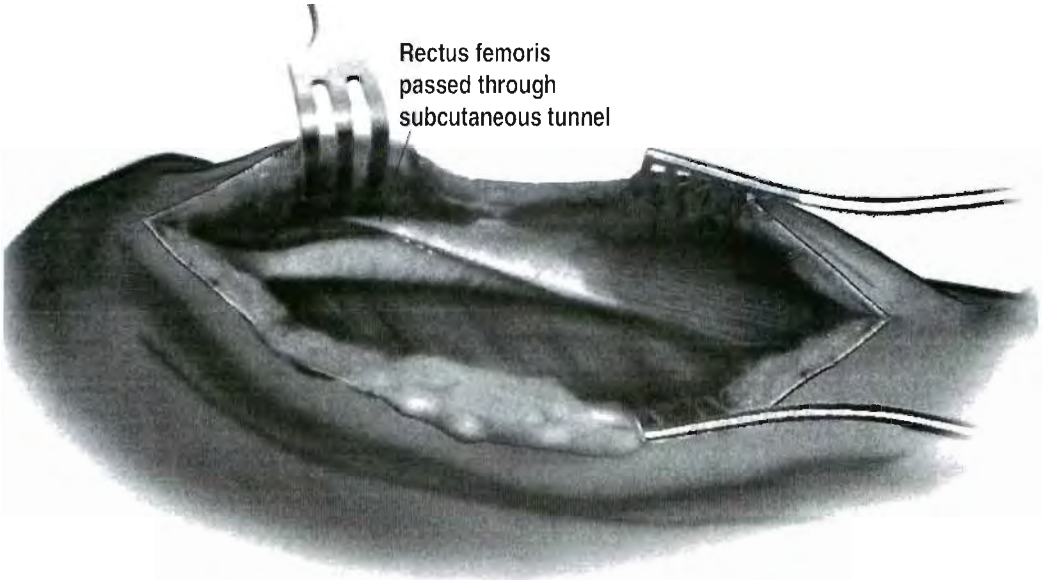


FIGURE 4-173. In performing the hamstring-lengthening procedure, we prefer to suture the proximal semitendinosus near the musculotendinous junction to the semimembranosus muscle belly. The gracilis muscle may be used in a similar fashion in the tendon transfer. When this is secured, the semitendinosus muscle is severed and dissected free distally with scissors dissection to allow it to be interwoven into the rectus stump. A subcutaneous tunnel is made from the anterior thigh incision to the medial hamstring incision, and the rectus is passed through the tunnel with a hemostat. The surgeon should make certain that the muscle has a free gliding path and is not tethered by subcutaneous tissue.



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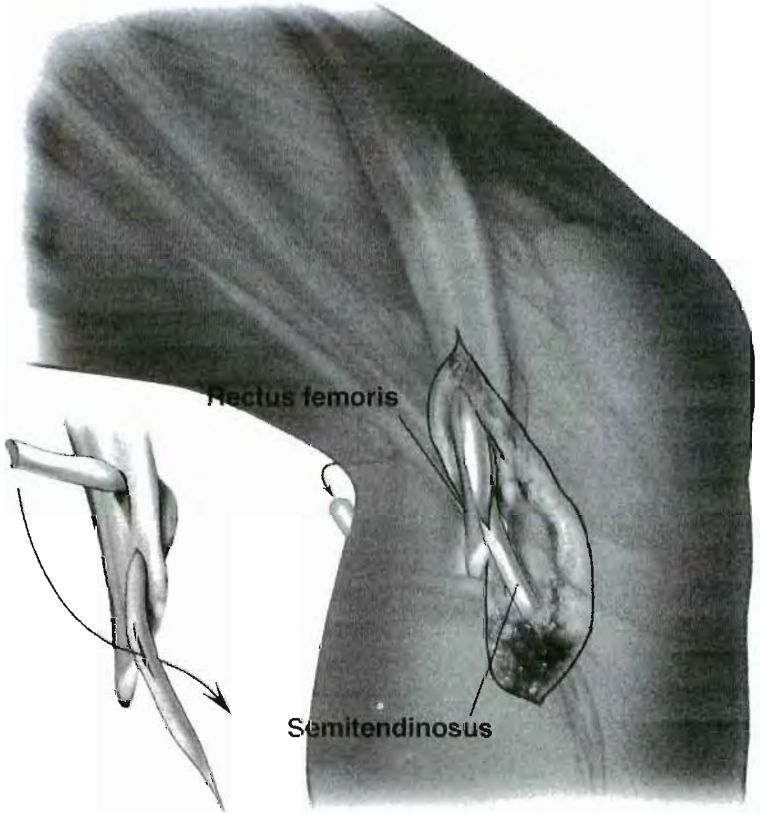

B

FIGURE 4-174. The tendon of the semitendinosus is passed through the fascia of the rectus femoris in two opposite planes, the planes 90 degrees to one another, using the method of Pulvertaft and sutured using #1 nonabsorbable suture. The tendon transfer should be fixed with the knee in about 15 to 20 degrees of flexion. Subcutaneous tissues are closed, followed by skin closure. No drains are used. If the patient has not undergone distal releases or other bony surgery, we prefer to use a Robert-Jones–type dressing. The wounds are covered with a sterile dressing, and Dacron or cotton batting is then applied distally to proximally and secured by a bias-cut stockinette rolled distally to proximally in a figure-of-eight fashion. The extremity is further protected by a knee immobilizer.

POSTOPERATIVE CARE

In the absence of bony surgery, the dressings are maintained for about 2 to 3 weeks, at which time the soft dressings are removed. The patient begins ambulation in orthotics, and if using only ankle-foot orthosis, a knee immobilizer is also used on a temporary basis. Knee range of motion and physical therapy are reinstituted. If the surgery accompanies bony surgery, rehabilitation must await bone healing and cast removal.

References

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5

THE KNEE

5.1 PROXIMAL PATELLAR REALIGNMENT (INSALL TECHNIQUE)

With subluxation or dislocation of the patella in childhood, the surgeon's options are limited by the open growth plate of the tibial tubercle, which prohibits operations that transfer the origin of the patellar tendon. For the growing child with recurrent subluxation or dislocation of the patella—whether owing to malalignment, trauma, or mild ligamentous laxity (e.g., that seen in Down's syndrome)—the proximal soft tissue realignment described by Insall and colleagues (1,2) provides a method of realigning the forces on the patella. For us, this method is preferable to detaching and then advancing the vastus medialis muscle. In cases in which advancement of the medialis muscle seems necessary, the muscle is usually so deficient that little is gained, and it is difficult to secure the muscle in place. The proximal realignment provides a secure repair with little tension on the suture lines and therefore earlier rehabilitation.

In cases of congenital dislocation associated with deficiency of the lateral femoral condyle or muscle structure, however, this operation is usually not sufficient. This is also true for children with Down's syndrome or other collagen disorders who have severe ligamentous laxity and poor tissue for repair. In such cases, we prefer to combine elements of this procedure with the semitendinosus tenodesis of the patella (3) (Figs. 5-1 to 5-4).

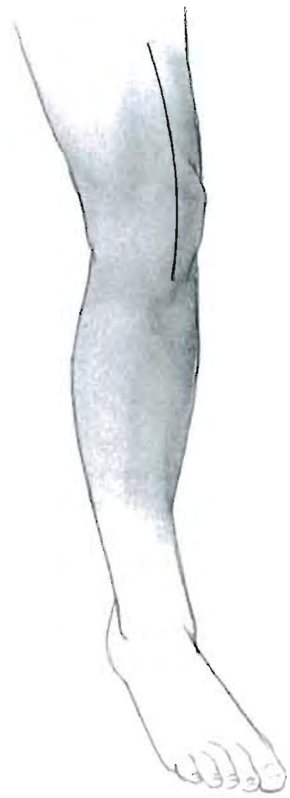
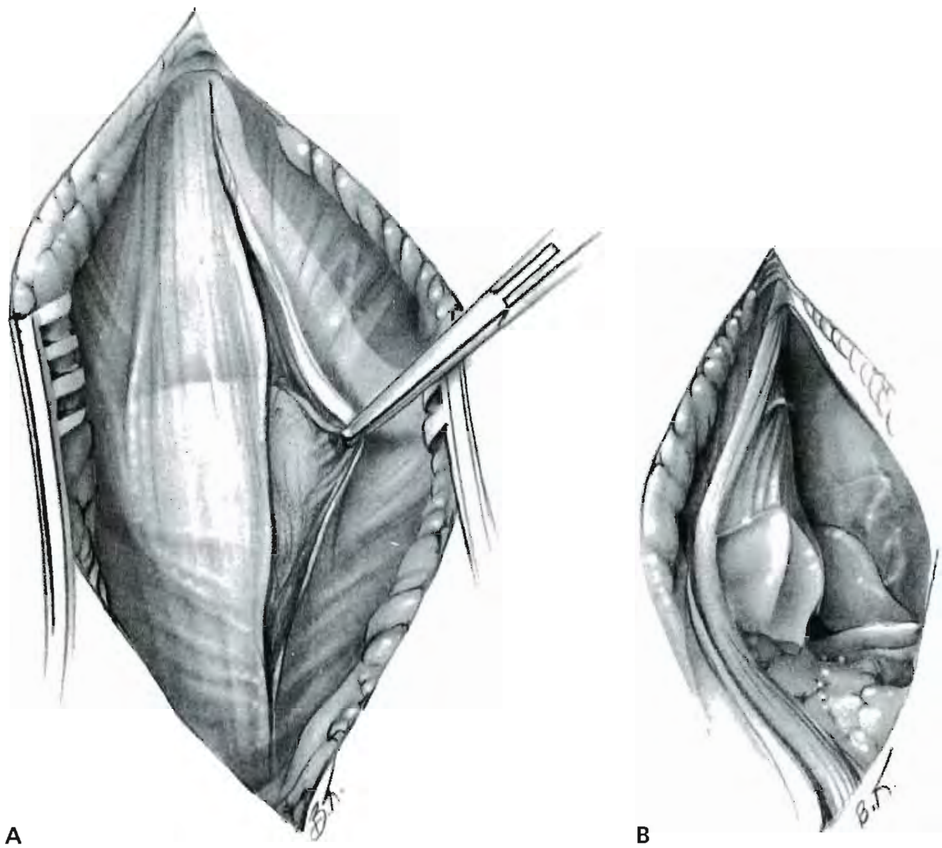


FIGURE 5-1. The operation is performed with the patient supine and a bolster under the hip to avoid the need for an assistant to hold the leg in internal rotation. The incision begins in the midline, just below the junction of the middle and lower one third of the thigh, and extends distally across the center of the patella to the tibial tubercle. The incision must be long enough to expose the entire quadriceps tendon.



A B

FIGURE 5-2. The flaps are reflected medially and laterally sufficiently to expose the medial and lateral border of the patella and the insertion of the vastus medialis and lateralis into the quadriceps tendon proximal to the patella. The first incision begins as far proximally as the quadriceps tendon and detaches the vastus medialis from this tendon, leaving just enough tendon on the muscle to hold sutures. As this incision is carried distally, it should be directed to cross the patella, dividing the medial one third from the lateral two thirds and then continuing down along the medial border of the patellar tendon. The quadriceps expansion overlying the medial one third of the patella is then elevated subperiosteally from the patella **(A)**. This allows the patella to be turned up laterally, exposing the joint. By dividing the fat pad, the undersurface of the patella and the joint can be inspected **(B)**.

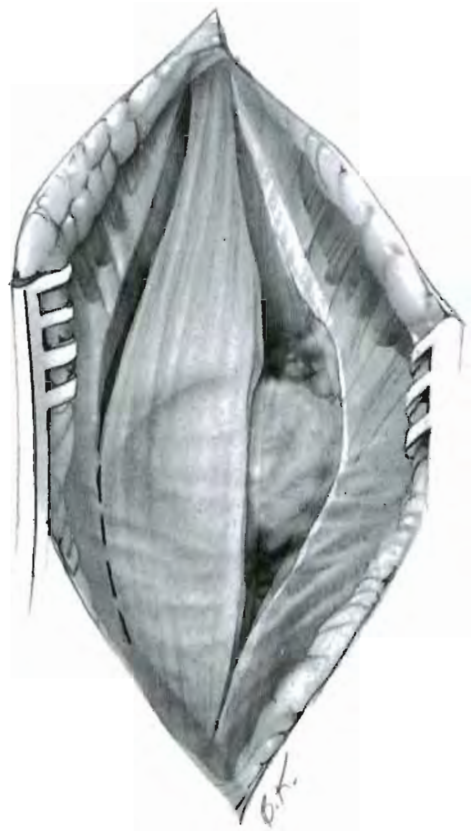


FIGURE 5-3. The next incision divides the lateral patellar retinaculum and separates the vastus lateralis from the quadriceps tendon. This incision begins in the quadriceps tendon proximally, opposite the medial incision. Detach the vastus lateralis, leaving a rim of tendon for suturing. As this incision approaches the patella, it skirts the lateral margin of the patella. The synovium should also be divided, with care taken to identify and coagulate the vessels that will be encountered. If the surgeon desires, the tourniquet can be released at this point to control any bleeding and then reinflated before beginning the repair.

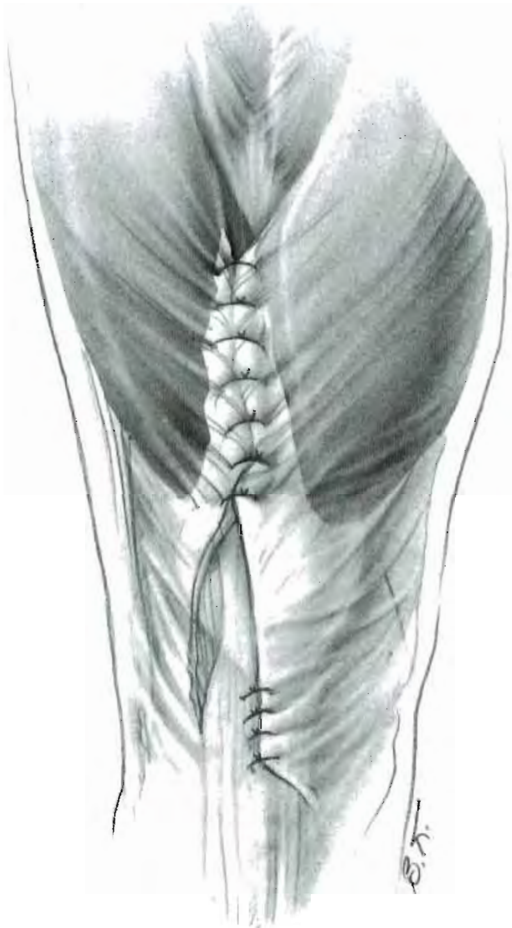


FIGURE 5-4. The repair is started proximally by bringing the cut edge of the vastus medialis and vastus lateralis together over the remaining portion of the quadriceps tendon, which is pushed deep to the repair. As the repair reaches the proximal pole of the patella, the patella begins to rotate medially, elevating the lateral portion of the patella. It is not necessary, nor is it possible, to continue this repair across the entire patella because the medial periosteal flap does not reach the lateral retinaculum. Rather, when the patella is rotated and displaced medially to a sufficient degree, the medial flap is sutured to the periosteum on the lateral two thirds of the patella without further effort to pull the patella medially. The knee can now be flexed to test the stability of the patella. The lateral incision is left open.

POSTOPERATIVE CARE

A compression bandage is applied around the knee for the first few days. This may be supplemented by a knee immobilizer for comfort, but this is not necessary to protect the repair. The patient can begin to ambulate with a three-point crutch gait as soon as possible, usually the second postoperative day. The pressure dressing can be removed in 3 days, and physical therapy is begun with active-assisted flexion and extension. It is best to discontinue the knee immobilizer early and rely on crutches for support because this promotes use of the knee. Children often come to rely on the immobilizer, which slows their progress. A full program of knee rehabilitation can be started at 3 weeks. The subsequent progress of the patient depends greatly on the patient as well as the underlying condition; however, most children should be back to normal within 6 months.

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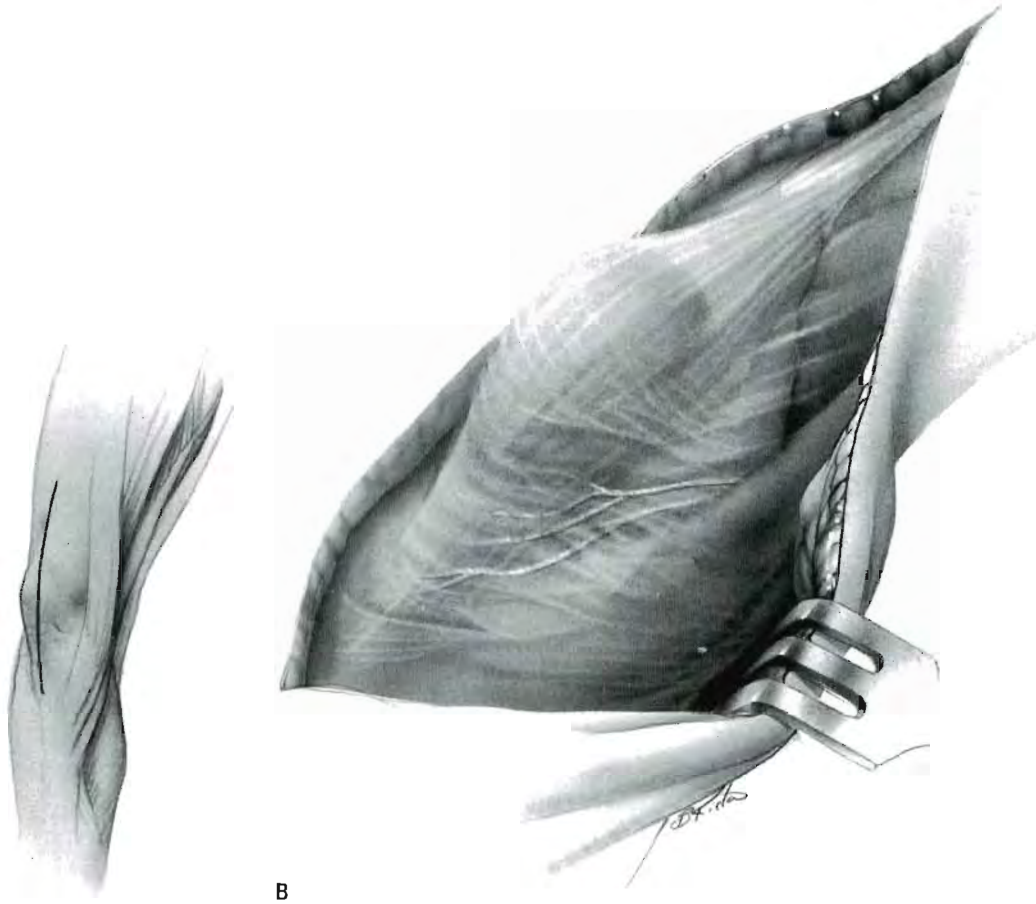
5.2 SEMITENDINOSUS TENODESIS OF PATELLA FOR RECURRENT DISLOCATION

The use of the semitendinosus tendon to realign the patella was first described by Galeazzi in 1922 and was first reported in the American literature in 1957 (1). Subsequent reports have been favorable (2,3). This procedure addresses several problems that the orthopaedic surgeon often encounters in the child with recurrent dislocation of the patella: ligamentous laxity, deficient lateral condyle, deficient medial musculature, and open growth plates. In all of the conditions in which recurrent dislocation of the patella is encountered (e.g., Down's syndrome, congenital dislocating patella), the semitendinosus tendon is usually normal. We have found this procedure, often in combination with a proximal realignment, to be an excellent solution to the unusual problem of recurrent dislocating patella in skeletally immature children (Figs. 5-5 to 5-10).



A B

FIGURE 5-5. The patient is placed supine on the operating table, and the entire leg is draped free. A tourniquet is used, and one incision is made. Although a medial parapatellar incision makes it slightly easier to reach the semitendinosus tendon, a long midline incision, as described for proximal realignment, is better cosmetically. The tendons on the medial side of the knee are illustrated **(A)**. Note the broad expanse of the sartorius, which is the most anterior. The gracilis tendon lies just behind the sartorius. The semitendinosus is the most posterior behind the knee and is the deepest or most posterior tendon inserting into the tibia. It is easily distinguished from the gracilis not only by the location of its insertion but also by its size: it is a much larger tendon. The surgeon should not make the mistake of taking the gracilis tendon for the repair.

The medial skin flap is elevated extensively around the medial side of the knee. The dissection must be carried both posteriorly and proximally. Flexing the knee aids in this dissection. The infrapatellar branch of the saphenous nerve can usually be observed emerging from the sartorius. Although a few of its sensory twigs may be divided, care should be taken with this nerve to avoid a large area of anesthesia **(B)**.

FIGURE 5-6. With the knee flexed, the skin flap is retracted with a long blade retractor, and blunt dissection is continued posteriorly and proximally **(A)**. At this point, care should be taken to avoid injury to both the infrapatellar branch of the saphenous nerve and the saphenous nerve itself (see Fig. 5-9). The tendon can be palpated. As mentioned previously, it is a larger structure than the gracilis tendon, which may be taken by mistake. It lies posterior to the sartorius and gracilis tendons in this location. After the tendon is identified and exposed, it should be followed to its musculotendinous junction, where it is divided.

Next, the tendon should be followed to its insertion posterior to the sartorius and gracilis tendons, freeing all extraneous attachments with care to avoid cutting the saphenous nerve **(B)**. If the tendon is not completely freed to its insertion, it will not have the proper direction and will soon become loose as the fascia that tethered it becomes stretched.

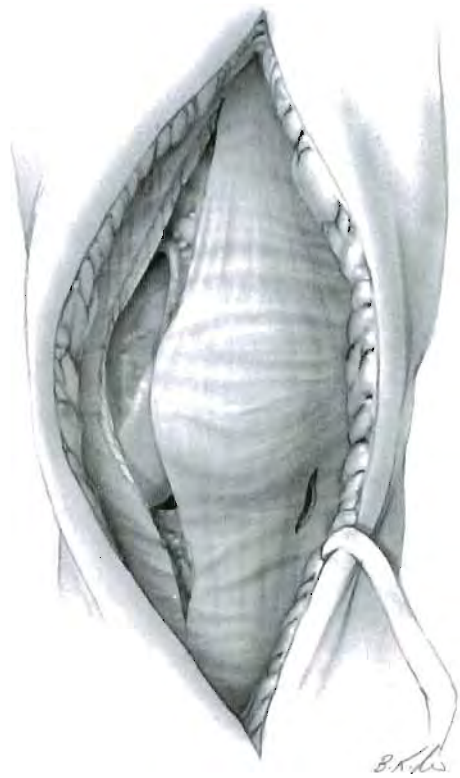
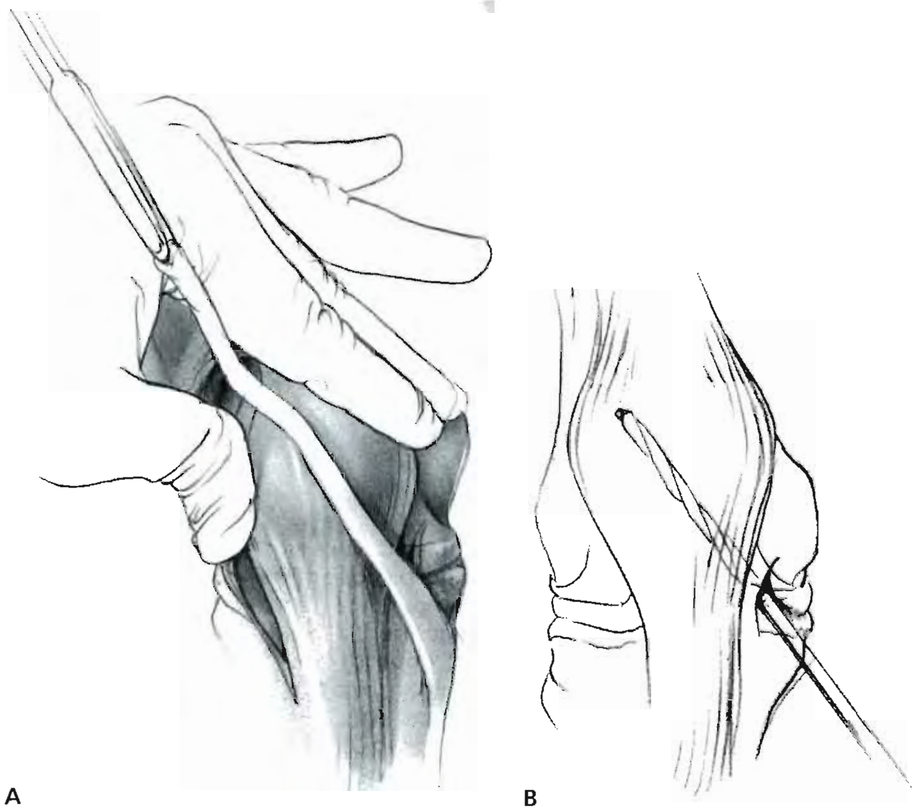


FIGURE 5-7. The lateral flap is now dissected to expose the lateral border of the patella. A complete lateral release should be performed, at the minimum, including both the capsule and the synovium. At this point, the surgeon can decide whether to perform a more extensive realignment of the patella with advancement of the vastus medialis muscle or complete proximal realignment. If nothing more is to be done (as illustrated here for simplicity), a small incision should be made in the medial capsule at the distal end of the patella. This will allow palpation of the inferior surface of the patella for more accurate placement of the drill hole.



A B

FIGURE 5-8. With the patella held in the desired position and the tendon pulled across the surface of the patella, the proper direction for the drill hole can be determined **(A)**. Starting at the inferior medial edge of the patella, a hole of sufficient size to allow passage of the tendon is drilled, emerging at the superior lateral corner of the patella **(B)**. In directing the drill, the surgeon must be careful to avoid penetrating the articular surface.

FIGURE 5-9. The tendon is drawn through the hole and pulled back on itself. Sufficient tension should be placed on the tendon to hold the patella in line with the intercondylar notch. This can be tested by flexing the knee while an assistant holds tension on the tendon. Tension should be sufficient to create a laxity of the patellar tendon.

Note the infrapatellar branch of the saphenous nerve that penetrates the sartorius muscle and branches over the medial capsule of the knee. The main branch of the saphenous nerve emerges from between the sartorius and gracilis tendons to continue down the leg. Care must be taken during both the dissection and the routing of the tendon to be certain that these nerves are neither cut nor kinked.

The operation is completed by suturing the semitendinosus tendon to the periosteum of the patella and, if sufficient length is available, to itself.

FIGURE 5-10. To restore tension to the patellar tendon and affect some redirection in its line of pull, a Goldthwait procedure can be added (4). This entails splitting the patellar tendon in half, detaching the lateral half, directing this half under the medial half of the tendon, and attaching it to the periosteum of the tibia under moderate tension. At the completion of this step, any muscle advancements or other steps to augment the realignment are completed, and the wound is closed over a suction drain.

POSTOPERATIVE CARE

The knee is immobilized in extension for 6 weeks. The drain can usually be removed the day after surgery, and the patient can be discharged on a three-point partial weight-bearing crutch gait within 3 days. Attempts to begin isometric quadriceps exercises can be started 1 to 2 weeks after surgery. After the discontinuation of immobilization, a rehabilitation program for the knee is started.

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5.3 SURGICAL REPAIR OF IRREDUCIBLE CONGENITAL DISLOCATION OF THE KNEE

Congenital dislocation of the knee is a rare disorder, especially if distinguished from congenital hyperextension. Curtiss and Fisher (1) distinguish three types of deformity: recurvatum, subluxation, and dislocation. Occasionally, a hyperextended knee will resist manipulation and require surgical treatment. More often, it is the subluxated knee and almost always the dislocated knee that will require surgery for reduction. The need will be apparent after a trial of manipulation and casting. It is doubtful that a trial of skeletal traction is desirable before an open reduction in view of the high incidence of epiphyseal injury and femoral fracture that is reported with its use (2).

Descriptions of the pathology in the dislocated knee have been similar (1,3–6). The axis of the tibia lies anterior to the axis of the femur. The quadriceps mechanism is shortened, with poor development of the entire muscle. The suprapatellar pouch is obliterated and filled with dense fibrous tissue, by which the quadriceps mechanism is bound to the anterior surface of the femur. In many cases, the muscle fibers of the quadriceps, including the medialis and the lateralis as well as the entire capsule, are adherent to the femur. The anterior capsule is short, and the collateral ligaments run anterior to the tibia and are shortened. The hamstring tendons are usually subluxated anteriorly as well, acting as extensors. In about half of cases, the patella is subluxated laterally, and the tibia is in valgus and external rotation. The cruciate ligaments have been described as usually present (1), usually absent (4), elongated (5), and shortened (7).

This is the pathology that must be corrected to allow the tibia to be reduced and flexed on the femur. Although there are consistent features, it appears that not all cases demonstrate exactly the same pathology or the same severity. The basic steps that must be taken to effect a reduction are as follows: free the quadriceps and lateral retinaculum from the underlying femur, divide the anterior capsule and extensor retinaculum, and lengthen the quadriceps mechanism. Although it has been recommended that the absent anterior cruciate ligament be reconstructed (4) or, if stretched, advanced (3), we doubt that this can be achieved with the precision that we now recognize as necessary to be beneficial to the long-term stability of the knee (Figs. 5-11 to 5-14).

FIGURE 5-11. The patient is positioned supine and a midline longitudinal incision is made from the tibial tubercle to the middle of the thigh. Sharp dissection is used to expose the quadriceps muscle, the patella, the patellar tendon, and the lateral retinaculum. The subluxated hamstring tendons and the collateral ligaments should also be identified but usually do not require extensive exposure.

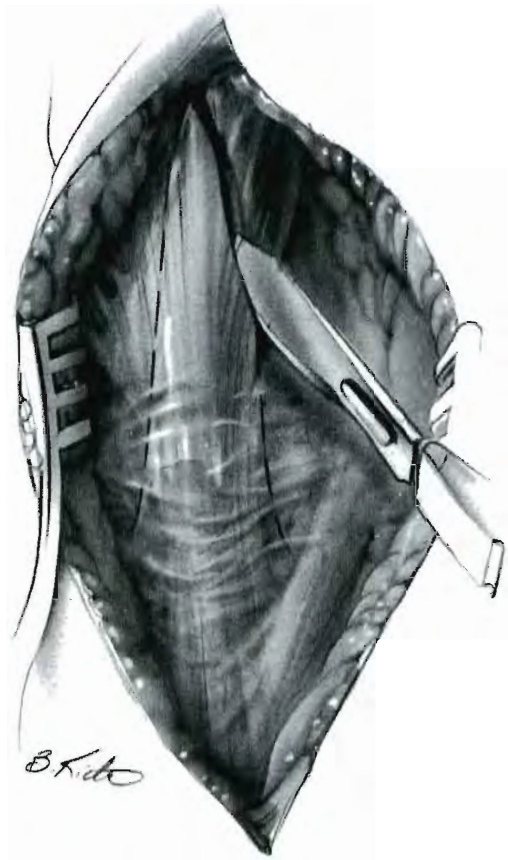

FIGURE 5-12. The most striking feature of the anatomy is the appearance of the quadriceps muscle. The amount of muscle is small, and the medial and lateral fibers insert into the quadriceps tendon well above the patella. Before proceeding, the surgeon must decide how the quadriceps mechanism will be lengthened. We prefer a V-to-Y advancement.

To accomplish this, the surgeon should expose as much of the quadriceps tendon proximal to the patella as possible. The medial and lateral fibers are detached from the tendon, leaving a small amount of tendinous tissue attached to the muscle for later repair. This incision is carried distally on each side of the patella to divide the medial and lateral retinaculum as far as the collateral ligaments. If the tibia is in valgus and external rotation, it is important to divide the iliotibial band.

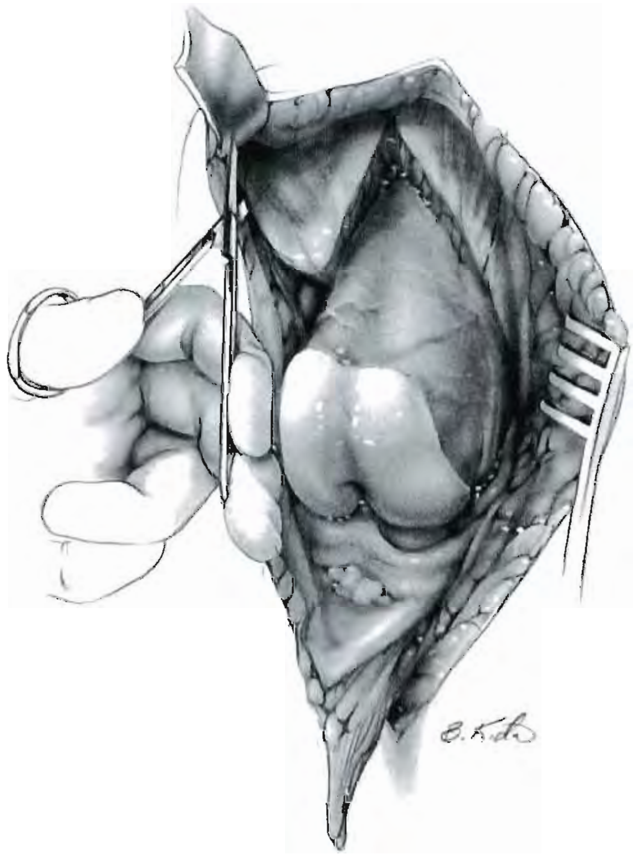

FIGURE 5-13. At this point, the joint can be inspected. The menisci are usually present and normal. The pathology in the cruciate ligaments is variable. The most striking feature, however, is the adherence of the quadriceps muscle and the lateral retinaculum to the femur. This usually prevents complete reduction and flexion of the dislocated tibia. Therefore, it is necessary to dissect these tissues free, to permit the tibia and the collateral ligaments to slide posteriorly and to allow sufficient mobilization of the quadriceps. To accomplish this, the posterior border of the lateralis *(scissors)* and the medialis *(dotted line)* are divided sharply, and the flap of muscle created is dissected free of its underlying attachments to the femur. At the completion of this step, there should be some elasticity noted when pulling on the muscle.

FIGURE 5-14. The knee can now be flexed and reduced. The amount of extension that permits redislocation should be noted. Any amount of extension less than 20 degrees almost always results in subluxation, and anything greater than 50 degrees is too much to permit reconstruction of the quadriceps. Therefore, with the knee flexed about 40 degrees, the medialis and lateralis are reattached to the quadriceps tendon in their new position, creating the V-to-Y advancement and repair. At this point, the surgeon will appreciate the time spent to plan the lengthening of the quadriceps because there is seldom an excess of tendon for the repair. The retinaculum cannot be closed, and no attempt should be made to do so.

Drains are placed, the wound is closed, and the leg is immobilized in the degree of flexion that was chosen for repair of the quadriceps muscle. This should be in sufficient flexion so that there is no tendency for the tibia to subluxate anteriorly, usually 40 degrees.

POSTOPERATIVE CARE

The knee is immobilized for 6 weeks. It may be advisable to obtain a lateral radiograph between 1 and 2 weeks to be certain that the knee has not redislocated. At 6 weeks, the immobilization is discontinued and the patient is allowed to kick free. The parents are taught techniques to stimulate quadriceps contraction, and gentle passive flexion and extension stretching are begun.

References

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6

THE TIBIA

6.1 DOME OSTEOTOMY OF PROXIMAL TIBIA

Osteotomy of the proximal tibia in the growing child is always difficult. Although the deformity usually occurs at the physis, the osteotomy must be performed at some distance from the physis to avoid damaging further growth potential. At the same time, the need for internal fixation causes the osteotomy to be performed even further from the site of deformity. All of the techniques of proximal tibial osteotomy in the growing child should aim for the same goals: to be as close to the site of the deformity as possible, to provide a large surface of bone for stability and rapid healing, to provide fixation that will avoid loss of correction, and to restore or preserve the normal mechanical axis of the leg.

Achieving the desired correction with a tibial osteotomy can be difficult. There are several methods that aid in this goal. First, draping both the operated and nonoperated leg into the sterile field from the anterior superior iliac spine to the medial malleolus is helpful in visualizing the correction and symmetry between the two legs. Stretching a Bovie cord from the center of the hip to the midpoint of the ankle joint and visualizing this on an image intensifier aids in determining the new mechanical axis. Finally, grids imbedded in radiolucent plastic are available that aid in determining the plane of the joint in relation to the axis of the bone. The surgeon may use any or all of these during an operation to avoid disappointment after the drapes are removed or the patient resumes walking.

A discussion of various techniques for proximal tibial osteotomy in the growing child follows. Their virtues and drawbacks are discussed. All of these techniques have been and can be used successfully.

The classic osteotomy of the proximal tibia is the dome osteotomy, in which a semicircular cut is made in the bone, and the distal fragment is simply rotated into the correct position. There are several problems with this technique that have led us to abandon it in favor of other techniques. Because this is still the most common technique used, however, it is described. The incision and dissection described for this osteotomy are the same for all others described here. This approach has the advantage of good exposure and cosmesis, and only one incision is necessary for both the tibial and fibular osteotomy.

Problems with the dome osteotomy are the lack of inherent stability at the osteotomy site and the near impossibility of producing the perfect dome in a bone that is triangular in cross-section. Fixation of this osteotomy traditionally has been accomplished with crossed Steinmann pins. Crossed pins are difficult to insert through the thick tibial cortex at the desired oblique angle and may not produce the degree of rigidity that is necessary to resist the pull of the quadriceps on the proximal fragment. It is important to note, however, that none of these problems is insurmountable and that many of the goals for the ideal osteotomy are met: length is not altered, and the cancellous surface is maximized for rapid healing (Figs. 6-1 to 6-8).

FIGURE 6-1. Visual inspection of the alignment of the leg is of critical importance to the surgeon. For this reason, as much of the leg as possible should be clearly visible to the surgeon. If a tourniquet is applied to the thigh and the leg is prepared and draped, there will be little of the thigh visible in the child. If a loose-fitting stockinette is covering the leg, the exact alignment of the tibia will also be obscured. For this reason, we prefer to prepare and drape the leg from groin to toes and then wrap the leg in an adhesive, translucent, flexible plastic drape. A sterile (gas autoclaved) tourniquet is then placed around the proximal thigh. This permits excellent visual inspection of the overall alignment of the leg.

The incision is oblique, beginning at the medial flare of the tibia and extending downward and lateral across the tibial tubercle. It is not necessary to extend the incision around the leg to provide access to the fibula.

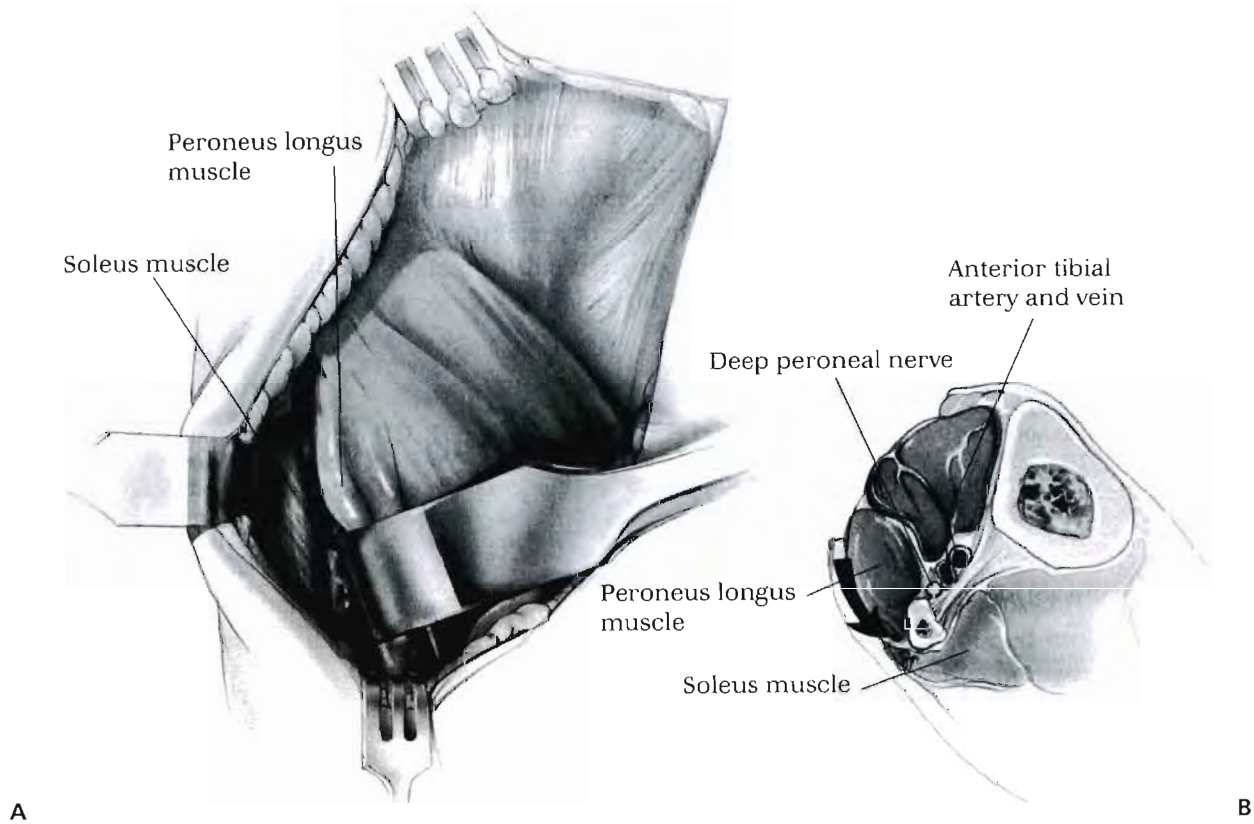


FIGURE 6-2. The entire incision is deepened through the subcutaneous tissue to expose the investing fascia of the muscles of the anterior and lateral compartments as well as the periosteum of the medial face of the tibia. The fibula can be divided first. The subcutaneous tissue is elevated from the fascia of the anterior tibial, the extensor digitorum longus, and the peroneus longus muscles. At this point, the sharp lateral border of the fibula can be palpated. This approach takes the surgeon posterior to the peroneal nerve.

A long blade retractor (e.g., an Army-Navy or small Meyerding) is used to pull the skin and subcutaneous tissue away from the muscle while a small, sharp rake retractor or small Meyerding retractor is used to pull the peroneus longus anteriorly **(A)**. The fascial interval between the peroneus longus and the soleus muscle is identified easily and opened with a knife. This plane can be followed to the fibula, and the fibular periosteum is exposed for a short distance by elevating the muscle with a periosteal elevator **(B)**.

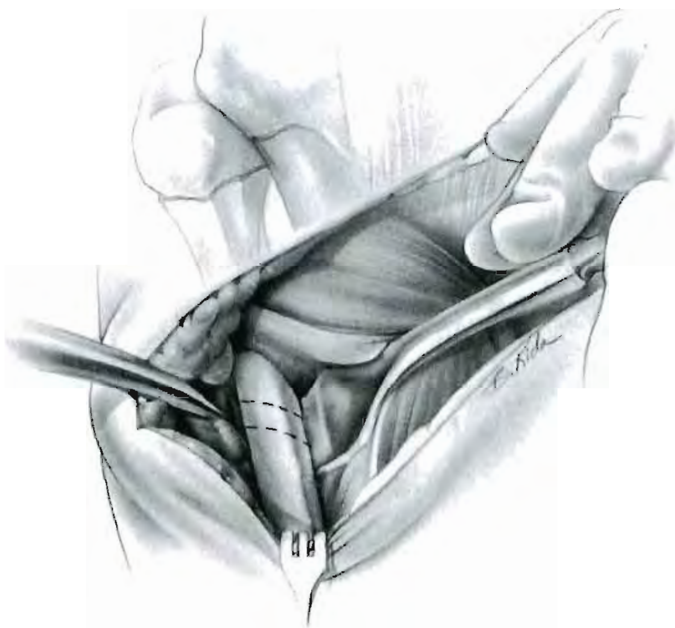


FIGURE 6-3. The periosteum is sharply incised, the fibula is exposed subperiosteally, and two small Chandler or similar retractors are placed around the fibula. The bone can be safely divided, or a section can be removed. The surgeon should be careful not to apply more retraction than is necessary with the Chandler retractors to avoid traction injury to the peroneal nerve. No attempt is made to close this exposure; the muscles are simply allowed to fall back into place.

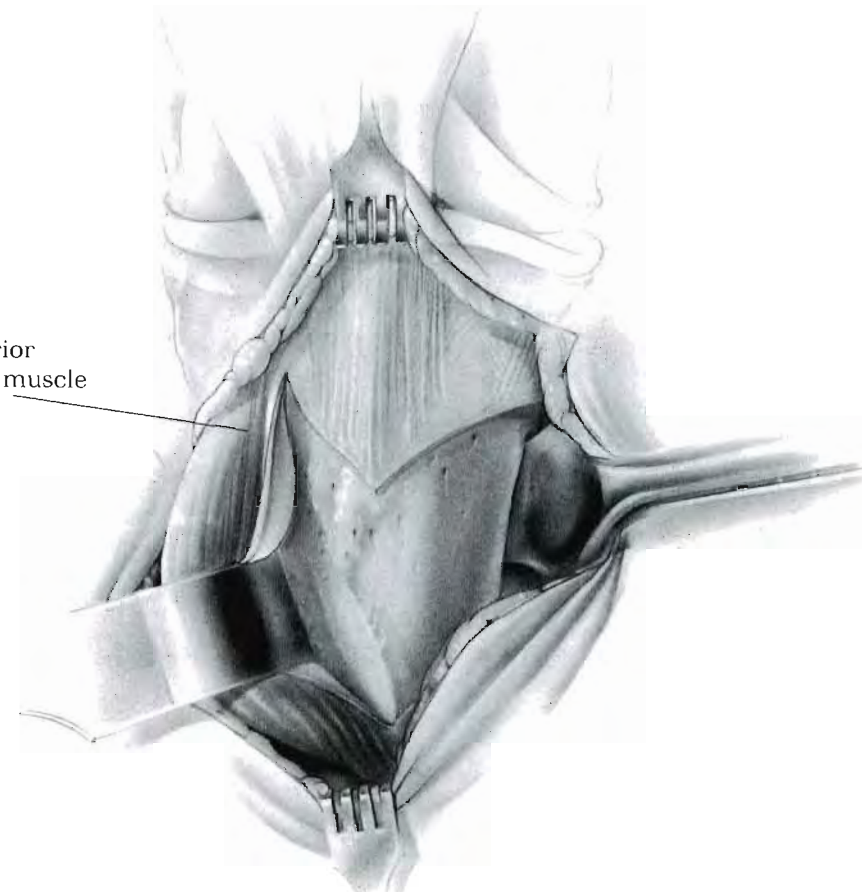


FIGURE 6-4. Exposure of the tibia is achieved by first incising the periosteum along the medial flare of the tibia, passing beneath the tibial tubercle, and continuing down the anterior crest of the tibia. The medial surface of the tibia is exposed by subperiosteal dissection around to the posterior surface of the tibia.

To expose the lateral surface of the tibia, it is necessary to detach a variable portion of the origin of the anterior tibialis muscle and reflect this muscle off of the lateral face of the tibia. To accomplish this, an incision is made along the lateral flare of the tibia joining the first incision below the tibial tubercle. In an effort to remain below the physeal plate, some of the muscle fibers can be cut, but this is of no concern. This muscle is elevated subperiosteally, exposing the lateral surface of the tibia.

Some surgeons prefer to enter the anterior compartment to expose the lateral surface of the tibia. This is done by incising the fascia over the tibialis anterior muscle close to the tibial crest, retracting the muscle, and then incising the periosteum over the tibia just lateral to the crest. The incision of the fascia over the tibialis muscle is made as far distally as possible to accomplish a fasciotomy of the anterior compartment.

It is important at this point, as on the medial side, to carry the subperiosteal dissection around the posterior corner of the tibia. Sufficient detachment of the muscle origins from the lateral flare of the tibia should be done to permit this exposure. The use of a curved periosteal elevator (e.g., the large Crego elevator) is also helpful in exposing the posterior surface of the tibia. During this exposure, the knee should be flexed and any pressure on the back of the tibia relieved so that the neurovascular structures are permitted to fall away. At the completion of this dissection, it should be possible to pass retractors behind the entire tibia to ensure protection of the soft tissues. This can usually be accomplished with a combination of different retractors (e.g., a small malleable retractor, a Chandler retractor, a Blount knee retractor).

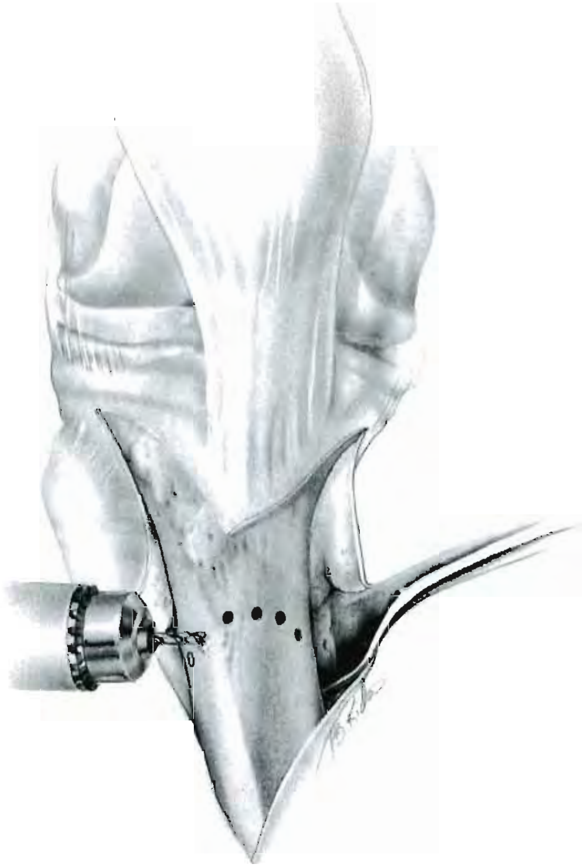


FIGURE 6-5. The dome to be cut in the tibia is outlined with multiple drill holes. The apex of the dome should be the first hole drilled and should lie about 1 cm beneath the tibial tubercle. It is easiest to drill the holes in the medial and lateral faces of the tibia by keeping the drill perpendicular to the surface of the bone. To preserve the same contour in the posterior surface, however, the drill should be passed in a straight anterior to posterior direction when drilling the holes in the posterior cortex.

After this, the holes are connected with an osteotome, first cutting the anterior cortex, then the medial and lateral cortex, and finally the posterior cortex. Again, care should be taken to be sure that retractors are protecting the soft tissues posteriorly.

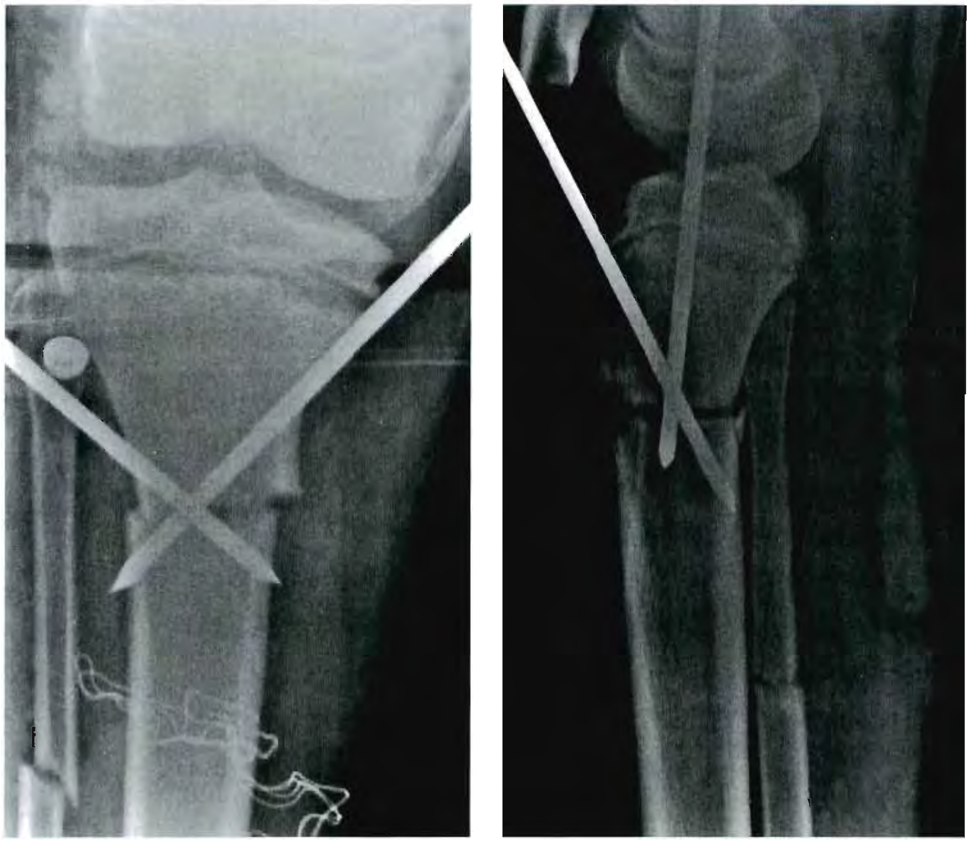
FIGURE 6-6. The osteotomy is now manipulated into the correct position. It is possible to correct varus and valgus, flexion and extension, and rotation. After correction in all the various planes is achieved, the osteotomy seldom retains the characteristics of the perfect dome. Therefore, some adjustment to the osteotomy surfaces is usually needed to achieve good coaptation and to remove bony prominences. This is most easily accomplished with a rongeur. Much of the difficulty in achieving good coaptation between the two surfaces is a result of the fact that the bone is triangular in cross-section in the area of the osteotomy.

After the desired correction is achieved, two smooth or threaded Steinmann pins are passed across the osteotomy site: one from the medial side and one from the

lateral side. It is important that the pins cross as far as possible above or below the osteotomy site, that is, that they are as far apart as possible when they cross the osteotomy. If the pins cross at the osteotomy site or are close together, there will be no rotational stability. If the pins cross the physeal plate, they should be smooth. Whether the pins are left out through the skin or buried beneath the skin is the surgeon's choice.

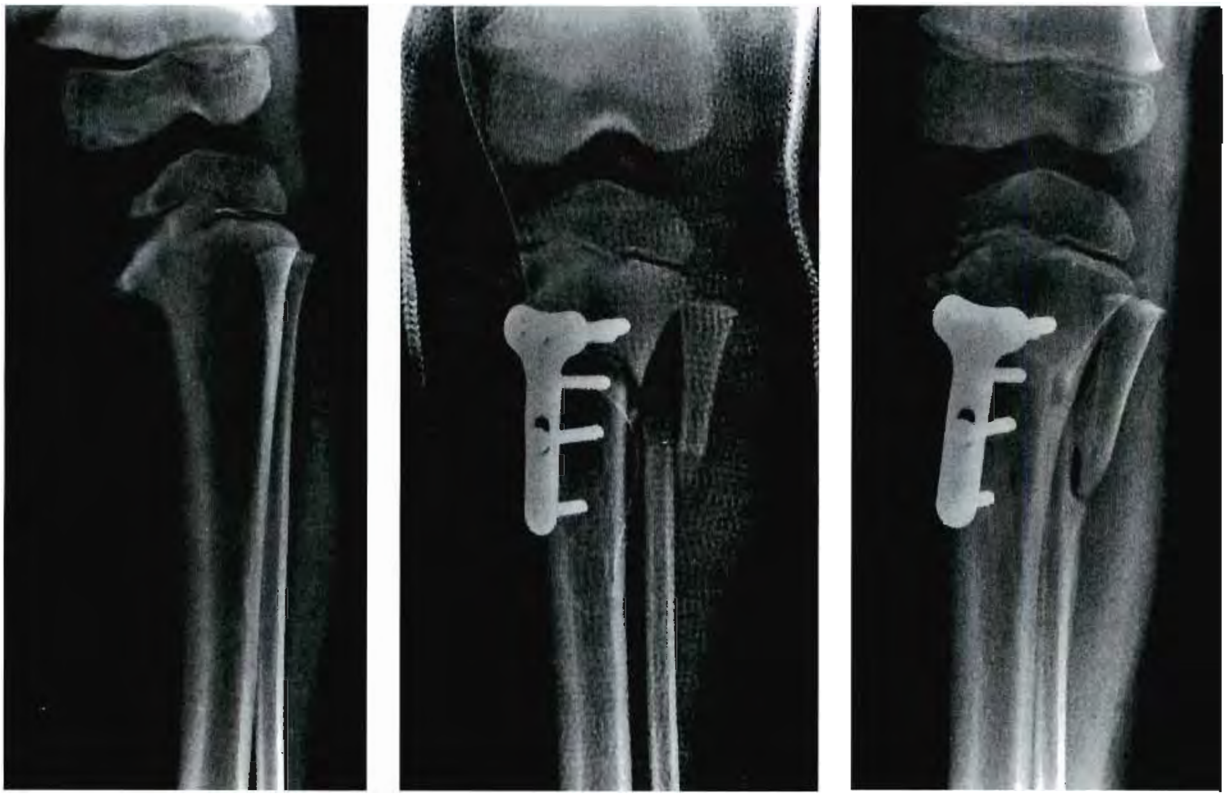
The final position and fixation should be checked radiographically. The position is best checked with a long radiograph, but the fixation is best checked with an image intensifier while stressing the osteotomy site. It is important when verifying the degree of correction that the osteotomy not be held forcibly in position because opening of the joint space could lead the surgeon to overestimate the amount of correction that had been achieved. This is discussed in more detail in Figure 6-31.

The wound is then closed by loosely approximating the periosteum and reattaching the muscle origin of the anterior tibialis muscle. It is neither possible nor desirable to close the periosteum completely. A suction drain is placed in the subcutaneous space, and the remainder of the wound is closed. A long-leg cast is applied in a position chosen by the surgeon. Usually, the knee is flexed about 45 degrees. This position aids in elevation during the postoperative period and permits non–weight bearing during ambulation if done as a unilateral procedure. This position, however, makes it impossible to check the alignment of the osteotomy in the postoperative period and decreases the ability of the cast to immobilize the osteotomy site, as compared with a straight-leg cast. For these reasons, the surgeon may prefer to cast the leg with the knee extended, but this is risky because the child will almost certainly bear weight on the leg.



A B

FIGURE 6-7. The problems with using two crossed Steinmann pins for fixation are illustrated in these postoperative radiographs of a 13-year, 8-month-old boy with adolescent Blount's disease who underwent a closing transverse wedge osteotomy with crossed-pin fixation **(A)**. The anteroposterior radiograph demonstrates the anatomic difficulty of gaining secure fixation. If this osteotomy were done more proximally, as it could have been, it would have been even more difficult to obtain fixation. If the pins are started distally, it can be difficult to penetrate the thick tibial cortex at the necessary angle. The lateral radiograph **(B)** illustrates the anterior angulation that results by the pull of the quadriceps tendon that is poorly resisted by the fixation.



A, B C

FIGURE 6-8. An alternative to cross-pins is the use of the T-buttress plate, as illustrated in this 3-year, 9-month-old child with Blount's disease **(A)**. The immediate postoperative radiograph shows the osteotomy done in the correct location, just beneath the tibial tubercle **(B)**. Three months later, the osteotomy is healed **(C)**. (Courtesy of Douglas H. Kehl, M.D., Scottish Rite Children's Medical Center, Atlanta, GA.)

POSTOPERATIVE CARE

The drain is removed when the drainage has slowed. If the procedure is unilateral, the patient can be ambulated as soon as comfortable, depending on age. It is important that weight bearing not be permitted. Therefore, if the patient is not to be trusted in this regard, it is best to obtain a rental wheelchair for a bed-to-chair program until the radiographs show sufficient healing to permit removal of the pins and weight bearing. This is usually between 6 and 8 weeks after surgery and depends on the degree of healing and the reliability of the patient. Application of a long-leg cast with the knee flexed 10 degrees can be used any time the surgeon thinks that weight bearing is permissible or desirable.

6.2 SPIKE OSTEOTOMY FOR ANGULAR DEFORMITIES OF THE LONG BONES

Over the years, many techniques have been developed for osteotomies of long bones. Most have been designed to achieve stability of the bone fragments. Since the 1960s, there has been an increased application of internal and external fixation devices for osteotomies in children. The risk for nonunion in children is low, and the requirements for maintenance of near-perfect alignment are obviated by the high potential for correction of minor malalignments by growth and remodeling. The spike osteotomy, originally described by Hass (1) was a subtrochanteric femoral osteotomy, which has been modified for the treatment of other angular deformities of long bones of the lower extremities. This technique can be used for any angular deformity of a long bone but is especially appropriate for a metaphyseal–diaphyseal junctional deformity (2). Using the spike osteotomy and proper application of a plaster cast, alignment can be maintained until healing occurs, without the use of adjuvant fixation. This avoids the problems associated with pin-track infection, secondary procedures for hardware removal, and stress shielding of bones during healing. The procedure is best for treating one-plane deformities; however, two-plane deformities can also be corrected using this technique. Significant degrees of angular deformity (45 to 50 degrees) may be corrected using this technique. When the procedure is used for correcting valgus deformities of the proximal tibia, the peroneal nerve must be visualized just proximal to the fibular head and as it courses around the fibular neck to ensure that it is not under tension. A proximal tibial valgus operation is described (Figs. 6-9 to 6-13).

FIGURE 6-9. The entire leg to be operated on is prepared and draped out in a standard sterile fashion. A sterile tourniquet may be used. We often prepare and drape out the opposite normal leg for clinical comparisons. Two incisions are made: an about 7- to 10-cm long incision just lateral to the subcutaneous boarder of the tibia starting just at the level of the tibial tubercle, and a second 3- to 5-cm long incision laterally at the junction of the anterior and lateral compartment of the fibula, to be used for the accompanying fibular resection and exposure of the perineal nerve as necessary.

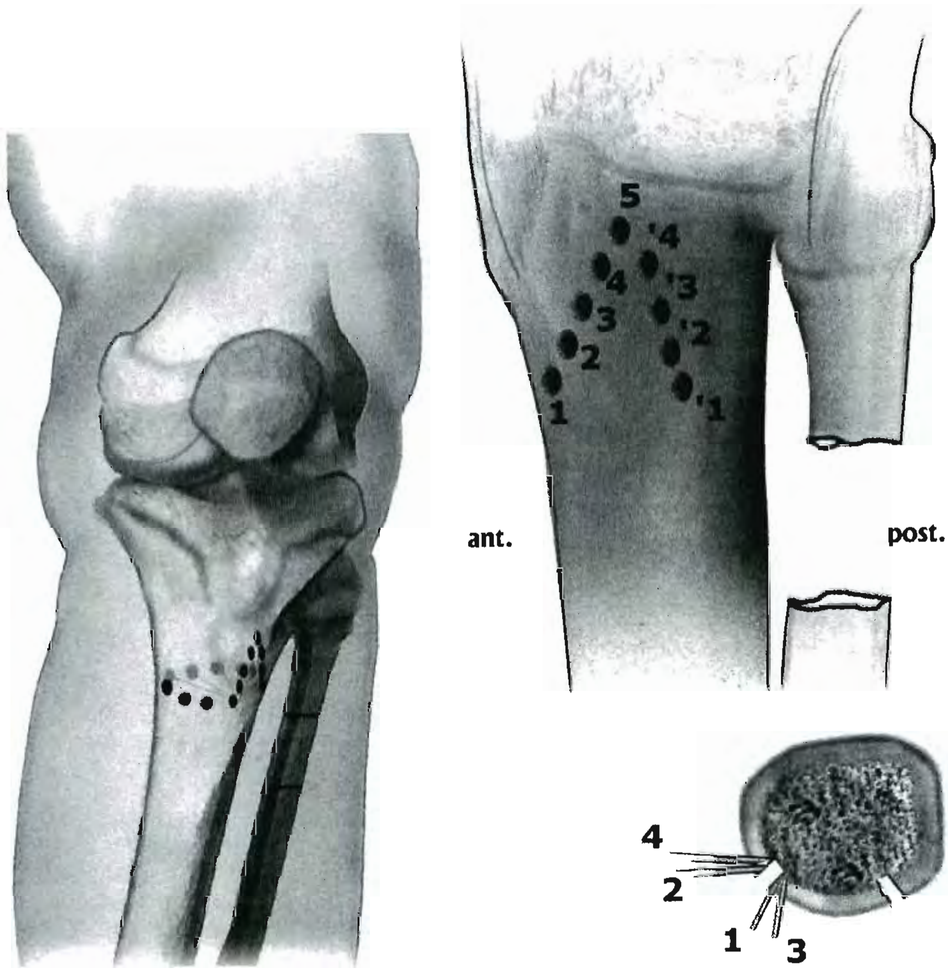


FIGURE 6-10. After the standard surgical approach and circumferential periosteal stripping of the bone (in this case, the tibia), the spike, which is unicortical, is outlined with drill holes. The cortex opposite the spike is penetrated by drilling through the holes at the base of the spike (see Fig. 6-11).

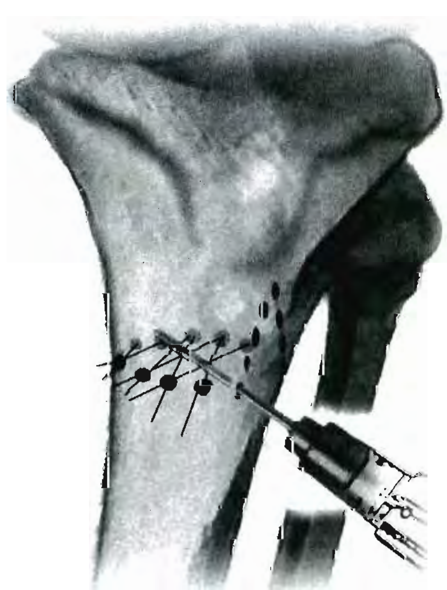


FIGURE 6-11. A single drill hole in the anterior cortex may be used to make multiple drill holes on the posterior cortex. Thus, a straight line of holes is created posteriorly at the level of the base of the spike. The base of the spike is about 1.5 to 3 cm wide, and the spike itself is 3 to 4 cm high, depending on the size of the bone. The spike is based in the diaphyseal fragment so that the tip of the spike will impale the metaphyses.

The spike is fashioned on the side of the bone toward which the angular displacement of the distal fragment will be performed. When correcting a varus deformity at the proximal end of the tibia, the spike is created on the lateral aspect of the bone. As many drill holes as possible are used to outline the spike to help prevent fracturing.

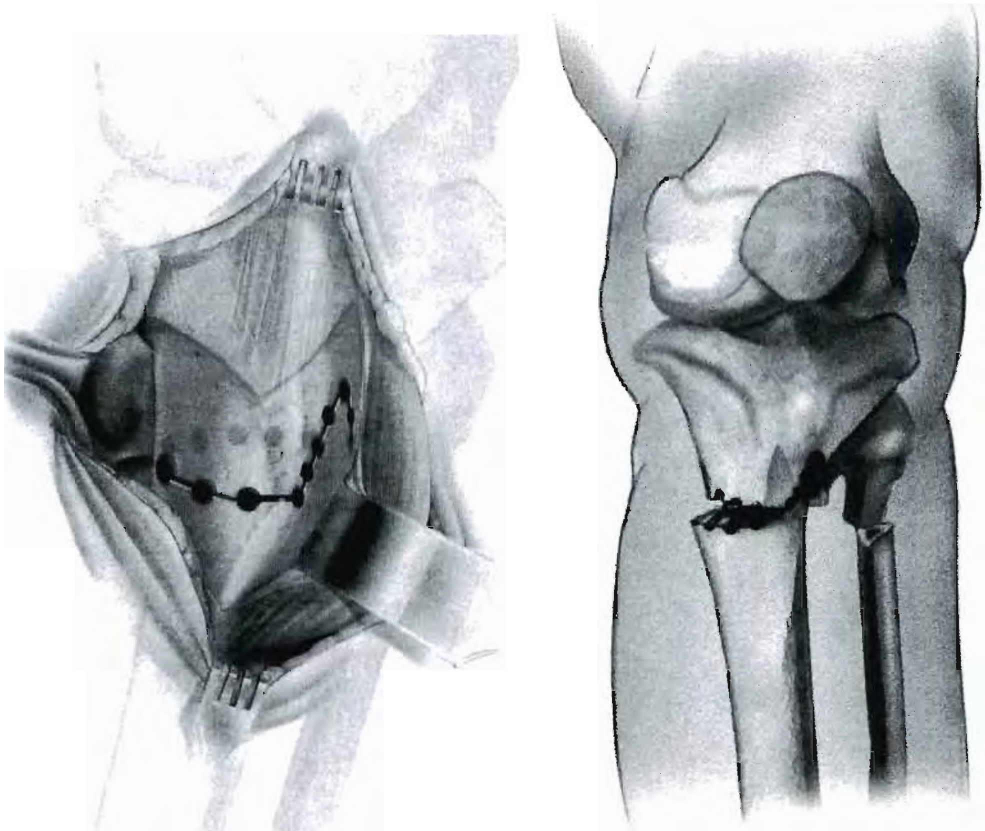

A B

FIGURE 6-12. The drill holes are connected starting first with the spike. A chisel or osteotome (we prefer a chisel because its bevel helps prevent fracturing) is used to connect the drill holes (see Fig. 6-10C). Take particular care that the spike itself does not fracture. After all the drill holes are connected **(A)**, the distal fragment is angulated, and the spike is impaled in the cancellous bone of the metaphysis **(B)**. The fragment is stable because of the tight fit of the base of the triangular spike in its slot. Stability is further achieved by insertion of the spike into the firm cancellous bone of the metaphysis. Although the spike osteotomy can be used in the diaphysis, stability is somewhat less because of the absence of cancellous bone. Correction in more than one plane is also possible, but again, some stability is lost because the spike fits less snugly in the slot.

When the osteotomy is used in the tibia, about 2 cm of the fibula is removed, and prophylactic fasciotomy of the anterior compartment is performed. The wound is irrigated and closed in the standard fashion and a plaster cast applied. The position of the osteotomy is maintained by a surgical assistant while a plaster cast is applied. Radiographs are taken in the operating room to assess the position of the fragment. The cast may be changed or wedged to correct any residual malalignment.

A B C

FIGURE 6-13. CF is an 11-year-old boy with achondroplasia. His bowing was progressing, and he was beginning to have lateral knee pain, indications for bilateral proximal tibial spike osteotomies. **A:** Preoperative weight-bearing radiograph. **B:** Immediate postoperative radiograph of the right osteotomy. **C:** Radiograph taken 3 months after surgery.

POSTOPERATIVE CARE

Depending on the location of the osteotomy, cast fixation is maintained until healing. Proximal tibial osteotomies generally heal within 12 weeks, supracondylar femur osteotomies in 7 weeks, and subtrochanteric femoral osteotomies in 12 weeks. In distal femoral or proximal tibial osteotomies, weight bearing is not allowed for 6 to 8 weeks, at which time protected weight bearing in a cast is permitted until healing. Children easily regain full function of the joint after the cast is removed.

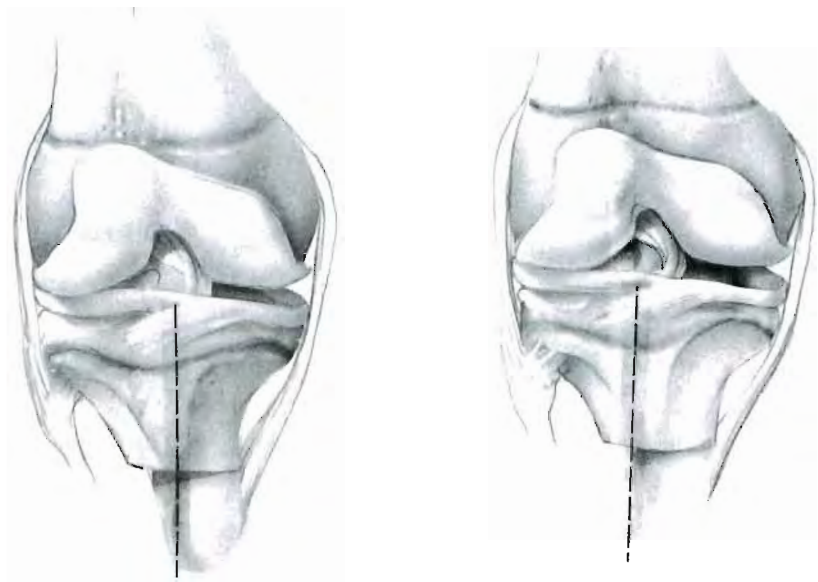
References

1. Hass J. A subtrochanteric osteotomy for pelvic support. J Bone Joint Surg 1943;25:281–291.
2. Dietz FR, Weinstein SL. Spike osteotomy for angular deformities of the long bones in children. J Bone Joint Surg [Am] 1988;70:848–852.

6.3 TRANSVERSE WEDGE OSTEOTOMY OF PROXIMAL TIBIA

Transverse wedge osteotomy is the second most popular technique for correcting angular deformity of the proximal tibia in the growing child after dome osteotomy. This is probably because of the surgeon's familiarity with this technique in adults. There are problems with this osteotomy in the growing child, however, that are not present in the adult. These do not necessarily make this a poor choice, but the surgeon should be aware of these differences (Figs. 6-14 to 6-21).

FIGURE 6-14. In the child with open growth plates, the osteotomy is performed below the tibial tubercle rather than above it. This region of the tibia tapers rapidly, resulting in a large change in the circumference of the bone over a short distance. After removal of a wedge of bone, the circumference of the distal segment will be smaller than the circumference of the proximal segment. Thus, cortical apposition will not be possible at some point around the circumference of the bone. The result is that there will be a loss of intrinsic stability at the osteotomy site in the area where the cortex of the smaller distal segment is opposed to the cancellous area of the larger proximal segment. This can result in further displacement of the osteotomy as the cortical bone of the smaller fragment sinks into the cancellous bone of the larger fragment. This problem can be aggravated by the strong pull of the quadriceps muscle on the proximal fragment, which tends to angle the osteotomy anteriorly. These factors place an increased importance on the method or strength of the fixation. This is a greater problem in the older, heavier child (e.g., the patient with adolescent Blount's disease), in whom the fixation cannot provide sufficient stability and in whom collapse at the osteotomy site can lead to secondary deformity (e.g., anterior angulation, loss of correction). The ideal fixation for this osteotomy in the child does not exist. The T-buttress plate is one solution. Some surgeons use external fixation for these osteotomies.



A B

C

FIGURE 6-15. Another potential disadvantage to the transverse wedge osteotomy is the displacement of the distal segment that can result if the closing of the wedge is not accompanied by displacement of the distal fragment. This is seldom a problem with a single osteotomy **(A)**, but with second and subsequent wedge osteotomies hinged on the medial cortex, as may be required in Blount's disease, this can result in significant displacement of the mechanical axis of the leg as the smaller distal segment shifts slightly medial to the knee joint with each osteotomy **(B)**. The solution to this problem is to combine medial or lateral displacement, depending on the osteotomy, with the valgus or varus correction **(C)**.

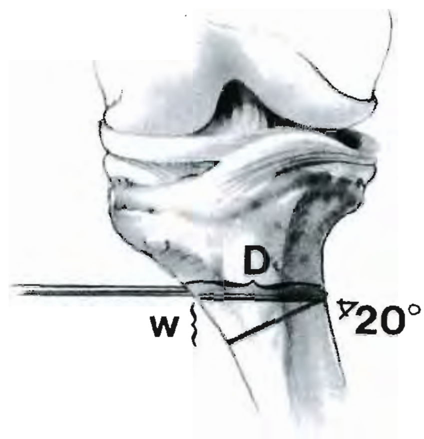


FIGURE 6-16. The final problem with the transverse wedge osteotomy is the calculation of the size of the wedge to be removed. Although we cannot verify the accuracy of the calculations, an excellent discussion of the principles involved is provided by Canale and Harper (1). According to the authors, the usual rule of 1 mm for every degree of correction is a reasonable approximation for tibias that are 5 to 6 cm in diameter. In smaller tibias, however, this rule will result in too large of a wedge being removed and overcorrection.

There are several methods to calculate accurately the width of the base of the wedge to be removed. The first is to draw the correction on a preoperative radiograph and measure the template for the necessary wedge. Care must be taken to account for the magnification factor of the radiograph, which can vary but is usually about 20%.

There is another method of preoperative planning. This can be done either preoperatively on the radiographs (again with care to include the magnification factor) or at the time of operation to measure its diameter. First, drill a wire through the bone at the proposed site of the osteotomy to determine the diameter of the bone. Then, along with the desired angle of correction, apply the following formula:

$$W \text{ (wedge)} = D \text{ (diameter)} \times \text{tangent of angle}$$

Canale and Marion (1) state that the following formula gives a reasonable approximation of the preceding formula without the need to calculate the tangent:

$$W = D \times 0.02 \times \text{angle}$$

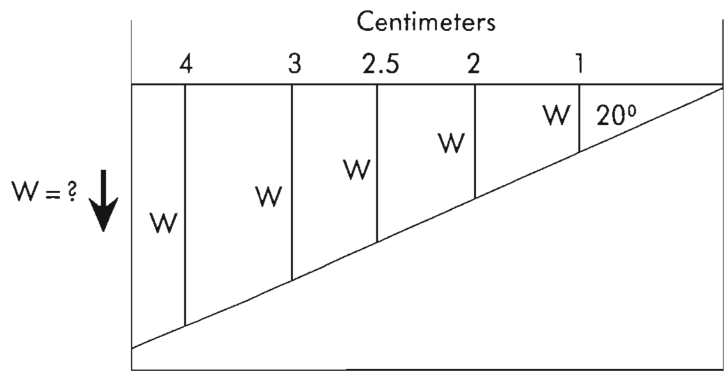


FIGURE 6-17. A final method to calculate the size of the wedge (W) is done at the time of surgery and avoids mathematic calculations. The diameter of the bone at the proposed site of the osteotomy is measured by passing a guide through the bone. A nomogram with the desired angle of correction relating various diameters and various widths of wedges is drawn to scale with the desired angle of correction before surgery and brought to the operating room. After the diameter of the bone is known, the size of the wedge can be measured directly from the nomogram.

FIGURE 6-18. The incision, the exposure of the tibia, and the exposure and division of the fibula are the same as described for the dome osteotomy. In the case illustrated, a lateral wedge is removed below the tibial tubercle for the correction of a varus deformity in a growing child. The lateral dissection must be thorough to allow the wedge to be removed and the T-buttress plate secured.

The first consideration is accurate placement of the wedge. The usual mistake is to place the wedge too distally as a result of fear of injury to the tibial tubercle. Often, the surgeon is afraid to dissect sufficiently to identify the tubercle. For these reasons, it is wise to verify the level of the proximal transverse cut by drilling a guide wire transversely through the tibia just proximal to the proposed site of the cut and viewing this radiographically. This cut should be about 1 cm distal to the tibial tubercle. The base of the wedge can be measured and the distal cut marked with an osteotome or a saw.

FIGURE 6-19. A power saw is used to remove the wedge of bone. Care should be taken to protect the soft tissues behind the tibia. If neither rotational correction nor displacement is needed, a small portion of the medial cortex can be left intact and fractured as the osteotomy is closed. Although this will result in slight medial displacement of the leg under the knee joint, it will confer an increased stability to the osteotomy. If the correction is large, if this is a repeat osteotomy, or if it is desired to remove the weight-bearing stresses from the medial side of the knee, however, it may be desirable to displace the distal fragment laterally.

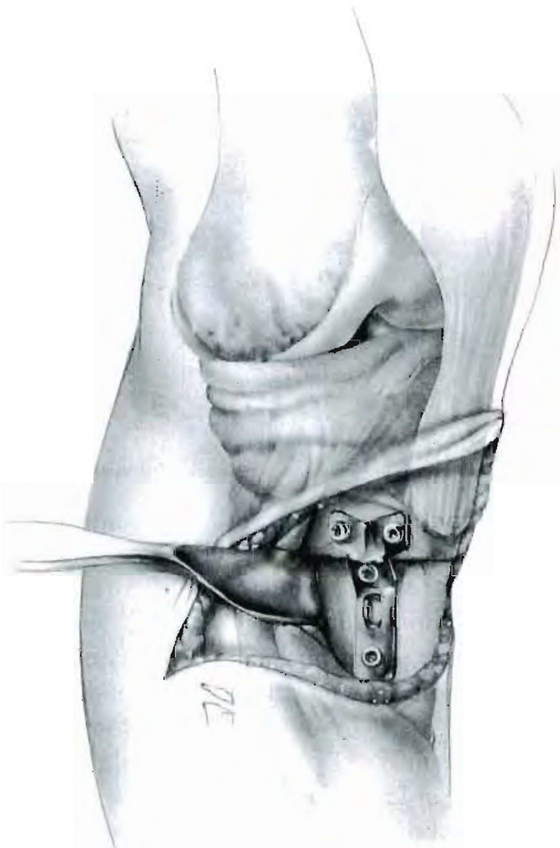


FIGURE 6-20. After removal of the wedge, the osteotomy is closed. The leg should be inspected visually to be certain that the desired correction has been achieved. If any questions exist, the osteotomy should be fixed temporarily with a smooth Kirschner wire, and a radiograph should be obtained. The osteotomy should not be held closed by manual force while this radiograph is obtained because this will force open the medial joint line, creating the impression of more correction than has actually been obtained at the osteotomy site. This is discussed in more detail in Figure 6-31.

When satisfactory correction has been obtained, a T-buttress plate is contoured to the lateral tibia and fixed in place. The proximal limb of the T will lie just beneath the physeal plate.

The periosteum is loosely approximated, a suction drain is placed superficial to the muscles and the periosteum, and the subcutaneous tissue and skin are closed. A long-leg cast is applied with the knee bent 45 degrees.

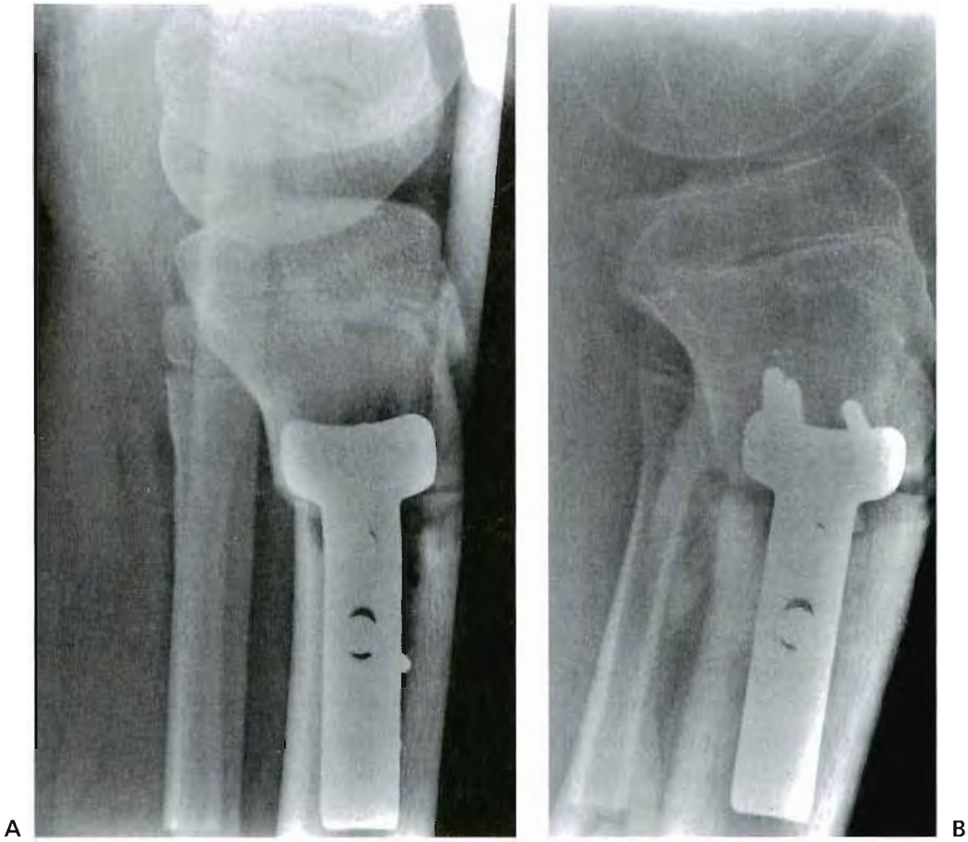


FIGURE 6-21. Immediate postoperative lateral radiograph of a closing transverse wedge osteotomy for adolescent Blount's disease is shown **(A)**. Notice the overhang of the proximal fragment posteriorly. Eight weeks later **(B)**, there is anterior angulation and delayed healing with collapse and resorption posteriorly. This method of fixation is not ideal for the very large adolescent because it resists the pull of the quadriceps poorly and because cortical apposition in all areas is not always achieved.

POSTOPERATIVE CARE

The fixation is not secure enough to permit weight bearing. Therefore, the patient is prohibited from weight bearing for the first 6 weeks, at which time healing is usually sufficient to permit removal of the cast, resumption of weight bearing, and rehabilitation of the knee. It is probably advisable to plan removal of the fixation.

Reference

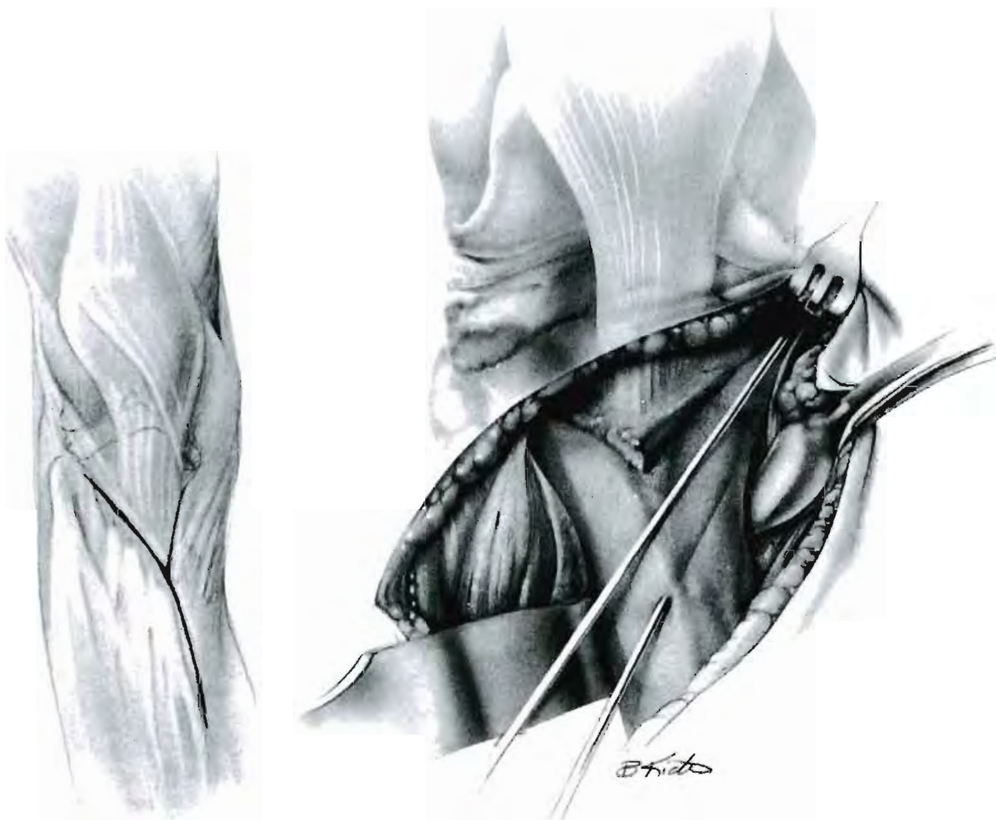
1. Canale TS, Harper MC. Biotrigonometric analysis and practical applications of osteotomies of tibia in children. In: Murray DG, ed. Instructional course lectures, vol XXX. The American Academy of Orthopaedic Surgeons. St Louis: CV Mosby, 1981:87.

6.4 OBLIQUE WEDGE OSTEOTOMY OF PROXIMAL TIBIA

An alternative to the classic transverse wedge osteotomy is the oblique wedge. We ascribe this osteotomy to Professor Heinz Wagner (although we cannot reference this). There is a reference to this technique in adults that also describes a precise way in which to measure the wedge (1).

The advantages of this type of wedge are its inherent stability, rapid healing because of the broad cancellous surface, and the fact that axial displacement of the tibia is minimized. Rotational correction is also possible with this osteotomy and is achieved by the shape of the wedge removed. We favor this osteotomy for correction of deformity in the proximal tibia, especially in older children and adolescents (Fig. 6-22 to 6-27).

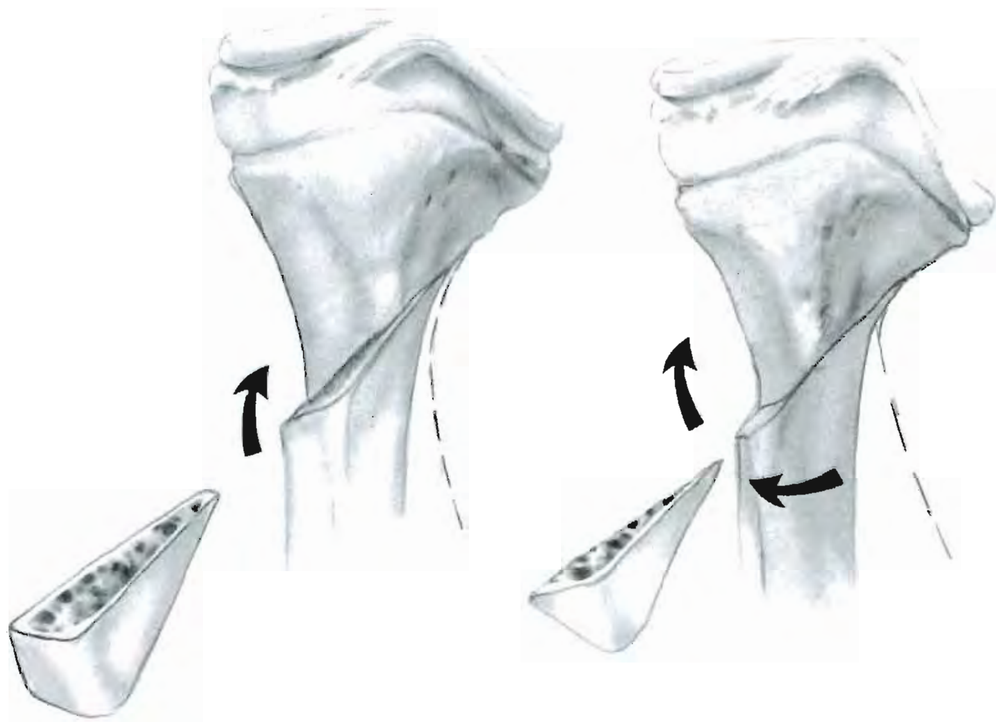
FIGURE 6-22. The incision is the same as that described for the dome osteotomy of the proximal tibia with the exception that it should be made slightly more oblique to give more distal exposure. If the osteotomy is being performed to correct valgus, the dissection of the muscles and the periosteum on the lateral side should be minimized because it is not needed and the intact lateral periosteum provides a good hinge for the osteotomy. The same is true for the dissection on the medial side if varus is being corrected. It may also be necessary to extend the incision in the periosteum more distally than with other osteotomies.



A B

FIGURE 6-23. For correction of a varus deformity, as illustrated here, the tibialis anterior muscle must be elevated subperiosteally to permit the laterally based wedge to be removed. The extent of the incisions in the periosteum that are possible through this oblique skin incision are shown in **(A)**. The periosteal elevation will extend more distally than with other proximal tibial osteotomies to permit the wedge to be oblique. Perhaps the most difficult part of the operation is to make the wedge oblique enough to realize its advantages. The periosteum should not be elevated in the proximal medial corner, where the osteotomy will hinge.

A guide wire is drilled from the distal-lateral to the proximal-medial side. It should penetrate the medial cortex just beneath the physeal plate. This wire will mark the proximal cut of the wedge. If desired, a second guide wire can be drilled into the bone to mark the distal cut **(B)**.



A B

FIGURE 6-24. The exact width of the wedge can be calculated (1) or estimated. We have found it easy to estimate the size of the wedge correctly: for some reason, it is much easier to be accurate than when estimating the amount of a transverse wedge. If the surgeon miscalculates, more bone can be removed or a small piece of bone from a too-large wedge replaced. Because of the large cancellous surface, healing is not impaired.

If only correction of varus or valgus is desired, the wedge of bone that is removed will be as wide anteriorly as posteriorly **(A)**. If correction of internal rotation is desired in addition to correction of the varus, however, the wedge of bone removed is cut wider anteriorly than posteriorly **(B)**. Thus, when the osteotomy is closed, the distal fragment will rotate laterally, producing the desired correction.

FIGURE 6-25. A power saw is used to remove the wedge. The posterior soft tissues are protected by a small, malleable retractor passed behind the osteotomy site from the lateral side. If only varus is to be corrected, the wedge should be removed to leave a small, thin segment of the medial cortex intact that can be fractured as the osteotomy is closed. If internal rotation is also part of the correction, the bone should be completely divided; however, an effort should be made to leave the periosteum intact because this will make it easier to close and fix the osteotomy.

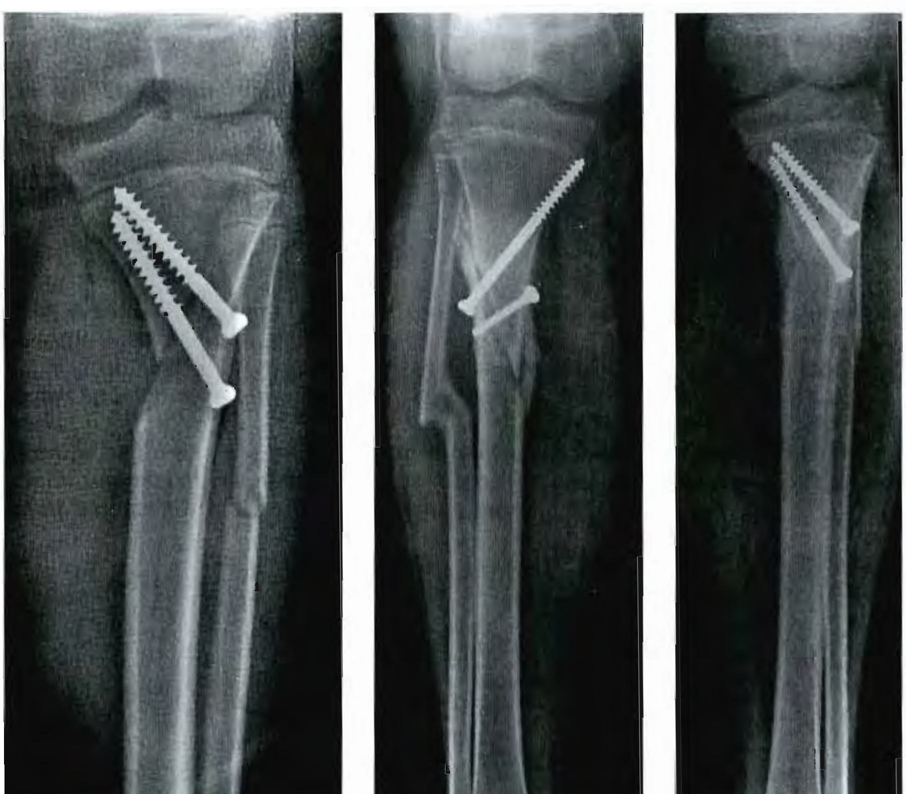
FIGURE 6-26. The osteotomy site is closed and fixed with two cortical screws that are inserted perpendicular to the plane of the osteotomy from the medial side. Because of the obliquity of the incision, it is often not possible to insert the distal screw in the proper direction through the incision. In such cases, it is inserted through a small stab wound over the subcutaneous border of the tibia. Subsequent removal of the screws is actually easier if both are placed through stab wounds because they can be difficult to palpate, but the small scars show exactly where they are.

The wound is now closed over a suction drain, and a long-leg cast is applied. Because it is possible with this osteotomy to achieve a tight closure of the periosteum, the surgeon may wish to perform a fasciotomy of the anterior compartment at this time.

FIGURE 6-27. BM is a 12-year-old boy with idiopathic genu valgum. Correction of the deformity was performed at the parents' request because of his appearance and the social problems it was causing him **(A)**. The osteotomies of the right leg **(B)** and left leg **(C)** were done differently and emphasize several technical points. The right osteotomy is more oblique than the left, which is desirable but more distal. Placing the screws in an osteotomy done to correct valgus is more difficult than in an osteotomy to correct varus. In long-standing deformities of the legs, there is deformity on the femoral as well as the tibial side of the joint. The optimal correction of the knee mechanics would require both a femoral and tibial osteotomy. Six weeks after the surgery, the casts were removed, and protected weight bearing with a four-point crutch gait was begun **(D, E)**. ▶

A

B



C-E

POSTOPERATIVE CARE

The drain can usually be removed on the first postoperative day. If the patient is old enough to ambulate reliably with a three-point partial weight-bearing crutch gait, ambulation is started the second postoperative day. Healing is usually sufficient in 6 weeks to permit removal of the cast, progression to full weight bearing, and vigorous rehabilitation of the knee.

Reference

1. Williams AT. Tibial realignment by oblique wedge osteotomy. Int Orthop 1986;10:171.

6.5 OBLIQUE CORONAL OSTEOTOMY OF PROXIMAL TIBIA

Rab (1) has described an oblique osteotomy of the proximal tibia in the coronal plane to correct the angular and rotational deformities seen in Blount's disease. The principle is the same as that introduced by MacEwen and Shands (2) for osteotomy of the proximal femur. Correction of varus or valgus requires an osteotomy in the coronal plane. Correction of rotation requires an osteotomy in the transverse plane. Because patients with Blount's disease have both deformities, an osteotomy angled in the frontal plane should correct both components of the deformity. A cut made at 45 degrees in the frontal plane corrects equal amounts of angulation and rotation. Rab (1) stated that this is the usual case in Blount's disease, but has provided a nomogram to help the surgeon determine the angle of the osteotomy when different degrees of varus, valgus, and rotation are present. The osteotomy is fixed with a single screw that allows for rotation at the osteotomy site. Therefore, the amount of correction can be determined after the drapes are removed and just before cast application. If vascular complications develop in the postoperative period, the cast can be removed and the correction reversed without losing fixation of the osteotomy (Figs. 6-28 to 6-32).

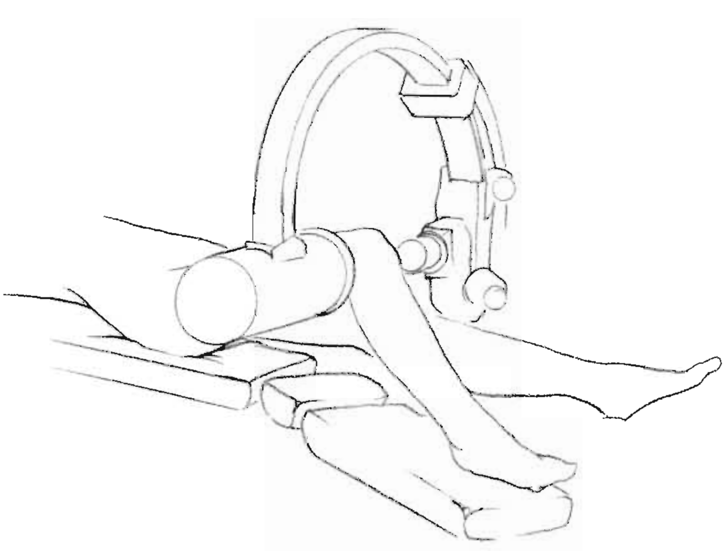


FIGURE 6-28. The patient is placed on a radiolucent operating table in the supine position. Image-intensifier control is an essential part of this procedure. The surgeon should be certain that he or she is able to obtain a good lateral view of the tibia. This is essential to confirm the location of the osteotomy and the depth of the saw or osteotomes. The image intensifier can be positioned horizontally over the operating table and moved toward the head or foot of the table when not in use to keep it out of the surgeon's way. Although Rab (1) describes a transverse incision below the tibial tubercle with a separate incision for the fibular osteotomy, we have continued to use and prefer the oblique incision described for the dome osteotomy of the proximal tibia. The exposure of the tibia is also the same as that described for the dome osteotomy (see Procedure 6.1). It is important that the exposure be sufficient to allow retractors to be placed behind the tibia. The fibula is divided as described previously.

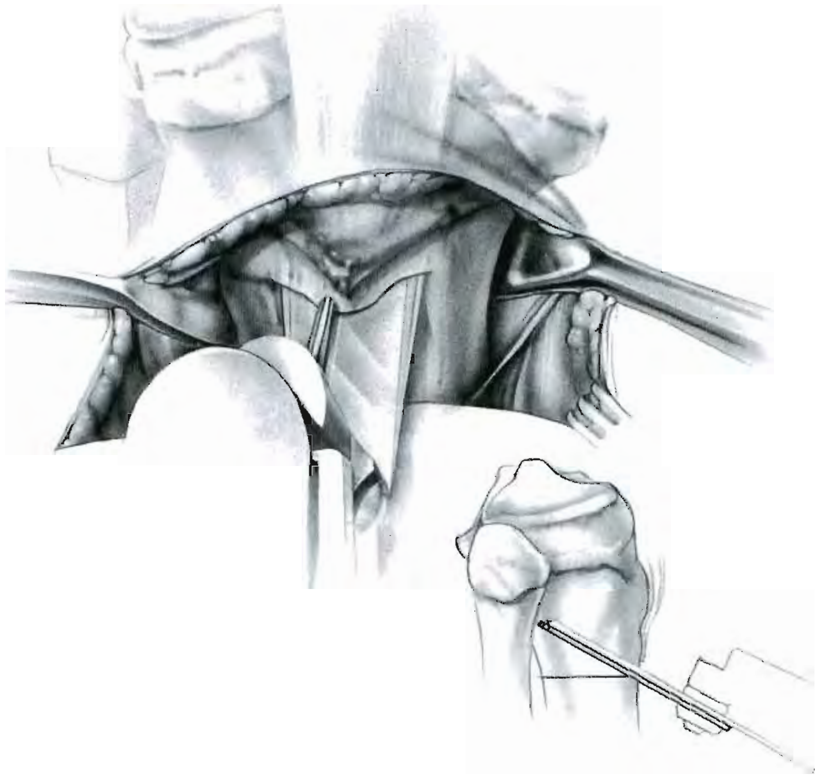


FIGURE 6-29. Beginning about 1 cm below the tibial tubercle, a smooth Steinmann pin is drilled into the tibia at the angle chosen for the osteotomy. The angle, depth, and location of this pin should be verified on the lateral image. The point at which the osteotomy cut will reach the posterior cortex should be a safe distance distal to the physeal plate. The saw is now used to create the osteotomy just distal to this pin. The progress of the saw is carefully monitored on the lateral view of the image intensifier. It is usually not possible to complete the osteotomy with the saw because the saw blade strikes the retractors. A narrow saw blade or a small osteotome can be used to complete the osteotomy. The distal fragment should be manipulated to loosen the periosteum from the posterior surface of the tibia, allowing free motion at the osteotomy site. It is possible to manipulate the distal fragment and demonstrate the correction of both the varus and the internal rotation.

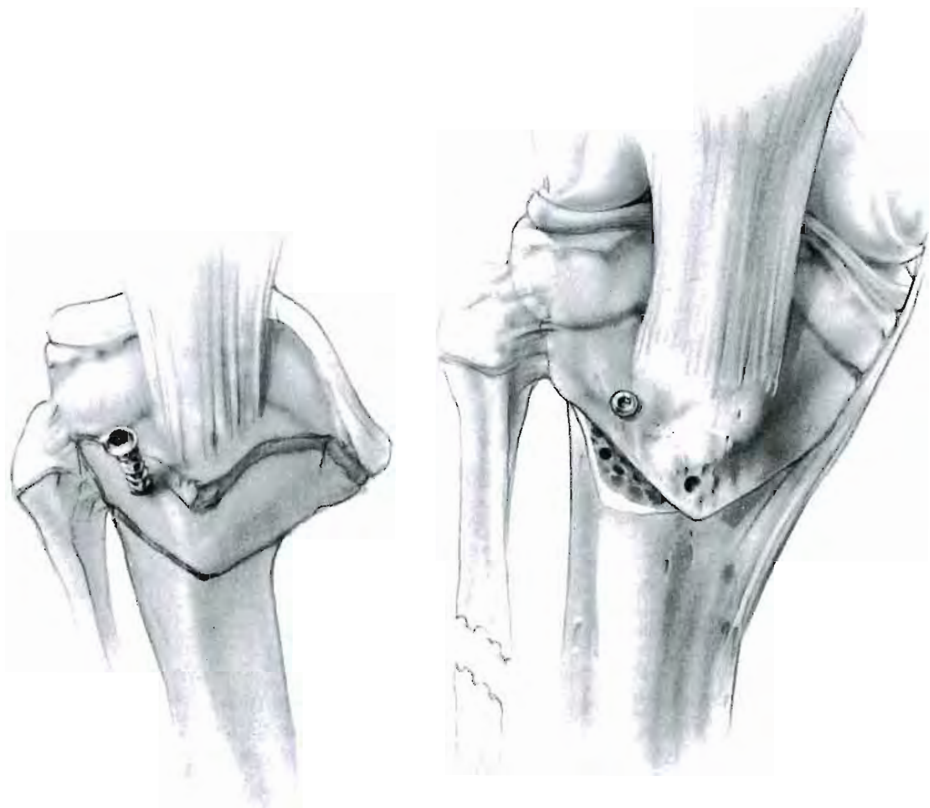


FIGURE 6-30. The osteotomy is fixed with a single screw that will hold the two fragments together while allowing motion between them in the plane of the osteotomy. This is achieved by first reducing the fragments to their original position, then drilling a screw hole lateral to the tibial tubercle that will penetrate both fragments. The hole in the proximal fragment should be overdrilled. It is important for good fixation that the screw penetrate the cortex of the distal fragment. Because this osteotomy is usually used in smaller children, a 3.5-mm cortical screw is chosen. The screw should not be tightened to prevent free motion between the fragments. Before closing the wound, the surgeon should verify that the fragments can move sufficiently to provide the desired correction.

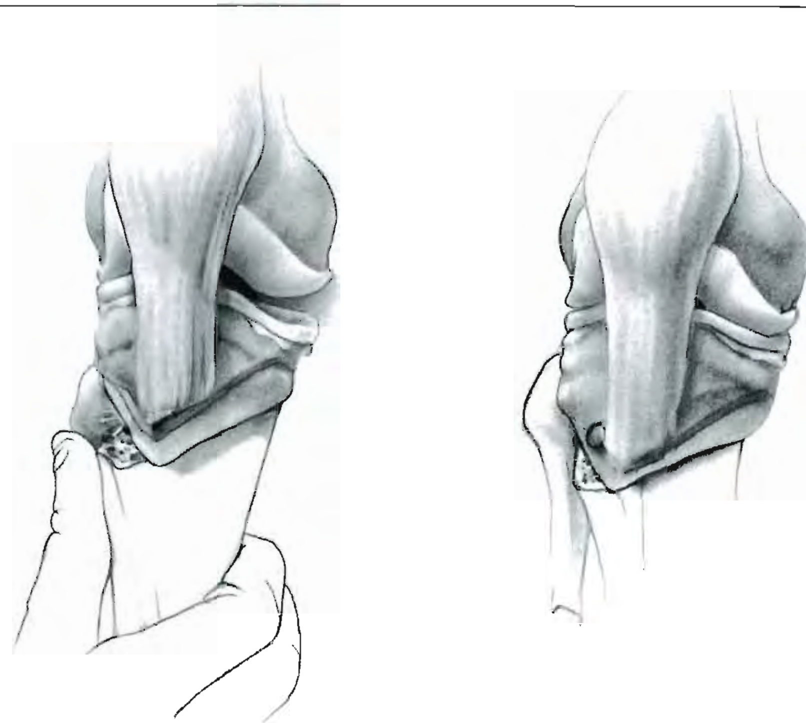


FIGURE 6-31. After the wound is dressed, the leg is manipulated into the correct position for casting. The correct position can be verified by image intensification, or better, a radiograph on a large film that includes the knee joint and the entire tibial shift.

There is a potential pitfall in determining the final position of the osteotomy that is present in all osteotomies for Blount's disease, but it is more difficult to avoid in this technique. Any time that the osteotomy is held in the valgus position while the degree of correction is being determined, there are two factors at play that can cause the surgeon to overestimate the amount of correction that has been achieved. First, the knee joint is being opened medially, and in many deformities around the knee, lax ligaments are the rule. Second, there may be more correction at the osteotomy site than the fixation will maintain when the force is released. When the leg lies on the table without being held or after the cast is removed and the patient begins to walk, the problem becomes apparent. The best solution to this problem is to fix the osteotomy rigidly and then force the leg back into varus for visual inspection while the radiograph is taken. In this osteotomy, rigid fixation is avoided; however, if the surgeon is aware of this potential problem, it can usually be avoided.

After the position of the osteotomy has been verified and deemed acceptable, a long-leg cast is applied. If the knee is kept straight, it is easier to maintain and verify radiographically the position of the osteotomy. With the knee straight, however, it may not be possible to keep a small child from walking on the leg. After the cast is applied, the position can again be checked with a radiograph. If the correction is not as desired or if a problem with the circulation develops, the cast can be removed, the position of the osteotomy changed, and a new cast applied, all without loosing fixation of the osteotomy site.

A B C D

FIGURE 6-32. A: Anteroposterior radiographs of a 2-year, 6-month-old child with bilateral Blount's disease. **B:** Image obtained at the time of surgery showing the guide pin in place in the left leg. Although this is in the physeal plate, the osteotomy cut was made beneath the pin. Anteroposterior **(C)** and lateral **(D)** views of the left leg 3 months after surgery show the correction that was obtained.

POSTOPERATIVE CARE

The drain is removed the day after surgery. The patient is usually ready for discharge within 1 to 2 days after surgery. Weight bearing is not permitted. Healing is usually sufficient at 6 weeks to remove the cast or place the patient in a long-leg walking cast. After cast removal, physical therapy is begun to rehabilitate the knee, and progression to full weight bearing is made as rapidly as possible.

References

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2. MacEwen GD, Shands AR Jr. Oblique trochanteric osteotomy. J Bone Joint Surg [Am] 1967;49:345.

6.6 OSTEOTOMY OF THE DISTAL TIBIA: WILTSE TECHNIQUE

Osteotomy of the distal tibia is an operation that is used more frequently in children than adults (1). Its need commonly arises from growth disturbance after epiphyseal fracture or from congenital problems of the leg, such as ball-and-socket ankle joint (Figs. 6-33 to 6-39).

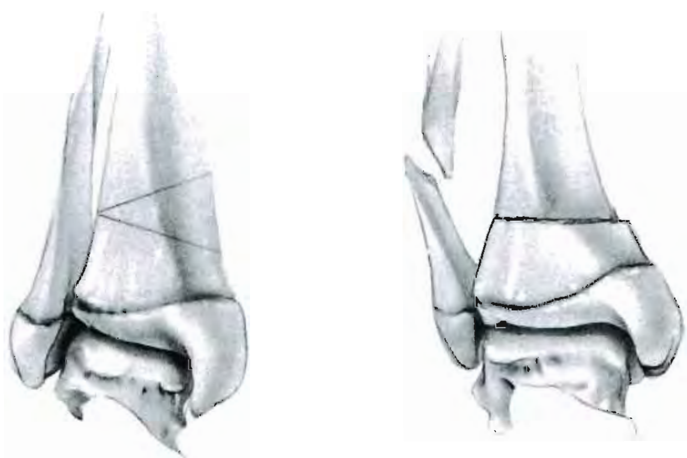

FIGURE 6-33. Wiltse (1) pointed out that if a simple closing wedge osteotomy is performed for a valgus deformity, malalignment with displacement of the ankle joint and a noticeable prominence of the medial malleolus will result and has described an osteotomy that avoids this problem. Although this problem can be true of any osteotomy, it is most obvious in the ankle and to a lesser extent in the distal humerus.

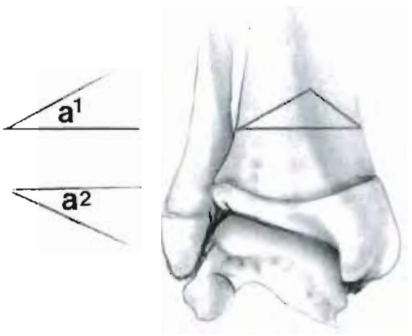

FIGURE 6-34. The calculation of the angles of the osteotomy do not need to be precise because considerable adjustment is possible in realigning the distal fragment; however, an approximation of the correct angles of the wedge will create a better fit, improved stability, and more rapid healing. The angle of the osteotomy at a^1 should equal the amount of angular deformity of the joint surface a^2. In addition, the greater the deformity, the further the apex of the osteotomy should be displaced laterally.

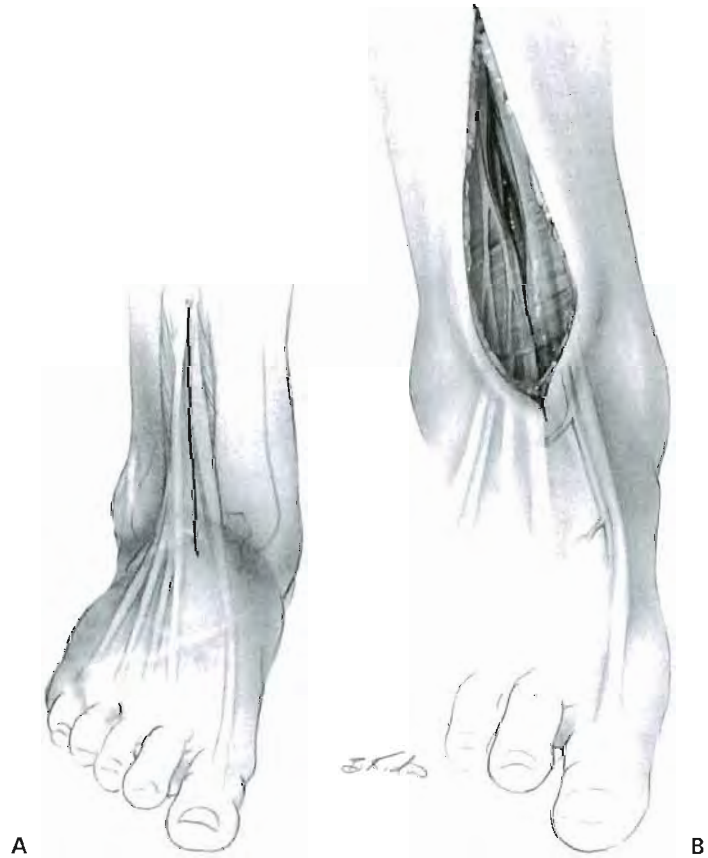

FIGURE 6-35. The approach for this osteotomy is similar to that for an arthrodesis of the ankle but with greater proximal extension. The incision is placed anteriorly between the extensor digitorum longus laterally and the extensor hallucis longus medially, where they come together just above the ankle joint. It should extend to the level of the ankle joint and far enough proximally to permit sufficient retraction to expose the entire anterior tibia **(A)**. The superficial peroneal nerve will have emerged from beneath the deep fascia and the retinaculum, and care should be taken not to injure it. When the fascia and retinaculum are split, the two tendons are identified and separated **(B)**. The neurovascular bundle lies lateral to the exposure in the proximal part of the wound; however, it lies anteriorly between the two tendons at the level of the ankle joint. Therefore, care should be taken to retract it medially with the tendon of the extensor hallucis longus. The periosteum is divided, and the entire circumference of the tibia is exposed subperiosteally.

FIGURE 6-36. The fibula is exposed through a small lateral incision and divided above the syndesmosis obliquely with a power saw.

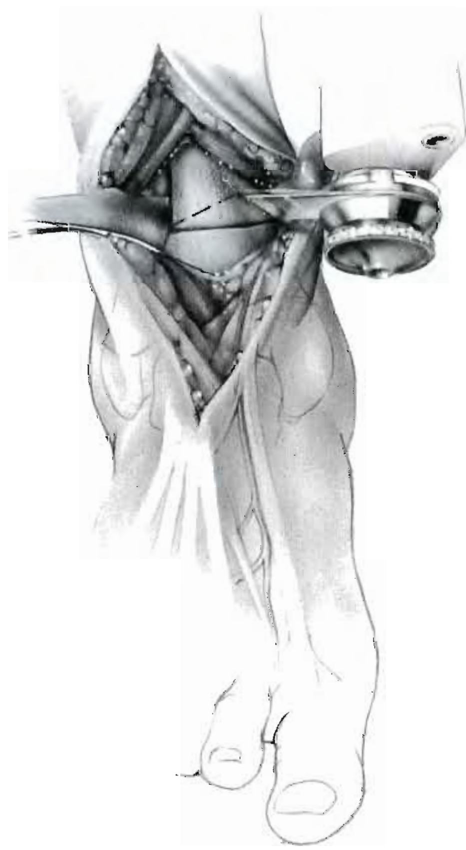

FIGURE 6-37. With retractors protecting the tissues, the transverse osteotomy cut is made first with a power saw. The appropriate triangle of bone is then removed more easily, again using a power saw with a smaller blade.

FIGURE 6-38. The distal fragment is rotated and displaced so that its medial side comes to lie against the medial face of the triangular cut. It is important to verify that the desired correction has been obtained. This can usually be done clinically but is best confirmed with a radiograph, which shows the tibial shaft as well as the ankle joint. If further adjustment is necessary, either for more correction or for better coaptation of the fragments, this can be achieved by removing bone with a rongeur. Stabilization of the osteotomy is achieved with a single Steinmann pin drilled from either the medial or lateral direction, as works best. It should engage the opposite cortex.

The wound is closed over a drain, and a short-leg cast is applied.

A

C

B

FIGURE 6-39. A: The standing mortise view of a 12-year-old boy with multiple epiphyseal dysplasia and residual club feet. He is limited in his walking by ankle pain. **B:** The osteotomy on the right leg was held in place by a single Steinmann pin, which is the usual method of fixation. On the left leg, a staple was used anteriorly as the only fixation. **C:** Six weeks later, the Steinmann pin was removed in the office, and the patient was placed in bilateral walking casts for an additional 4 weeks. The configuration of the osteotomies and the correction achieved is demonstrated on standing radiograph at that time.

POSTOPERATIVE CARE

The drain can usually be removed the day after surgery, and the patient is started on a three-point non–weight-bearing crutch gait. Healing is usually complete in 6 weeks, at which time the cast and pin are removed in the office, and the patient is instructed to progress to full weight bearing.

Reference

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6.7 FRAGMENTATION, REALIGNMENT, AND INTRAMEDULLARY FIXATION FOR TIBIAL DEFORMITY IN OSTEOGENESIS IMPERFECTA (SOFIELD PROCEDURE)

In 1959, Sofield and Millar (1) reported their 10-year experience using fragmentation, realignment, and intramedullary rod fixation in 52 children with osteogenesis imperfecta, congenital pseudarthrosis of the tibia, rachitic deformities, and fibrous dysplasia. They used Steinmann pins, Rush rods, and Kuntscher rods depending on the size of the bone. In 1965, Williams (2) reported on his experience using two heavy Steinmann pins that were threaded in the center. These rods and the technique for their use are described in the section on treatment of congenital pseudarthrosis of the tibia (see Procedure 6.11). Bailey and Dubow (3) developed a telescoping rod with a T piece at each end to hold the rods at the ends of the bone so that it would elongate as the bone grew. There is a fixed T piece at one end of the solid central rod and a second T piece that screws onto the end of the hollow rod. Use of these rods was reported by other investigators (4,5).

The surgeon decides whether to use an extendable rod or a solid rod of fixed length. The solid rod has the advantage of greater strength and easier insertion with fewer complications, but it has to be replaced every 2 to 4 years depending on growth. The extendable rod is designed to elongate with the growth of the bone. Its insertion, however, requires an arthrotomy of the knee and ankle joints. The T piece can come loose, requiring subsequent arthrotomy for repair. At times, these rods become locked and do not elongate, and they are more likely to bend in the bone (6). There is evidence in the literature for either choice, and the surgeon's familiarity with one technique probably is the deciding factor (7,8).

We prefer to use Rush rods. They are inserted easily, they are relatively inexpensive, and multiple rods of all sizes can easily be stocked. The length is adjusted by cutting the end of the rod. When the rod becomes too short, the rod can be replaced through a small incision on an outpatient basis. The Williams rods are best when it is necessary to leave the rod in the foot for fixation, but the difficulty in replacing them for growth makes the Rush rods our rod of choice in all other circumstances.

The surgeon should remember that the tibia is smaller than the femur. Before beginning the operation, be sure that there is sufficient bone or a medullary cavity to accept the rod of choice. Because of this, it is often necessary to straighten the tibia first with less than ideal fixation and then later, when it is bigger, to use an intramedullary rod. One of the techniques to accomplish this is to perform a percutaneous drilling of the bone followed by manual osteoclasis with correction by casting alone. Also, in some children with small, fragile bones and frequent fracture, intramedullary fixation with a smaller diameter than a Rush or Bailey-Dubow rod, such as a Steinmann pin, may be beneficial in conjunction with appropriate bracing (Figs. 6-40 to 6-46).

FIGURE 6-40. A tourniquet is used. This makes correction of both tibias at the same operation possible without the need for blood transfusions. In addition, it is possible to correct the femurs first and then to apply tourniquets before operating on the tibias. This makes it possible to correct both tibias and femurs at the same operation, which is a great advantage to the patient. The tibia is approached over its anterolateral border, extending along the medial or lateral parapatellar border, as the surgeon desires. As in the femur, it cannot be emphasized enough that the entire bone from physis to physis needs to be exposed. The most common error in the severe deformities is to attempt too few osteotomies and not have the rod central in the bone. To do less does not allow correction of the deformity, which is almost always present in the metaphysis and makes central insertion of the rod impossible. The fibula is often accessible through the same incision because of the deformity. It is usually necessary to remove a small portion from the fibula at the apex of the bow to allow it to straighten and shorten without becoming prominent after the tibia is corrected.

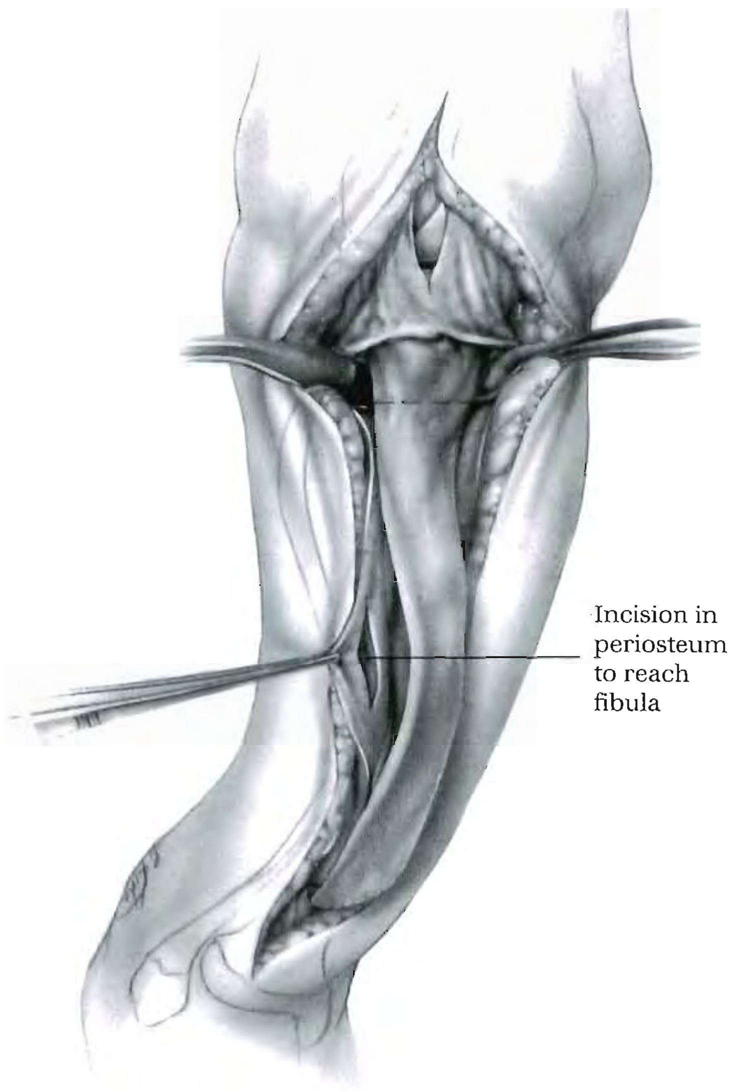


FIGURE 6-41. After exposure of the periosteum, it is incised, and the entire bone is exposed subperiosteally. At this point, the apex of the fibula can usually be reached by making a small incision through the periosteum. Using a rongeur, a portion can be removed. At the same time, the knee joint is opened to allow access to the starting point anterior to the cruciate ligaments. Using a power saw (not an osteotome, which will tend to fragment the bone), the entire diaphysis and as much of the metaphysis as necessary is removed.

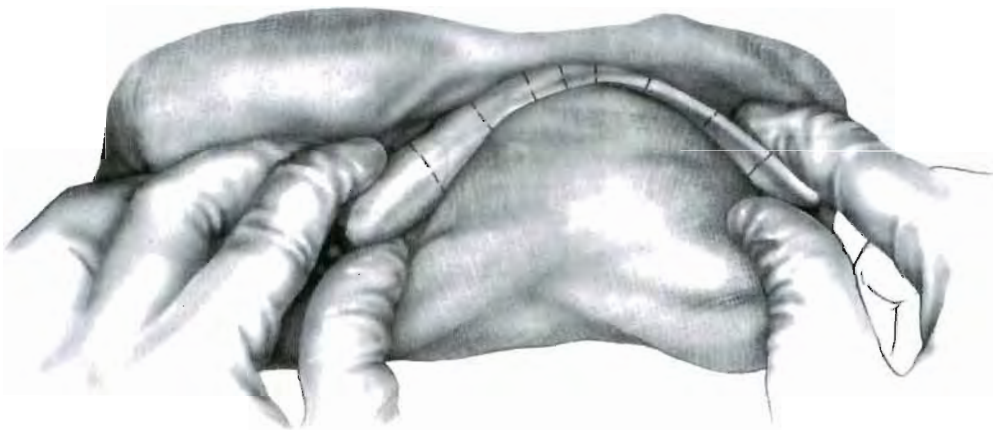
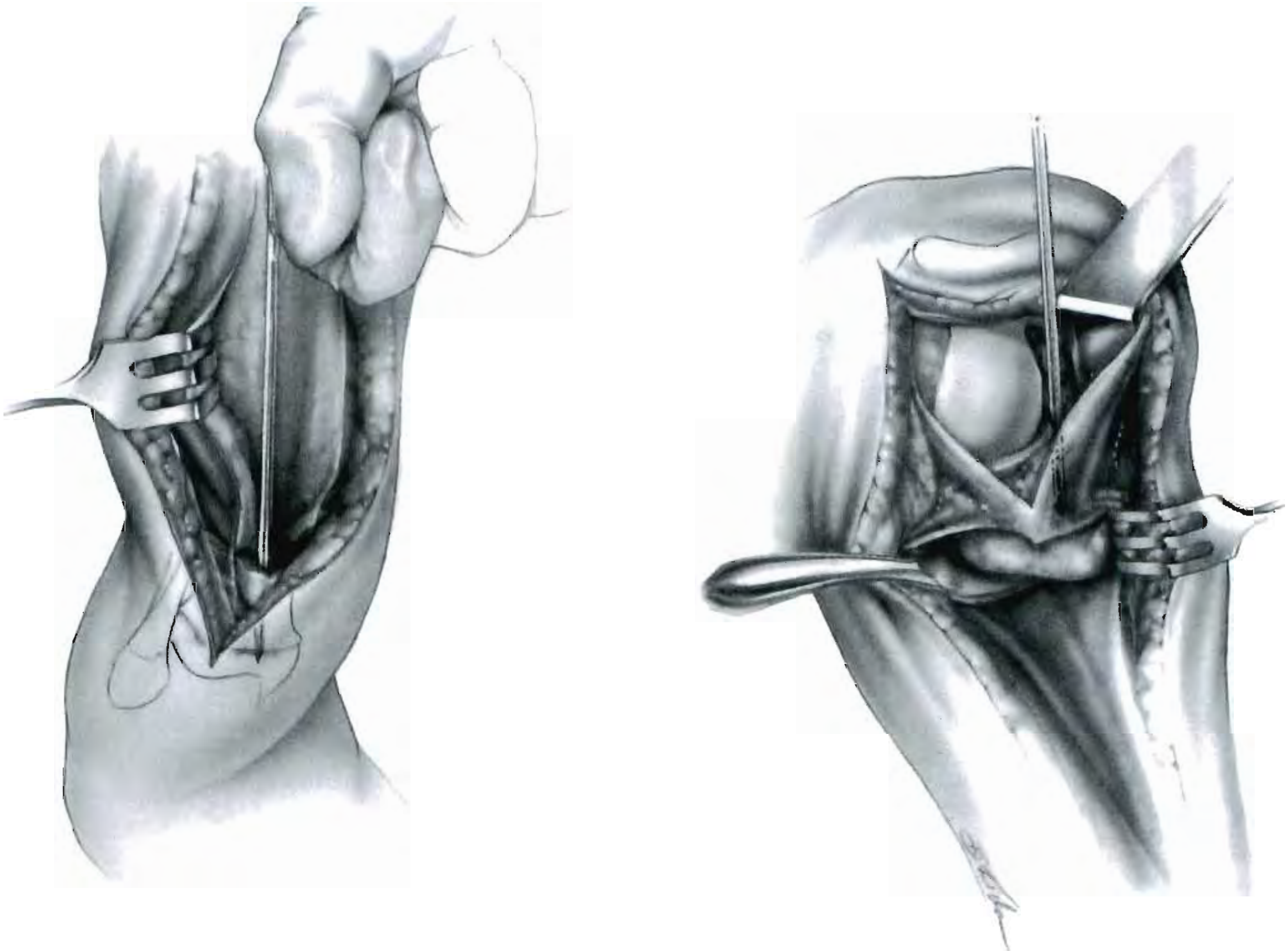


FIGURE 6-42. The bone is taken to a prepared spot on the back table, where it is prepared. Two steps must be taken. First, the bone should be divided into as many pieces as necessary so that it can be realigned. The number of pieces, however, should be kept to the minimum necessary because each of these osteotomies will have to heal. This is often delayed, as can be seen on the radiographs and by the patient's complaints of persistent aching and tender areas. The bone should be cut with the power saw and must be held firmly but not crushed. Sometimes, holding it by hand is the only option.

Second, each piece of bone should have a central canal large enough to accommodate the selected rod. In some cases, the canal is larger than the rod, and nothing needs to be done. It is usually futile to attempt to redirect the canal into a more central location; the surgeon has to accept its location. In other cases, the bone is hard, with almost no central canal. Start with a small drill and progress to a size just slightly larger than the rod.



A B

FIGURE 6-43. Using a drill, awl, or other device, prepare the track in the distal fragment, where the rod will go. This track should pass through the physeal plate because it will be the only strong bone in the distal fragment for fixation. Its location should be verified in both planes with the image intensifier **(A)**.

The proximal track can be made directly from within the knee joint. With the knee acutely flexed, a central point anterior to the cruciate ligaments is penetrated with the awl. The awl or drill is then advanced until visible at the proximal osteotomy site **(B)**.

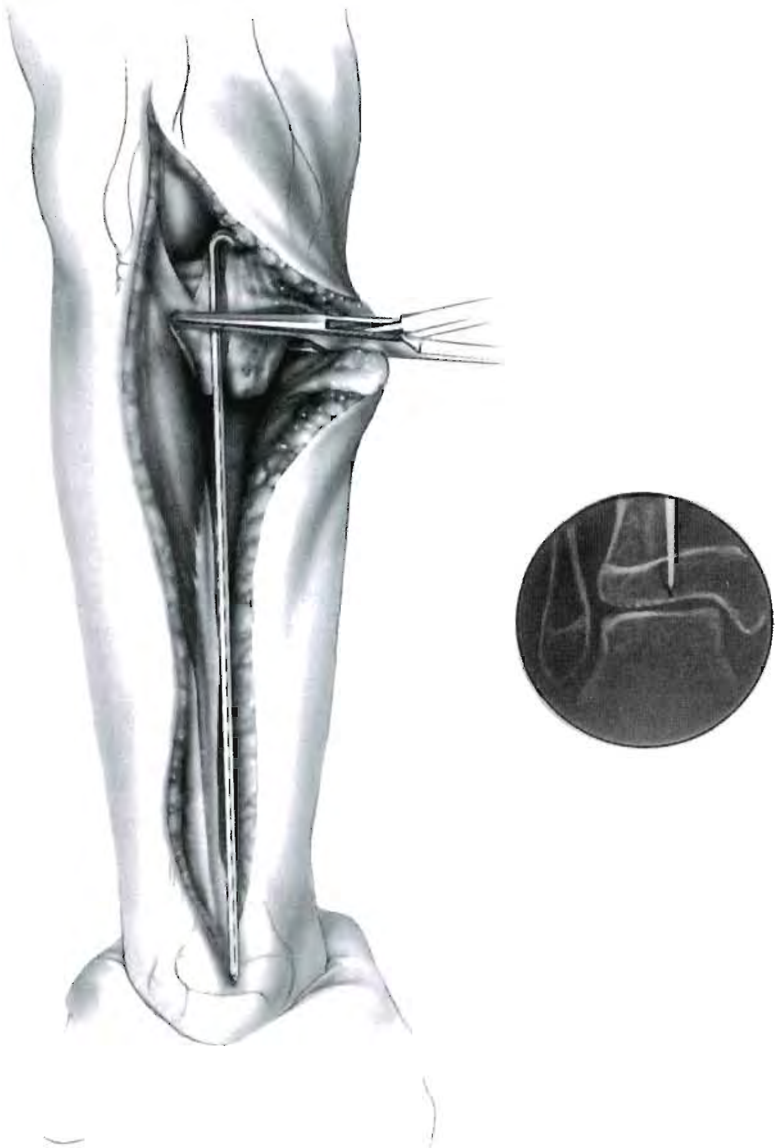


FIGURE 6-44. The length of the rod is determined. It must not be too long and overstretch the vital structures of the leg, but it also must not allow undue shortening. To do so will render the muscles of the foot, particularly the gastrocnemius muscle, ineffective and will not keep sufficient tension on the segments of the tibia to hold them in apposition.

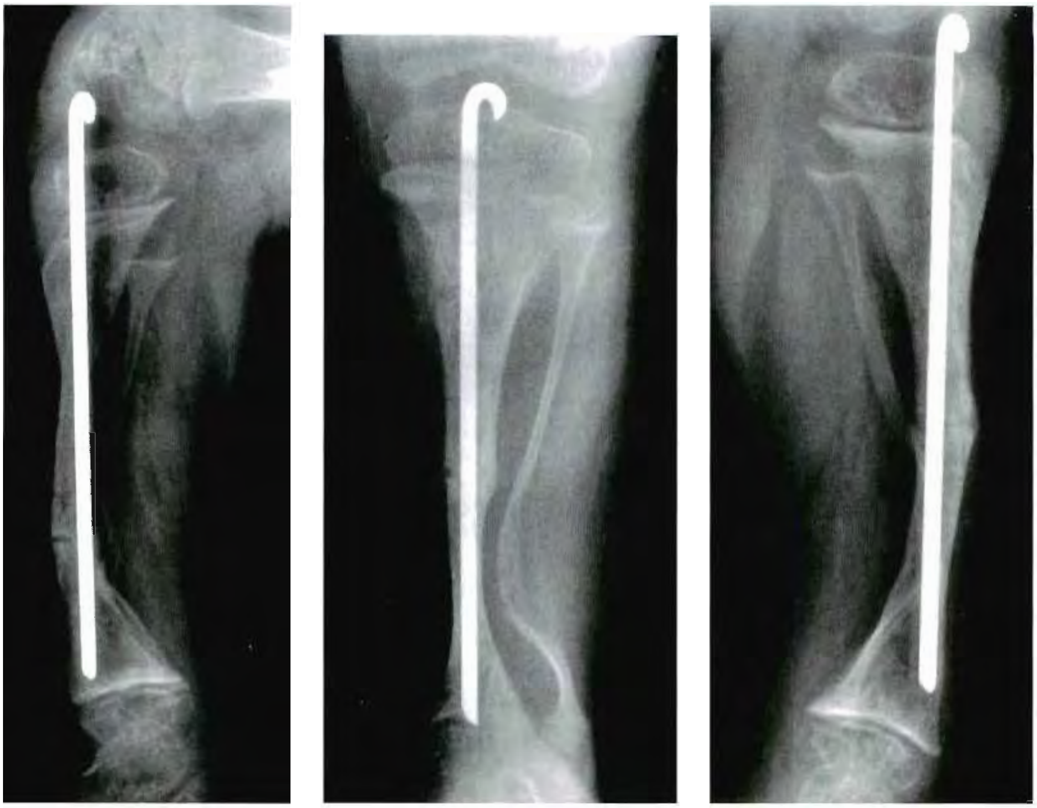
Pulling on the foot and with the image intensifier in position, the size of the rod can be determined by trying various lengths and checking their position on the image intensifier.

◀ **FIGURE 6-45.** The rod then is inserted proximally through the knee, and the various fragments that have been cut are threaded on the rod as it is advanced. They should be placed to give the best contact between the fragments. Also, remember that some of the bone must be discarded or the bone will be overlengthened in relation to the soft tissues. When the fragments are fitted, the rod is advanced into the distal fragment, and its position is checked on the image intensifier. This is the most difficult part of the operation because, if the rod is not correctly placed, residual angulation will remain. We believe that this is the main advantage of the Bailey-Dubow or Williams rod: it ensures that the surgeon places the rod in the correct location because it must penetrate the joint for the distal piece to be inserted.

The periosteum is closed with a running absorbable suture. A drain is placed along the tibia before the crural fascia and skin are closed. A light fiberglass cast is applied with the knee bent to control rotation.

A B C D

E, F



G

FIGURE 6-46. Anteroposterior **(A)** and lateral **(B)** radiographs of a 5-year-old boy with osteogenesis imperfecta who has never walked. Close inspection of these tibias show that it would be difficult to insert a rod or Steinmann pin of any strength because of the narrow medullary canal. Therefore, at the first operation, the patient underwent multiple fragmentation osteotomies of both femurs and closed osteoclasis of both tibias **(C)**. After healing, he was placed in long-leg braces and began standing. Eighteen months later, the growth of the tibias was sufficient to accept a ⅛-inch Rush rod, and the patient underwent bilateral fragmentation osteotomies of the tibias as well as replacement of the femoral rods to accommodate growth. One year after that procedure, healing of the osteotomies had occurred. Anteroposterior **(D, F)** and lateral **(E, G)** views are shown. Note the growth that has taken place: all of the rods penetrated the physis at the original surgery 1 year earlier. In addition, note that at the midportion of each tibia, a small lucent line remains in the bone. These areas occasionally remain tender or even a source of pain and such symptoms probably indicate pseudarthrosis in these areas.

POSTOPERATIVE CARE

The cast can usually be removed in 4 to 6 weeks to allow fabrication and fitting of the braces. After some callus is seen around the osteotomy sites, the bone is usually stable enough. The braces, however, should be preplanned and can usually be fabricated and fitted within 48 hours. Depending on the patients' condition and the goals of the surgery (walking or simply pain relief from recurrent fractures), the patients may stand in the cast and braces. We believe that this results in better healing of the osteotomy sites, but patient selection may be a greater factor.

After healing is complete, it is important to follow the patient closely with radiographs to determine when the rod needs to be replaced. If this is done before the rod become so short that it allows recurrent deformity, then it is easily replaced as an outpatient procedure. Recurrence of a distal deformity may necessitate a single distal osteotomy, realignment, and the reinsertion of a longer rod.

References

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6. Williams PF, Cole WHJ, Bailey RW, et al. Current aspects of the surgical treatment of osteogenesis imperfecta. Clin Orthop 1973;96:288.
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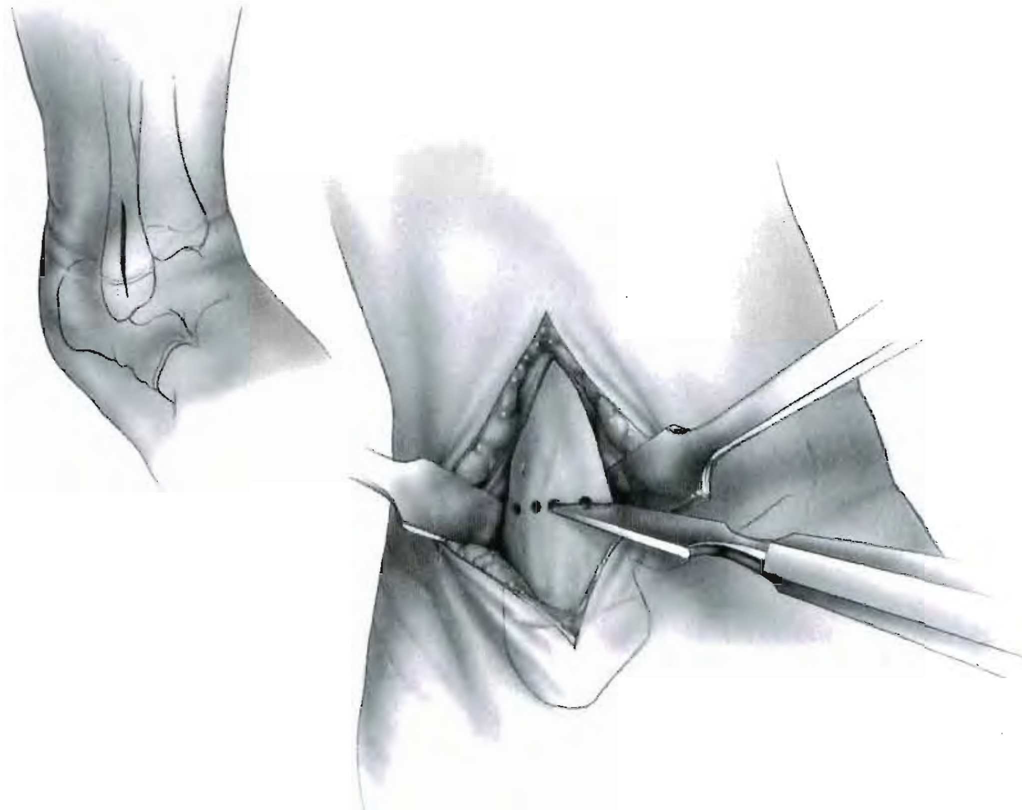
6.8 SUPRAMALLEOLAR ROTATION OSTEOTOMY OF THE DISTAL TIBIA AND FIBULA

The need to correct rotational deformity in the leg is not common. The most common indications are in children with myelodysplasia and severe external or internal rotational malalignment interfering with ambulation, for residual internal rotation after clubfoot correction, and in those few children with significant and persistent tibial rotation. Frequently, there is debate about whether to place this osteotomy distally or proximally. Although the decision is usually made by the preference of the surgeon, there are some factors to consider. With the distal osteotomy, the operation is less, and the fixation is less. Proponents of the proximal osteotomy cite better fixation and healing. The two main problems of the distal osteotomy are that healing can be slow and, despite reports of not needing fixation, matching the rotation on both legs precisely and holding it reliably are not done easily.

If the osteotomy is performed distally, the main consideration is actually to be distal, that is, distal enough to be into the metaphyseal bone just proximal to the physis. If necessary, use an image intensifier to identify the correct location. Although it is suggested that this may be done percutaneously without fixation (1), it is not difficult to use crossed pins, as suggested by Banks and Evans (2). It is also possible to use a plate, but this most likely will require removal at a second operation. Although we have tried the percutaneous technique without fixation, we prefer to use a small incision, elevating and preserving the periosteum, as well as fixation.

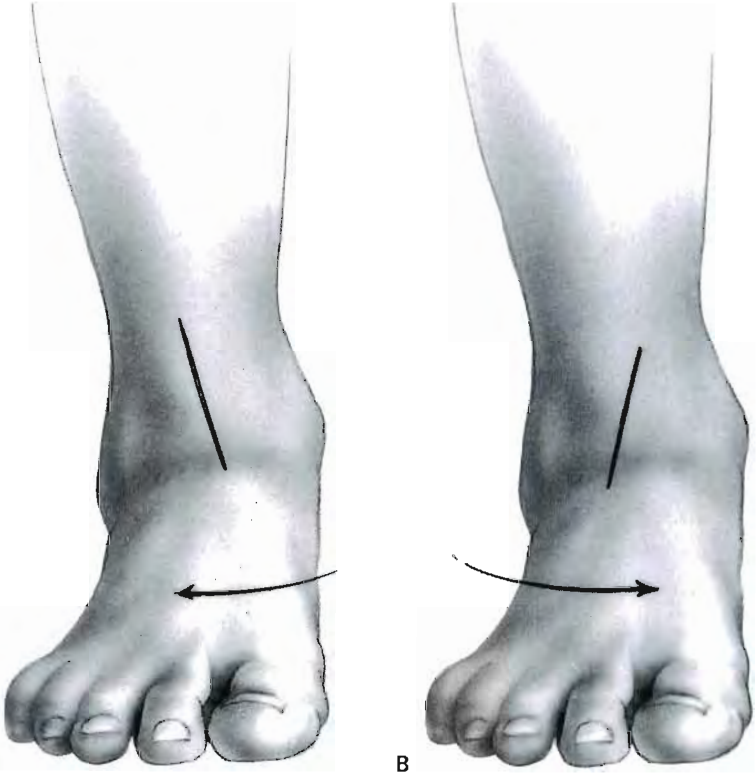
The operation is performed under tourniquet. If only one leg is to be done, a sandbag under the hip of the operated side makes the fibular osteotomy easier. Because visual alignment of the foot with the thigh is important, it is best to have both the leg and thigh in the operative field. In this way, the knee can be bent to 90 degrees and the tibia rotated to the desired position. Both legs can also be compared. It is probably not necessary to osteotomize the fibula if 20 degrees or less of rotation is planned (Figs. 6-47 to 6-51).



A

B

FIGURE 6-47. The fibula may be divided first. A 3-cm incision directly over the subcutaneous border of the fibula just above the flare will allow direct access to the bone **(A)**. After placing a few small drill holes, an osteotome is used to complete the osteotomy. This should be transverse **(B)**. The surgeon can also use a power saw with a small blade. Copious irrigation should be used to avoid heat damage to the bone that may delay healing. Care should be taken to stay beneath the periosteum because there is a small vein close to the medial surface of the fibula in this location that, if cut, will cause considerable bleeding. The wound can be closed before starting the tibial osteotomy.



A B

FIGURE 6-48. The incision for the tibial osteotomy is made just lateral to the anterior border of the tibia. It needs to be about 4-cm long and should extend from just above the crease of the ankle proximally. If there is to be considerable rotational correction, the incision can be oblique so that after the rotation, it will be straight. This will avoid any tension on the skin. If the rotation is to be external **(A)**, the incision will angle from the proximal-lateral side to the distal-medial side. The opposite is true if the rotation is to be internal **(B)**.

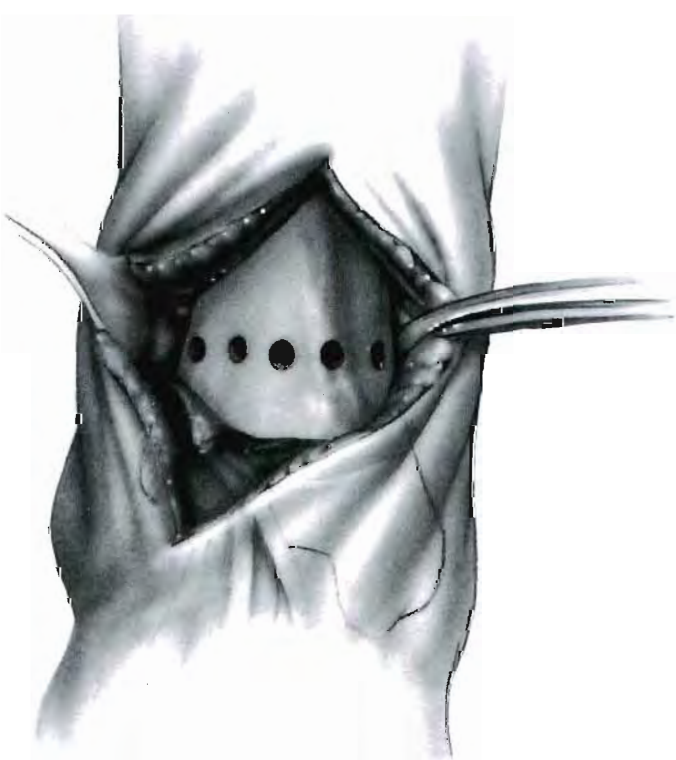


FIGURE 6-49. The most simple approach for this operation, which requires limited exposure of the tibia, is medially to the anterior tibial tendon and all of the other structures on the front of the ankle. After this medial subcutaneous border of the tibia is exposed, the physis should be identified, either by feeling for the soft cartilage with a Keith needle or by viewing with the image intensifier. The incision in the periosteum should extend down to the physis. It is further opened with two transverse cuts just above the physis. The Crego periosteal elevators are ideal to elevate the periosteum. With one Crego elevator around the tibia and a small Chandler retractor opposite, excellent exposure is obtained. Multiple drill holes are placed through the cortex 1 cm above the physis.

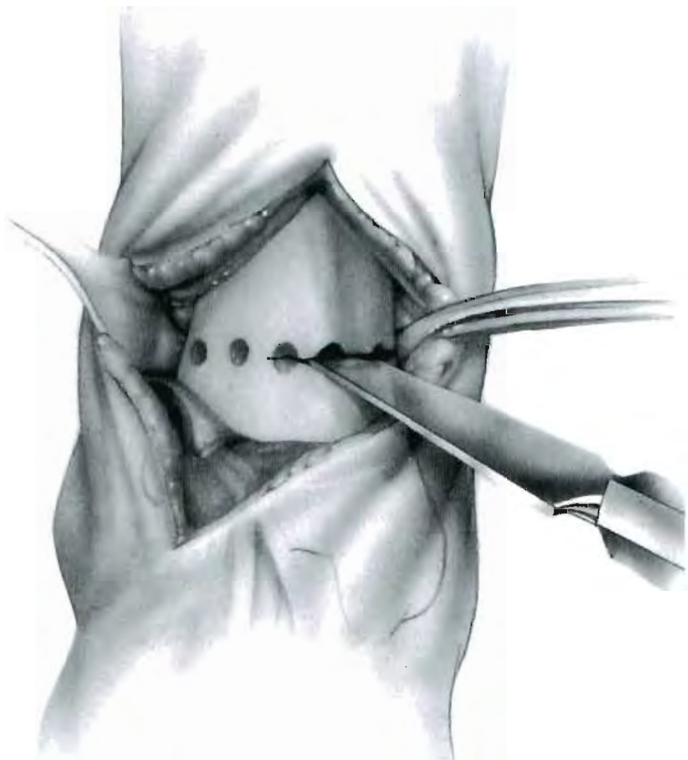


FIGURE 6-50. Multiple drill holes are made transversely and connected with a sharp osteotome. To facilitate this part of the operation, care should be taken to drill adequately the posterior, lateral, and medial cortex. If this is not done, there may be a tendency for the bone to break, leaving a spike that could interfere with rotation and apposition. If rotation is to be simple and not produce an angular deformity, the osteotomy must be transverse and not oblique.

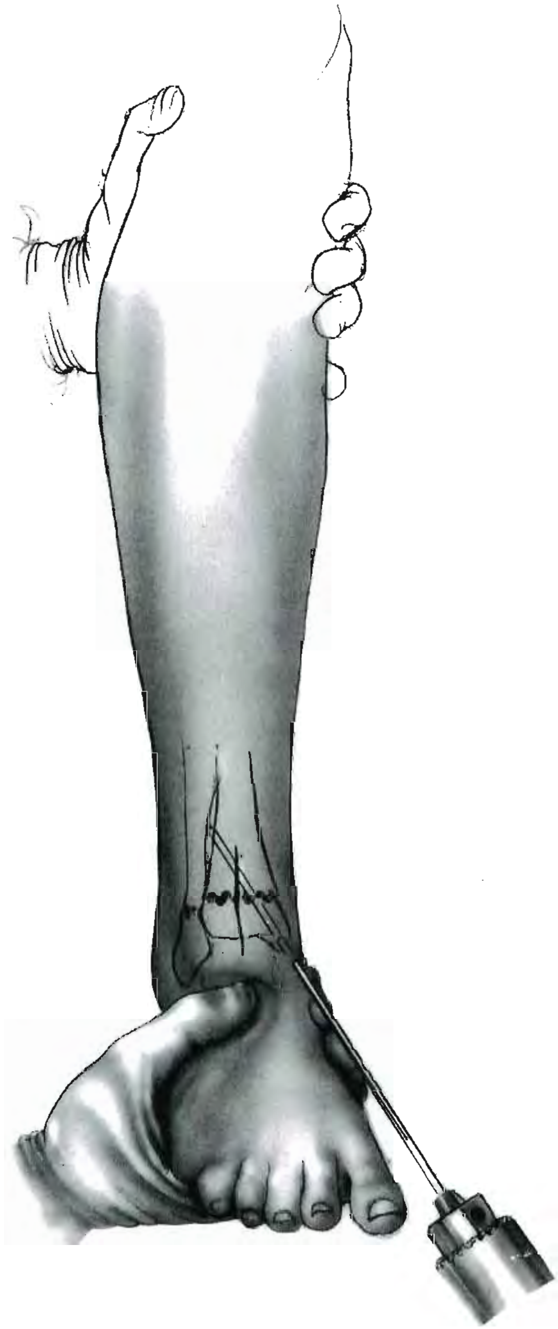


FIGURE 6-51. The knee is bent to 90 degrees, and the tibia is rotated to the desired correction. At this point, a smooth Steinmann pin is inserted from the medial malleolus across the osteotomy site and through the lateral cortex of the tibia. If desired, a second pin can be placed from the lateral side, but in our experience, this pin, along with a long-leg cast with the knee at 90 degrees, is sufficient. The pin should be left protruding through the skin to facilitate removal.

POSTOPERATIVE CARE

The patient is placed in a long-leg cast with the knee bent 90 degrees. The pin should be well padded so that it does not move with the cast and cause wound problems. When healing is verified radiographically, usually at 6 weeks, the cast is removed. The pin can simply be pulled out with a pliers. Although this may cause the child some anxiety, it is not painful. Ambulation is resumed as quickly as possible.

References

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6.9 ILIZAROV LENGTHENING OF THE TIBIA

The Ilizarov method and apparatus for limb lengthening have been widely used by Professor Ilizarov, in Russia, since the 1950s and have been used by some surgeons in Italy since the late 1980s. Experience in the United States, although brief, is more widespread. For this reason, there are few published series of a significant number of patients from a North American center (1).

The Ilizarov device differs from the Wagner and monolateral devices (e.g., the Orthofix device) in that it consists of rings rather than a unilateral frame, and it is connected to the bone by small, smooth wires (1.5 and 1.8 mm) that are joined to the rings under tension as opposed to heavier threaded pins that engage both cortices but do not pass through the limb. In mechanical testing, the Ilizarov device is the least rigid, allowing more axial motion and shear at the osteotomy gap than the other devices (2). This is believed by its proponents to promote better bone formation by avoidance of stress shielding.

It is apparent that this lack of rigidity does not sacrifice anything in terms of control of the bone fragments. In fact, because of the multiple planes of fixation in both the horizontal and vertical axis, the ability to control the fragments may be better than with other fixators. The wide latitude permitted the surgeon in the construction of the frame also allows for correction of angular and rotational deformities to a greater extent than is possible with any other device.

The trade-off for these advantages is a significant learning curve. The surgeon requires a thorough knowledge of the cross-sectional anatomy because of the insertion of multiple transfixing wires through the limb and the fact that these wires will be pulled through the soft tissues during the lengthening. The correction of rotational and angular deformities requires a level of preoperative planning not required by most other surgical procedures. Finally, it is apparent that the apparatus does not eliminate the myriad problems encountered in any attempt at lengthening a limb (3).

The wide and varied application of the Ilizarov device to clinical problems makes it impossible within the scope of this atlas to do more than illustrate a typical case to acquaint the surgeon with its use and general principles (Figs. 6-52 to 6-61).

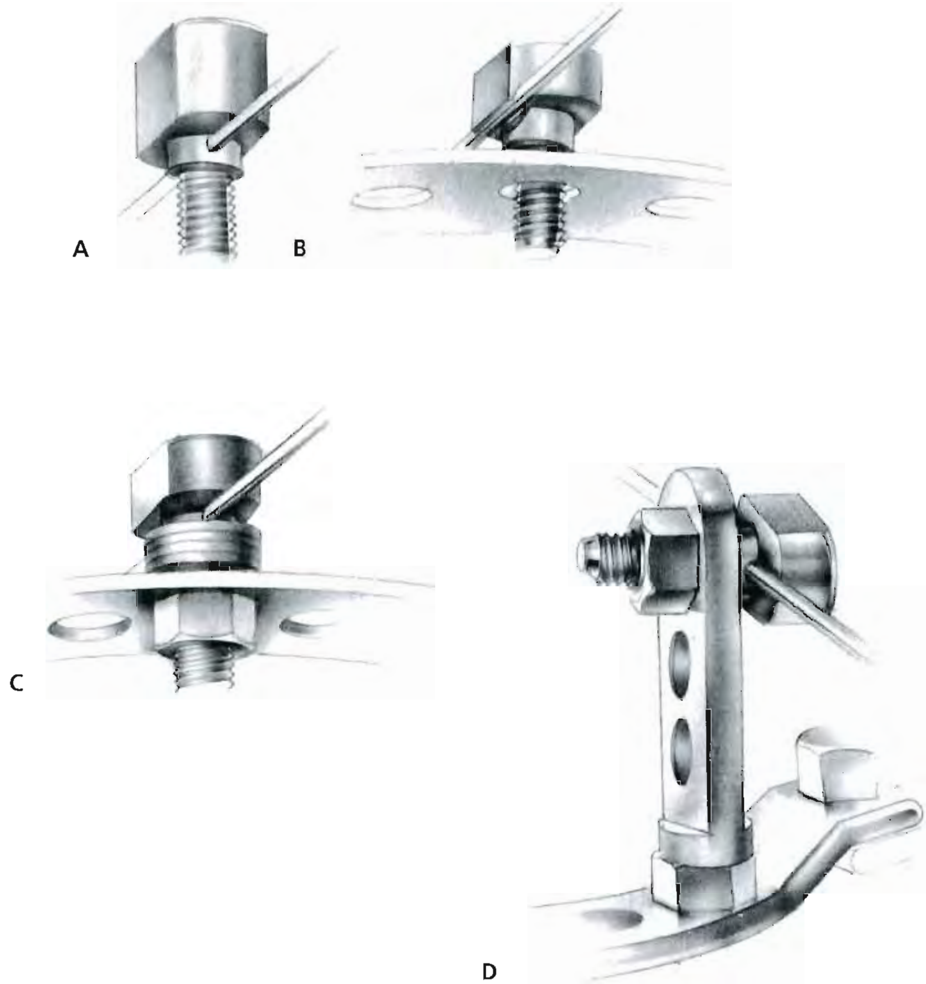
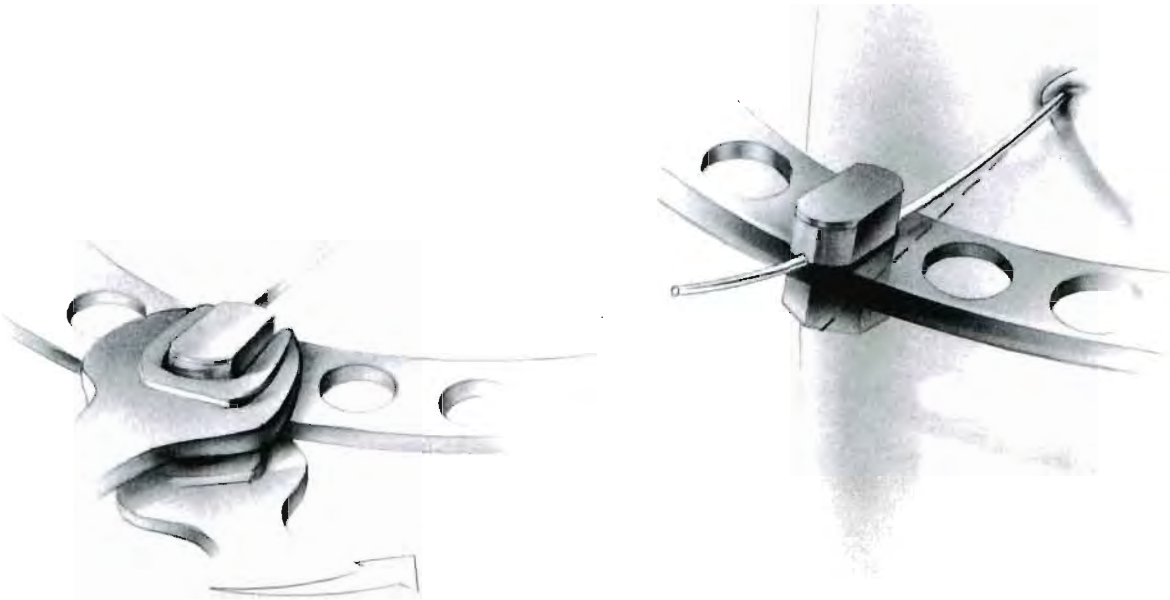


FIGURE 6-52. Two sizes of wire may be used, depending on the size of the patient. The 1.8-mm wires are used in the lower extremity. Wires are also available with an "olive" on the wire. These are used to resist anticipated lateral forces on the bone during the lengthening.

The wires are attached to the rings in a variety of ways. To avoid pressure on the skin and bone, the wires must not be bent to reach the ring; rather, adjustments must be made in their method of attachment to the ring so that they are left completely straight. There are different connectors that permit this adjustment in either the horizontal or vertical plane. If the wire passes directly over the hole, a cannulated bolt is used **(A)**. If the wire is passed to the side of the hole, a slotted bolt is used **(B)**. If the wire is above or below the ring, the appropriate bolt is raised above or below the ring with washers **(C)**, or a post can be used **(D)**. This latter technique is used most often to place a single wire through the bone in a plane different from the ring and is called a *dropped wire.* It is used in small children in place of a second ring.



A

B

FIGURE 6-53. The wire is first tightened on one side. The bolt holding the wire should be held with a wrench to prevent it from rotating and bending the wire **(A)**. If this is not done, the bolt will twist the wire and cause it to deviate from its proper position **(B)**.

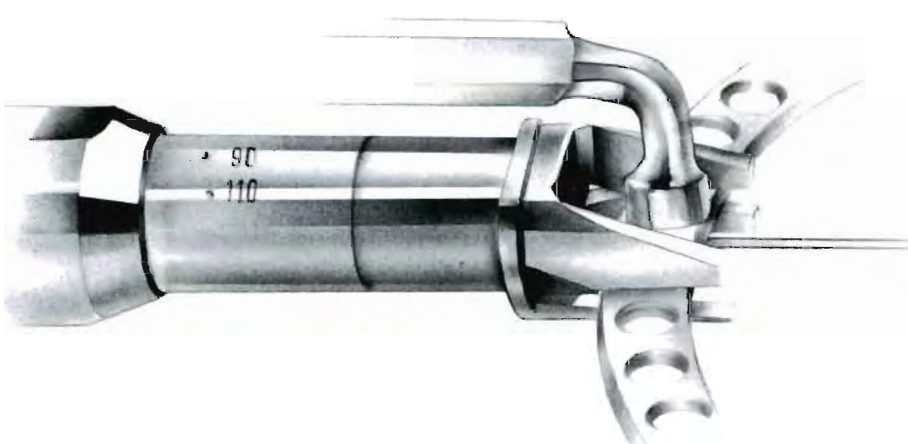


FIGURE 6-54. The wires are tightened with a tensioning device to about 100 to 130 kg of force by observing the markings on the device and then are held by tightening the remaining nut. After each wire is tightened, it should be cut, allowing a sufficient length of wire to remain in case there is need to retighten the wire. The remaining wire is bent over the nut.

FIGURE 6-55. As much of the apparatus as possible should be assembled before surgery. In the tibia, the entire apparatus can usually be assembled. The most proximal and distal rings should lie just distal and proximal to the physeal plates, respectively.

The rings are constructed from half rings, which are bolted together. The connections are offset to maintain both halves of the ring in the same plane. The diameter of the completed rings should allow about two finger breadths between the ring and the skin. Five-eighths rings are also available and can be used around the knee to permit more flexion.

Each segment of bone will be fixed to two rings that are rigidly linked by connectors. Initially, only two connectors are used to connect these rings, to avoid interference with wire placement. After all of the wires are placed, however, additional connectors are added to provide rigidity. The rings that will be closest to the osteotomy should be close together to allow the osteotomy to be done in the metaphysis. In the other segment removed from the osteotomy, the second ring can be further from the first ring for enhanced stability. In joining two rings together, it is best first to position the rings with their joints exactly anterior and posterior. The two connectors are then placed on the medial side of these joints, leaving more of the lateral side of the ring free for attachment points for the wires.

These ring assemblies, one proximal and one distal, are connected with two threaded rods or lengtheners of the correct length. These connectors are placed just lateral to the point where two half rings join to form a complete ring. These connectors will be removed to complete the osteotomy, and the rings will be joined, making four connectors.

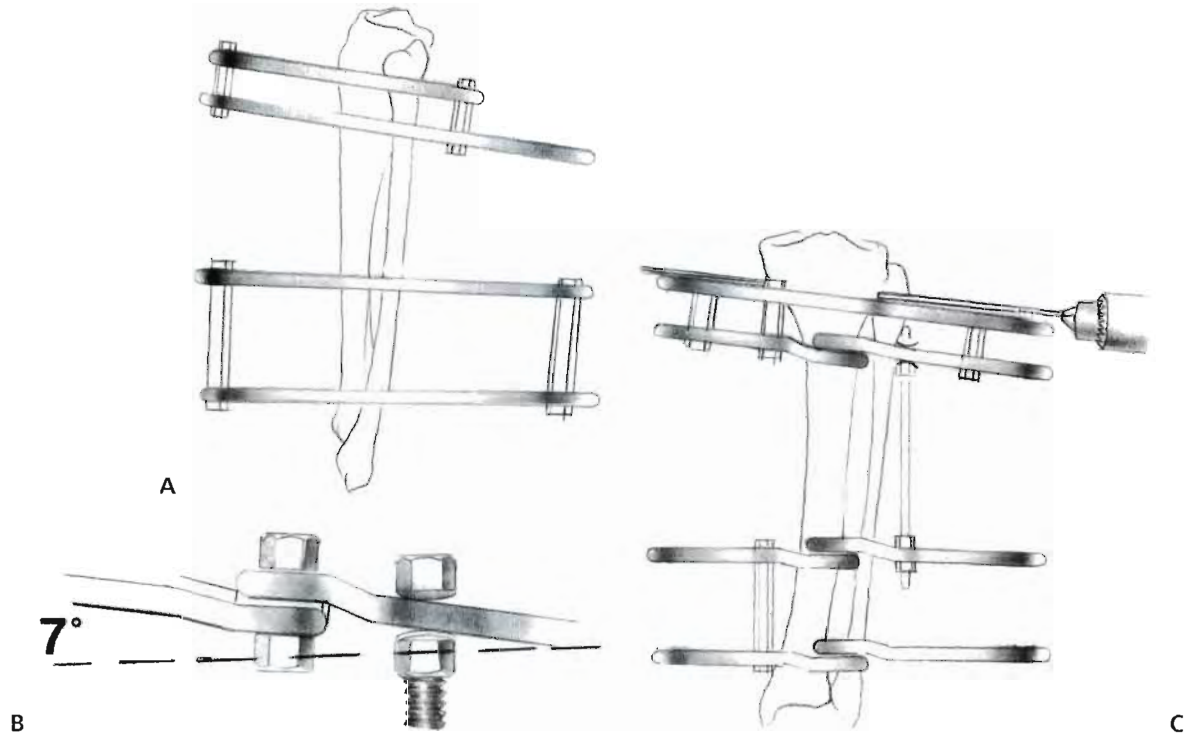


FIGURE 6-56. If anterior and valgus angulation is anticipated, the proximal and distal rings will not be assembled parallel to each other. Rather, the proximal set of rings will be fixed to the tibia with about five degrees of posterior angulation **(A)**. This degree of adjustability in the initial frame is achieved by placing a conical washer on the rods, connecting the two sets of rings with the convex side facing the ring **(B)**. This will allow 7 degrees of motion in either direction. After the osteotomy is completed, the proximal and distal sets of rings will be joined together in parallel, creating about 5 degrees of recurvatum, which will straighten during lengthening. Varus can be built in by directing the fixation wires at a slight angle to the epiphysis **(C)**. Again, when the rings are finally joined parallel to each other, a small amount of varus will be built in, which will correct during lengthening. Many surgeons do not believe that this step is necessary in most tibial lengthenings, and the subsequent description does not include this feature.

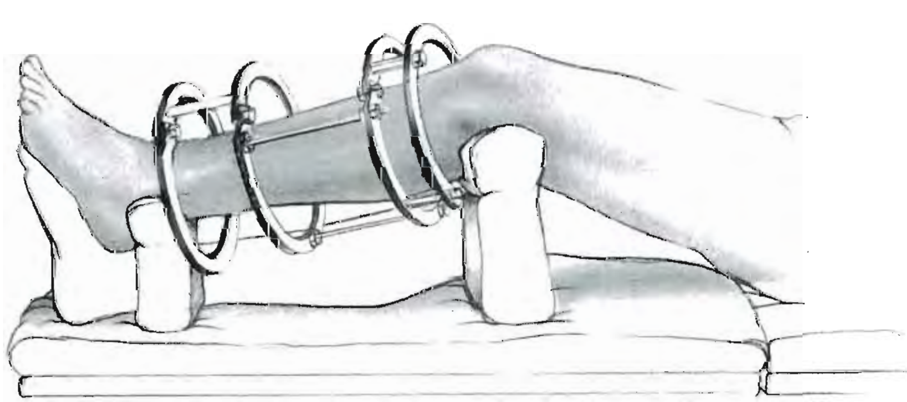
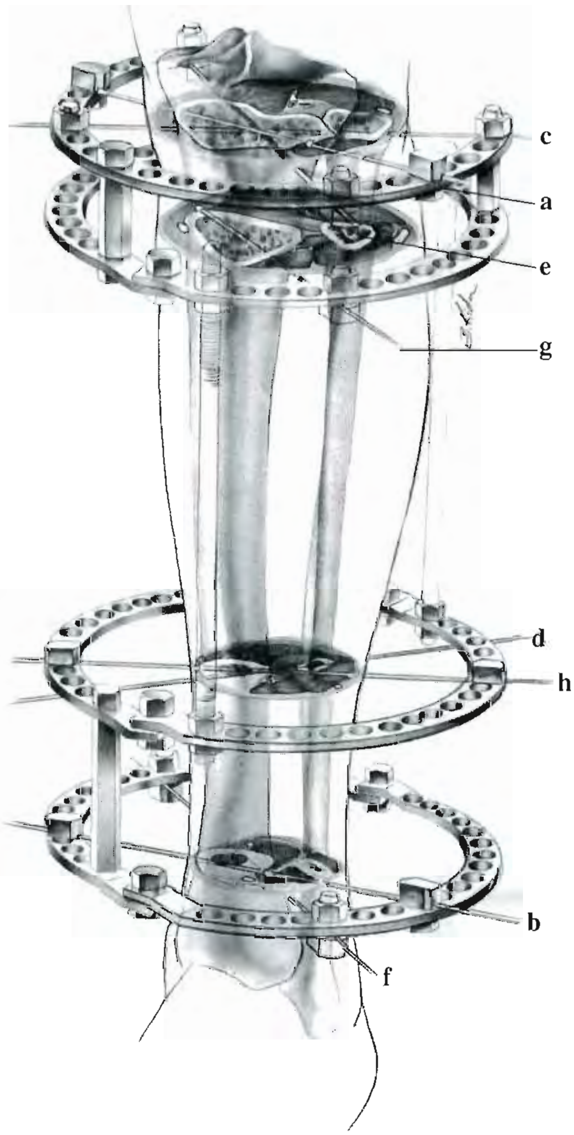


FIGURE 6-57. The patient is placed supine on the operating table with the limb draped free. A tourniquet is usually not necessary but can be used. The surgery is greatly facilitated by having the limb supported free. The preconstructed frame is placed on the leg.


c
a
e
g
d
h
b
f

◀ **FIGURE 6-58.** The first wires placed are transverse. They attach to the most proximal and most distal ring. They should be placed as close to the epiphyseal plate as possible.

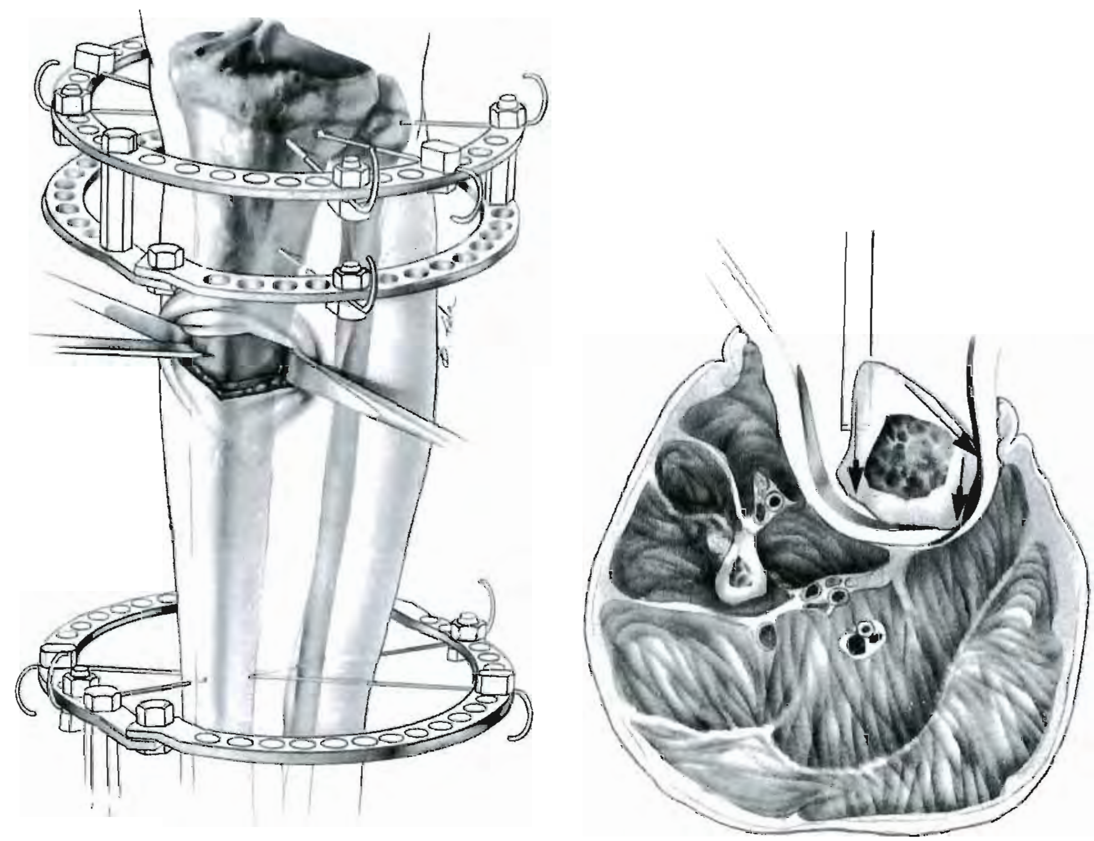
First, the most proximal transverse wire is placed laterally to medially **(a)**. This wire should be an olive wire. This wire is parallel to the knee joint or proximal physis. Next, the most distal wire is placed just proximally to the distal physis in the same transverse plane **(b)**. This should be an olive wire passing laterally to medially. It is possible, at this point, to secure the frame to the leg by these two wires. Care should be taken to allow sufficient room, about two finger breadths, for the soft tissues. The connecting bar should lie directly over the anterior surface of the tibia, and it should be parallel to the anterior border of the tibia.

The next two wires are the fibular wires. These are not olive wires. They are passed laterally to medially. Proximally, the wire should pass through the fibular head, where the peroneal nerve is known to be posterior **(c)**. It should aim anteriorly and medially almost perpendicular to the medial face of the tibia. Distally, the fibular wire attaches to the more proximal of the two rings to avoid pinning the syndesmosis. The direction of this wire is the same as that of the proximal fibular wire **(d)**.

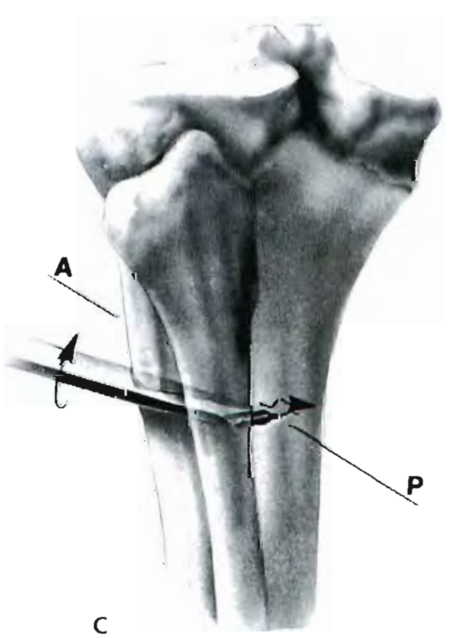
The next wires are parallel to the medial face of the tibia and attach to the most proximal and most distal rings. These are smooth wires passed laterally to medially **(e, f)**.

The final wires are two transverse olive wires attaching to the more central rings proximally and distally. They pass medially to laterally **(g, h)**.

After all of the wires, four proximal and four distal, are connected, the two threaded rods or lengtheners that were used to connect the proximal two rings with the distal two rings are removed in preparation for the osteotomy.



A B



C

FIGURE 6-59. A principle that is emphasized in the Ilizarov technique is that only the cortical bone is cut, leaving the medullary space with its vessels intact (hence the terms *compactotomy* and *corticotomy*). This osteotomy should be performed in the metaphysis about 1 cm distal to the wires. Unlike the femoral osteotomy, which is performed at the distal end of the bone, the osteotomy of the tibia is performed in the proximal tibia.

A small 1- to 2-cm incision is made just lateral to the crest of the tibia. The periosteum is incised vertically, and the medial and lateral surfaces of the tibia are exposed subperiosteally. Care should be taken to protect the periosteum during the subsequent maneuvers **(A)**.

Using the 1-cm osteotome, a cut is made in the anterior cortex only. The 0.5-cm osteotome is used to cut the lateral and then the medial cortex **(B)**. Because it is not possible to cut the posterior cortex without violating the medullary space, it is fractured by placing the osteotome in the posteromedial and posterolateral corners, alternately, and twisting it to crack or fracture the posterior cortex **(C)**. To ensure that the osteotomy is complete, the proximal and distal rings are grasped, and the distal rings are rotated externally (relaxing the peroneal nerve). Both the periosteum and the wound are closed.

It is difficult to believe that this maneuver does not disrupt the medullary blood supply, and it is probably not an important factor in healing. In addition, fracturing the posterior cortex in the manner described can lead to propagation of the fracture into one of the pin sites. The technique of the osteotomy described for the lengthening with a monolateral fixator would seem preferable because it is not difficult, it avoids this complication of fracture, and it does not appear to affect the healing.

The fibula is divided in its midportion, a safe distance from the peroneal nerve. It is advisable to remove a small section of the fibula to avoid premature consolidation.

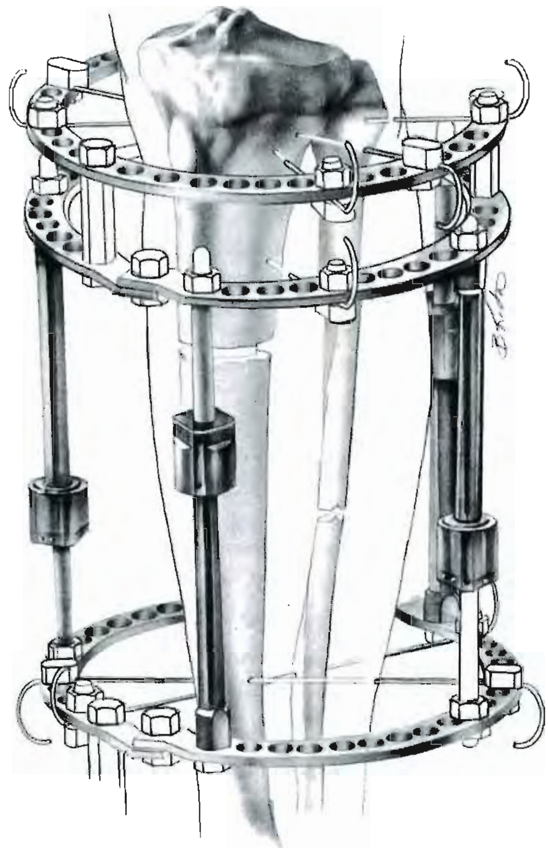


FIGURE 6-60. The two sets of rings are joined by four lengtheners. Additional connectors are added between pairs of rings to increase their rigidity.

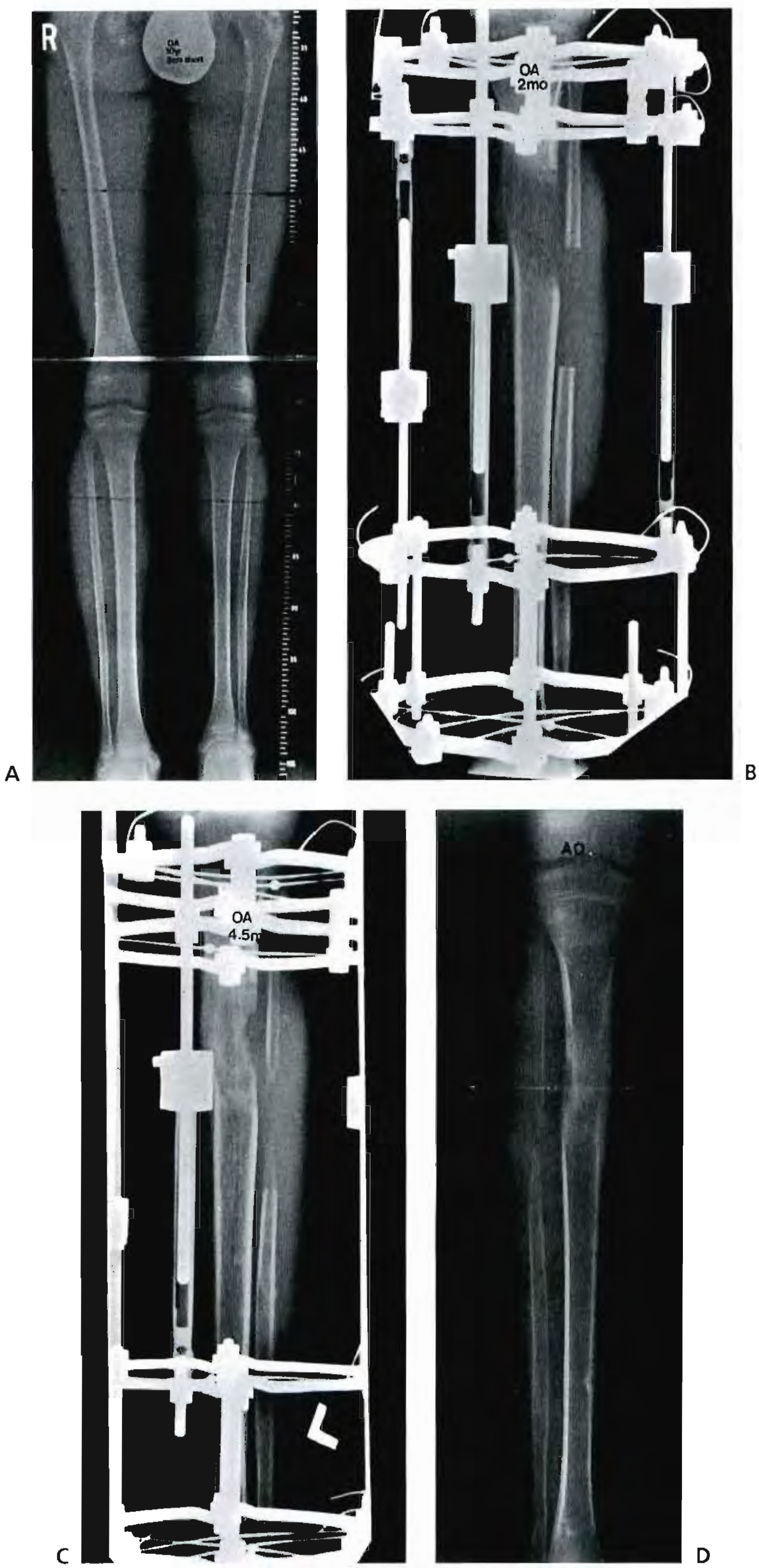

R
OA
2mo
OA
4.5m
AO
L
A
B
C
D

FIGURE 6-61. OA is a 10-year-old boy with congenital shortening of the tibia associated with a ball-and-socket ankle joint. Now 3-cm short, his final discrepancy is calculated to be near 6 cm **(A)**. Two months **(B)** and 4.5 months **(C)** after lengthening the amount of correction, the regenerating bone can be seen. Fourteen months after lengthening and 6 months after removal of the apparatus, the maturation of the regenerated bone is apparent **(D)**. (Courtesy of Deborah F. Stanitski, M.D., F.R.C.S.C., Charleston, SC.)

POSTOPERATIVE CARE

Physical therapy is started as soon as the patient can tolerate it. It is best to start on the first postoperative day with gentle range-of-motion exercises and progress to weight bearing on the second or third day. Lengthening of the leg can begin on the third to fifth day for children and later for adolescent and adults. The use of the lengtheners greatly simplifies this because each "click" is equal to a one-quarter turn, or 1/4 mm. Four turns per day produces the recommended amount of lengthening.

Note that 1 mm/day is the usual amount of lengthening. This may have to be increased if premature consolidation is occurring or decreased if there is a break in the callus formation.

When there is radiographic evidence of cortical bone formation in the regenerated bone, consideration is given to removal of the connecting rods and the apparatus. It is best to remove the lengtheners connecting the two sets of rings first. The leg should be stable clinically and free of discomfort with manipulation and weight bearing. If this is the case, the patient may be allowed to bear weight with crutches for a few days before removal of the wires. This allows for reapplication if fracture occurs. Many surgeons prefer to protect the leg in an orthosis for some months after removal of the apparatus.

References

1. Velazquez RJ, Bell DF, Armstrong PF, et al. Complications of use of the Ilizarov technique in the correction of limb deformities in children. J Bone Joint Surg [Am] 1993;75:1148.
2. Paley D, Fleming B, Catagni M, et al. Mechanical evaluation of external fixators used in limb lengthening. Clin Orthop 1990;250:50.
3. Paley D. Problems, obstacles, and complications of limb lengthening by the Ilizarov method. Clin Orthop 1990;250:81.

6.10 TIBIAL LENGTHENING WITH A UNILATERAL FIXATOR

The advantages and disadvantages of a monolateral device compared with other lengthening devices for tibial lengthening are the same as for lengthening of the femur. The basic technique of inserting the screws can be found in the description of femoral lengthening (see Procedure 4.15). Whereas the description of the femoral lengthening showed the use of the limb reconstruction system, the use of the standard lengthener is shown here. In our opinion, this lengthener offers no advantages over the limb reconstruction system for simple lengthening and has no ability to allow for correction of deformity (Figs. 6-62 to 6-68).

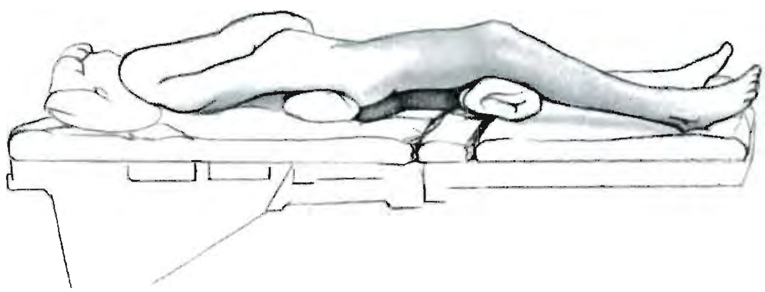


FIGURE 6-62. The patient is placed supine on a translucent operating table with a bolster under the hip and a large roll under the knee to aid in positioning the leg. The leg is draped free. The image intensifier is set up on the side of the operated leg. The operation begins by dividing the fibula while seated on the side of the operated leg. The surgeon moves to the opposite side of the table to insert the screws into the tibia while the image intensifier is positioned on the side of the operated leg. This allows the image intensifier to remain in place to monitor the placement and depth of the screws without disturbing the surgeon. After the pins are inserted and the template removed, the surgeon can move back to the opposite side of the table to perform the tibial osteotomy because the image intensifier will no longer be required.

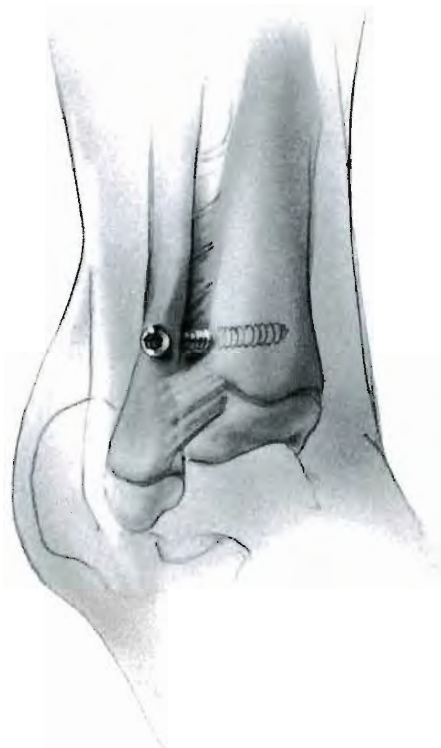


FIGURE 6-63. With the patient positioned as described, the surgeon begins by dividing the fibula. It is necessary to remove a piece of the fibula to delay union. Lengthening is delayed to allow early callus formation, and if the fibula is merely divided, it is possible that premature union of the fibula will occur before tibial lengthening is completed. Many surgeons choose to do the fibular osteotomy proximal and do not fix the mortise with a screw.

An incision is made over the subcutaneous border of the distal fibula, and a small section of the bone above the syndesmosis is exposed subperiosteally. To stabilize the tibial-fibular syndesmosis, the fibula is fixed to the tibia with an AO cortical screw. A 3.2-cm drill is used to make a hole that passes through the fibula into the tibia, engaging both the lateral and then the medial fibular and tibial cortex. The tibia lies anterior to the fibula; therefore, the drill must be aimed in an anterior direction as it passes from the tibia to the fibula. The holes in the fibula and the tibia are tapped, and a cortical screw of appropriate length is inserted. This screw should be fully threaded because the objective is to hold the fibula in its normal relationship to the tibia. If this screw is lagged or overtightened, it will tilt the distal fibular fragment.

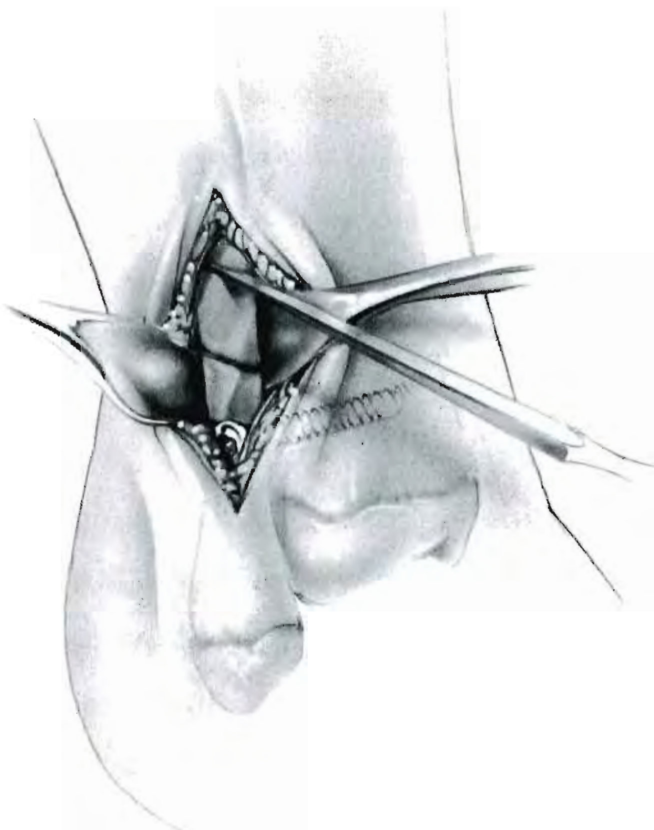
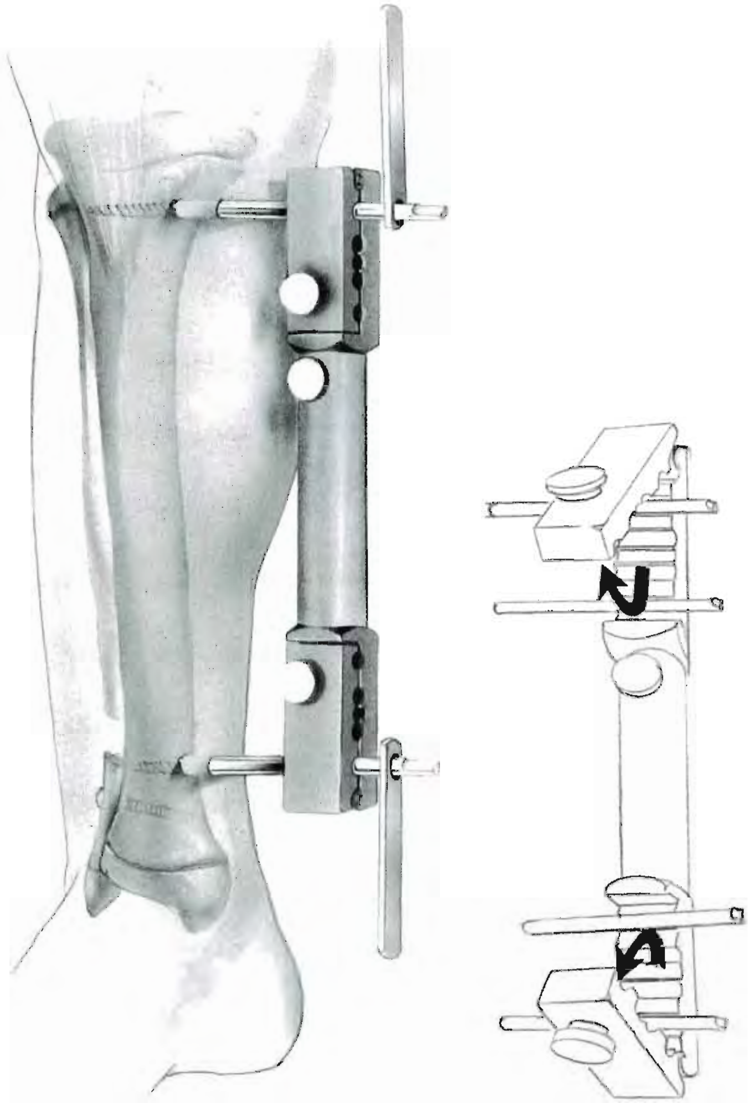


FIGURE 6-64. One centimeter above the screw, the entire circumference of the fibula is exposed subperiosteally. This is important because there is a small vein that is close to the medial surface of the fibula in this area. If it is divided, it can cause considerable bleeding after the tourniquet is released. The soft tissues are protected by two small retractors, and a 1-cm section of the fibula is removed with a power saw. The periosteum is approximated to lessen the bleeding, and the wound is closed. A drain can be placed in the subcutaneous space if the surgeon wishes.

FIGURE 6-65. In addition to the limb reconstruction system described for lengthening the femur, there are two different lengtheners: one that will lengthen 5 cm and one that will lengthen 10 cm. If the 5-cm lengthener is used, the template is fully collapsed; if the 10-cm lengthener is used, the template is fully extended. Illustrated here is the case of a smaller child in whom the smaller lengthener is used and the template is fully ▶



A B

collapsed. Only two screws proximal and two screws distal will be used. In larger children who are approaching adolescence, it is desirable to use three screws proximally and three screws distally for better fixation and stability.

The fixator can be placed directly over the anterior tibia. Some surgeons believe that this position lessens the tendency for the tibia to go into valgus during lengthening. We have tried this but believe it offers no advantage. In addition, if the limb reconstruction system is used to correct the deformity, the fixator should be located over the medial surface of the tibia.

The template is aligned with the axis of the tibia unless medial or lateral displacement of the distal fragment is desired. The proximal screw should be placed about 1 cm distal to the physeal plate of the proximal tibia. The image intensifier is used to identify this location. The most proximal screw is placed first, and the most distal screw is placed second **(A)**. This is different than with fracture fixation because the tibia remains whole, and there is no adjustment for screws placed in different axes with the lengthener. The placement of these two screws is crucial because it determines the position of the lengthener and of all the other screws. No adjustment is possible when using the leg lengthener.

The remaining screws are now placed as described for the technique of femoral lengthening (see Procedure 4.15). The placement of the screws is much easier in the tibia because the bone is subcutaneous. The incision for the screws can be made through the skin and the periosteum with one cut. After all the screws are placed, the template is removed **(B)**.

FIGURE 6-66. The osteotomy of the tibia is now performed. A small incision about 2 cm in length is made just lateral to the tibial crest. This incision should start at the level of the most distal of the proximal screws. Through this incision, a small area of the tibia 1 cm below the most distal of the proximal screws is exposed circumferentially. This task is aided by using the curved Crego periosteal elevators. Care should be taken not to damage the periosteum.

Multiple drill holes are now made in the tibia. The drill guard can be used to avoid overpenetration of the posterior cortex with damage to the soft tissues posterior to the tibia **(A)**. A small osteotome is used to complete the osteotomy, as described in the technique of lengthening the femur with a monolateral fixator (see Chap. 4, Fig. 4-117). Completion of the osteotomy can be verified by rotating the distal screws externally (to avoid stretching the peroneal nerve) while holding the proximal screws.

The periosteum can be approximated loosely with interrupted absorbable sutures. If desired, a fasciotomy of the proximal part of the anterior compartment can be performed by sliding a scissors distal and proximal to cut the fascia **(B)**. A drain may be used. The wound is closed.

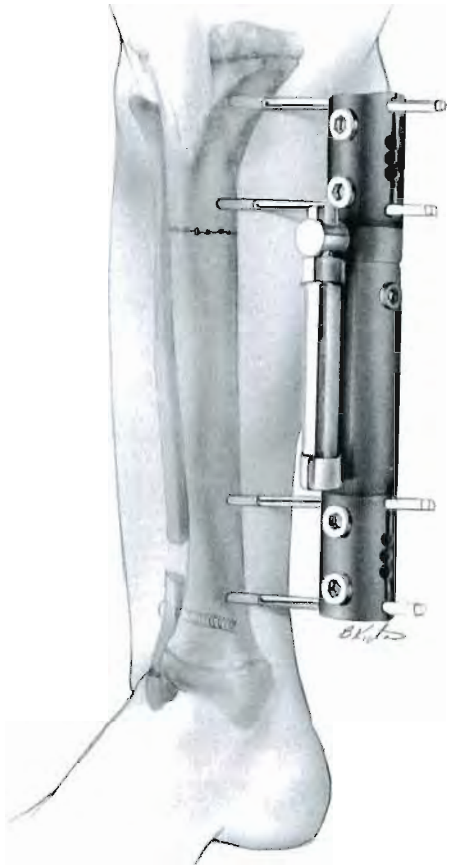
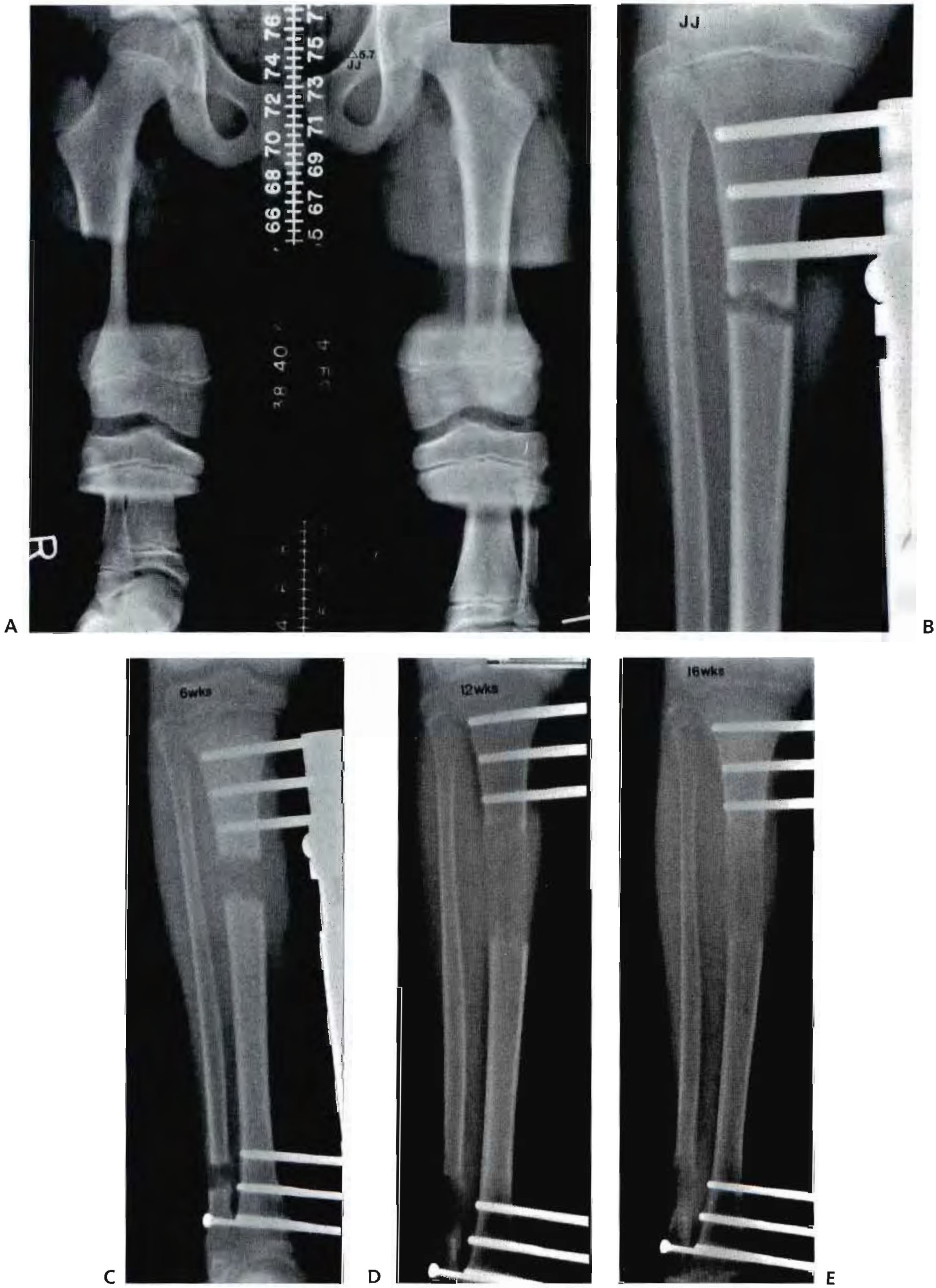


FIGURE 6-67. The lengthener is secured to the screws with the holes for the distraction and compression bar facing upward and the body-locking nut facing outward. The distraction and compression bar is attached to the device with the adjusting nut facing toward the patient's head. This is then fully compressed to achieve maximal stability at the osteotomy site. The body-locking nut is tightened. Now, the distraction and compression bar is lengthened until it becomes tight. This ensures that when lengthening begins, there will be no slack, and the first turns will distract the bone.


R
JJ
A
B
6wks
12wks
16wks
C
D
E

◀ **FIGURE 6-68. A:** Scanogram of a 14-year-old boy with congenital shortening of the tibia and fibula. Note the ball-and-socket ankle joint; as in the normal ankle, the physeal plate of the fibula lies at the level of the plafond. The discrepancy is 5.7 cm, with an anticipated discrepancy at maturity of 6.3 cm. **B:** The osteotomy site 2 weeks after surgery and 1 week after lengthening has begun. **C–E:** Lengthening at 6, 12, and 16 weeks, respectively. The callus remains homogenous without gaps. The fixator remained in place for 21 weeks. The patient's subsequent course was uneventful, and he returned to full athletic activity 18 months after his initial surgery.

POSTOPERATIVE CARE

The day after surgery, range-of-motion exercises for the knee and ankle are started. The patient can be ambulated as soon as he or she is comfortable, usually on the first postoperative day if only the tibia is lengthened. Full weight bearing can be permitted at this time. Continuous caudal analgesia speeds the postoperative progress and greatly improves the child's attitude toward the operation.

Distraction begins when there is evidence of some callus formation. This occurs between 1 and 2 weeks, depending on the age of the child and the circumstances. Distraction is done by the patient while at home and is monitored. At first, this may be done every week, but the interval increases to every 3 to 4 weeks depending on the family and how well the lengthening is going.

Lengthening is done at a rate of 1 mm/day in four increments. The patient turns the distraction bar one-quarter turn four times per day. The surgeon must realize that 1 mm/day is the usual rate, and it should serve as a guide. In many children, this is too slow, and premature consolidation may result, whereas in others, a break in the callus may be observed, indicating that the rate of distraction needs to be slowed or even halted for a while.

In tibial lengthening, the ankle rather than the knee is the joint that causes the most problem. There are no firm guidelines regarding how much motion must be maintained during lengthening. We have accepted up to 30 degrees of fixed equinus in adolescents without subsequent problems or the need for corrective surgery. It may seem that if the ankle is anatomically normal, it will recover normal function; however, in those patients with a short fibula, ball-and-socket ankle joint, and so forth, the surgeon should probably exercise greater caution.

After the desired length has been obtained, the body-locking nut is tightened while awaiting consolidation of the gap. Although in the past it was necessary to await formation of a cortex to loosen the body-locking nut and permit compression of the callus, it is now possible to apply the dynamic locking collar to prevent shortening while allowing compression of the callus (see Fig. 4-104).

When there is radiographic evidence suggesting sufficient healing to remove the device, we prefer to remove the dynamic locking collar, leave the body-locking nut loose, and permit full unprotected weight bearing for 2 weeks. If the patient experiences no discomfort and there is no break in the callus on the radiographs, the body of the lengthener is removed. Protected weight bearing and a cast or brace are usually used at this point.

6.11 REPAIR OF CONGENITAL PSEUDARTHROSIS OF THE TIBIA WITH WILLIAMS RODS

Congenital pseudarthrosis of the tibia is an uncommon condition characterized by persistent nonunion of a pathologic tibial fracture. The unique biologic characteristics of this condition are not well understood. The treatment of this condition entails some form of bone grafting along with fixation of the fragments as the initial treatment. Although historical results of treatment have been poor (1), more recent series using intramedullary fixation with the Williams rod technique have shown great improvement (2,3).

In addition to the unique biologic characteristics, there are unique mechanical characteristics. Usually, the operation is performed initially on small children with open physeal plates. There is an anterior and lateral bowing of the tibia that must be corrected as a part of the treatment. The bone is small and osteopenic. The distal segment is often short, making fixation to it difficult and insecure. The soft tissue coverage in the leg of a small child is not great. The fracture may take a long time to heal, necessitating that the fixation serve its purpose for years. Finally, there is a great tendency to refracture, encouraging the surgeon to avoid the stress shielding that occurs under a rigid plate and the stress riser created by the screw holes that remain when the plate is removed.

All of these factors make intramedullary fixation the ideal choice. The stimulus of weight bearing is preserved, no stress risers are created in the bone, and the device can cross the ankle into the talus and os calcis with little morbidity to help secure fixation of a short distal fragment. Williams rods, which were originated by Peter Williams of Melbourne, Australia, solve the problem of finding rods that are small enough for the tibias of small children and can be inserted easily.

The Williams rods are special-ordered from Zimmer (Zimmer Co., Warsaw, IN) and consist of two Steinmann pins threaded on one end. One end is a male thread, and the other is a female thread that allows the two rods to be joined. The available sizes are ⅛, 3/16, and ¼ inch in diameter (Figs. 6-69 to 6-73).

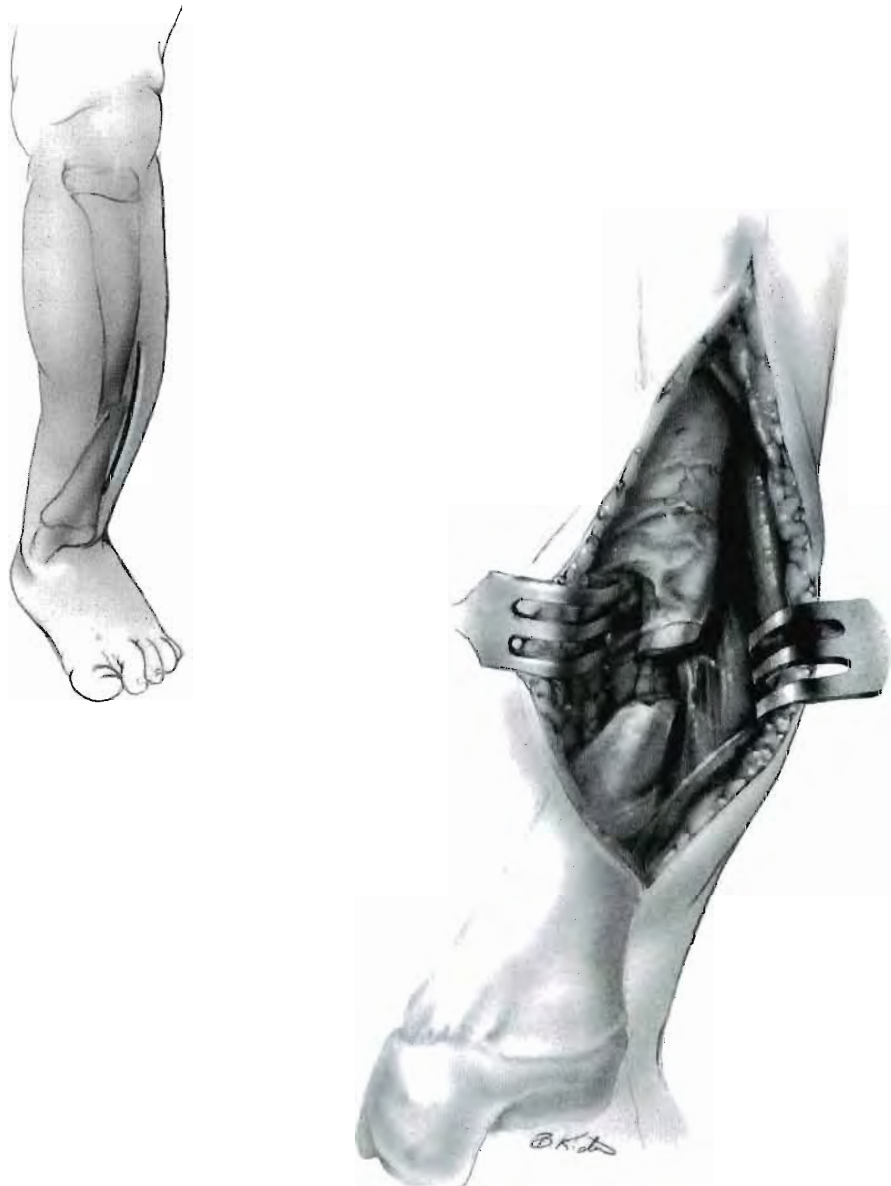
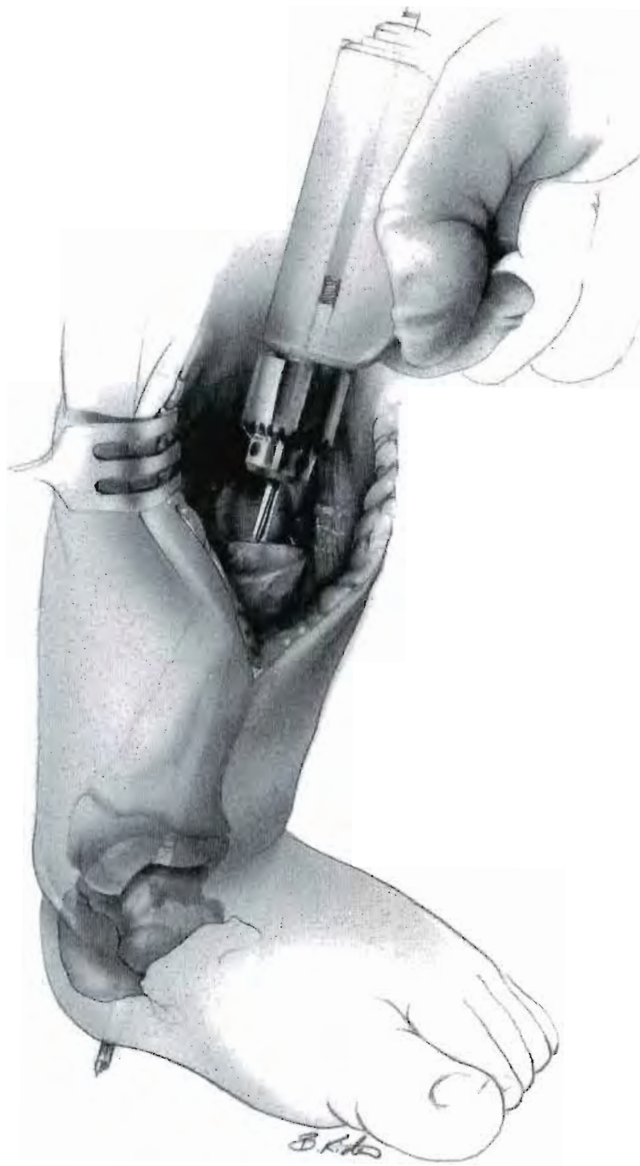


FIGURE 6-69. The pseudarthrosis is exposed through an anterolateral incision over the midportion of the tibia. There is debate among surgeons over what and how much of it should be excised. Some surgeons believe that all of the abnormal-appearing tissue and bone should be excised, whereas others advocate that only sufficient bone be resected to correct the deformity and expose a reasonable medullary canal. We are converts to the latter position because some of the worst results have followed radical excision of abnormal soft tissue and bone. There is no evidence that radical excision enhances healing; the result depends on the natural history of each case. If radical excision is performed, however, the surgeon should give some consideration to the blood supply of the distal segment of the tibia.

A pseudarthrosis of the fibula often coexists. When the fibula is intact, however, it may be necessary to divide it to correct the tibia. If this creates a pseudarthrosis, it does not appear to affect the ultimate outcome. In those cases, however, in which the fibular pseudarthrosis is distal, there may be instability of the tibial-fibular syndesmosis and thus the ankle mortise. In such cases, the surgeon should consider stabilization by intramedullary fixation of the fibula with a Kirschner wire or by establishing a bony union between the distal tibia and the distal fibula.



◀ **FIGURE 6-70.** Williams rods that will fit snugly in the medullary canal are joined, forming a long rod with a point on each end. It may be necessary to drill the medullary canal of the proximal and distal fragments to allow passage of a suitably sized rod. The rod is drilled up the proximal fragment through the tight portion of the medullary canal to be certain that the rod will pass and to establish the proper direction for the rod that, in turn, will assure proper alignment of the proximal fragment. If any residual bow remains in this fragment, the rod should start anteriorly and medially. In some cases, there is considerable bow that is unacceptable from a mechanical point of view and that makes central placement of the rod impossible. In these cases, a second osteotomy should be performed at the proximal extent of the bow. Minimal periosteal stripping should be done so that this intercalary segment of bone is not completely stripped of periosteum and thus its blood supply.

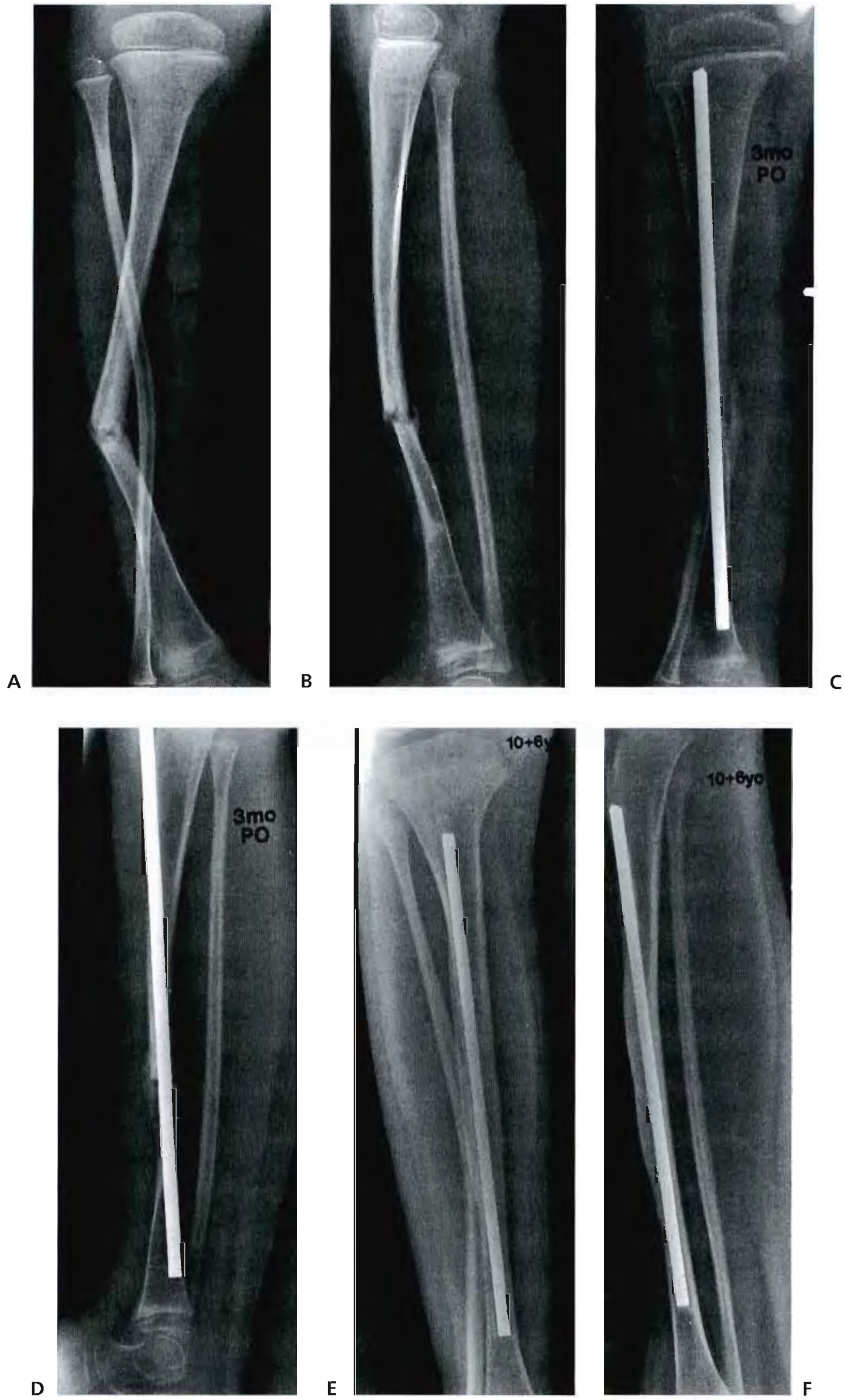
Next, the rod is drilled into the distal fragment, again in such a way as to ensure proper axial alignment of this fragment. This can be checked on an image intensifier. This segment of the rod that is drilled into the distal fragment should be the male, threaded portion that will leave the female end in the tibia. The reasons for this will become obvious in the next steps. When the direction is satisfactory, the rod is drilled through the physis, the ankle joint, the talus, the calcaneus, and out the bottom of the foot. The drill is placed on that section of the rod that protrudes from the foot, and the rod is withdrawn until the junction between the two rods is flush with the cut end of the bone.

If it is anticipated that the rod will need to be left in the calcaneus crossing the ankle joint, the foot should be held carefully in the correct anatomic position while the rod is being drilled across it. It is often necessary to leave the rod ankle neutral in the calcaneus in very small children or in cases in which the pseudarthrosis is distal and the fixation in the distal fragment is insufficient. If the pseudarthrosis is in the midshaft, this is usually not necessary. It is desirable to leave the rod across the physeal plate for two reasons: this is the strongest region within the tibia that aids in fixation, and the extra length of the rod will permit extra growth.

FIGURE 6-71. The rods are unscrewed and the proximal portion that is not within the bone is set aside. The tibia is reduced into the correct alignment and held temporarily in position by drilling the rod in the distal segment, part way into the proximal segment. Because this is the male end of the rod, the threads can easily be cleaned of bone fragments when the rods are joined again. The female portion of the rod that was removed is placed over the tibia, and the desired length is measured from the threaded end with the aid of an image intensifier. It is usually desirable and not at all harmful to have the rod cross both physeal plates. This extra length allows for extra growth and provides better fixation, as mentioned previously. The extra length of rod that will be discarded is cut from the sharply pointed end in an oblique manner to produce as sharp a point on the remaining rod as possible.

FIGURE 6-72. The rod is backed out of the proximal fragment, and the female segment that was just cut to length is reattached. The two joined rods are further withdrawn from the distal fragment until the cut end of the rod is flush with the cut end of the distal fragment. The fragments are reduced, with care taken to hold the correct alignment, and the rod is drilled into the proximal fragment under image intensifier control until the tip comes to lie within the proximal physis. The leg is checked again for correct alignment, and the image intensifier is used to ascertain that when the rods are unscrewed, the portion remaining will lie at the desired level distally (i.e., within the calcaneus or within the distal epiphysis). The distal tibial epiphysis is small in the growing child, and there is not much room for fixation. If the male end, with its thin, threaded portion, were left in the epiphysis, it would not add much fixation, which is another reason for leaving the female rod in the tibia. If all is correct, the rod protruding from the foot is unscrewed and removed.

The bone graft is added, and the wound is closed over a suction drain. A cast is applied. It is important that the patient not bear weight for the first several weeks; if the child is young or the reliability of the parents to enforce bed rest is at all in doubt, a double spica cast can be used to ensure non–weight bearing. In addition, the small, chubby legs of small children may require a spica cast for good immobilization.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◀ **FIGURE 6-73. A, B:** Pseudarthrosis in a 6-year-old girl. The pseudarthrosis had been present for 2 years, and amputation had been recommended. She was treated with electrical stimulation for 1 year without improvement. **C, D:** Radiographs show the result 3 months after surgery. Notice that these rods did not cross the physeal plates and that, proximally, the rod lies anteriorly because of the residual bow in the proximal fragment. This latter problem could have been improved by an additional osteotomy of the proximal fragment. **E, F:** Four and a half years later, the tibia remains united. The patient has remained in a solid AFO during this period. The amount of growth at both ends of the bone is illustrated by the distance the physeal plates have moved from the ends of the rod.

POSTOPERATIVE CARE

The drain can usually be removed on the first postoperative day and the patient discharged 1 or 2 days thereafter. How long the patient should avoid weight bearing is a more difficult question. In all cases, healing occurs much more slowly than after an osteotomy through normal bone, and the surgeon is usually forced to permit ambulation before healing is complete. In most cases, we have permitted ambulation by 8 weeks in older children who can be immobilized in a cast or an orthosis. In small children, however, with chubby legs, 3 months is probably safer. All children, regardless of the success of the healing, are maintained in an orthosis until skeletal maturity. The orthosis is a solid ankle-foot orthosis (AFO) that grips the tibial and femoral condyles and has an anterior "clam shell" that maintains a tight fit over the anterior aspect of the tibia.

The patient is periodically monitored radiographically for union as well as correct positioning of the rod. If the distal physis continues to grow (a good prognostic sign), the rod eventually pulls out of the bones of the foot and the ankle joint because of the motion in the foot that loosens the rod distally while it remains fixed proximally. At this point, the patient is usually older, and an articulated ankle AFO can be used.

The rod can be left in the tibia indefinitely. If the patient grows to the point at which the rod is very short, it need not be replaced as in osteogenesis imperfecta, provided the bone is well healed. If healing is not sufficient, however, the rod should be exchanged for a longer and, if possible, thicker rod when fixation is jeopardized. The rod is most easily retrieved proximally, where it usually comes to lie against the anterior lateral cortex.

References

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6.12 PROXIMAL TIBIAL AND FIBULAR EPIPHYSIODESIS, PHEMISTER TECHNIQUE

Epiphysiodesis of the proximal tibia and fibula is less seldom performed than epiphysiodesis of the distal femur. There are several reasons for this. First, the proximal tibia grows more slowly and therefore provides less correction. Even when the discrepancy is in the tibia, it is often not the best choice because the epiphysiodesis must be performed several years before the cessation of growth to achieve the desired correction. This results in a greater chance that the calculations of the ultimate discrepancy will be in error. For these reasons, epiphysiodesis of the proximal tibia and fibula is done most often in combination with epiphysiodesis of the distal femur when more correction is needed than can be obtained in the distal femur or when disease or injury has destroyed the opposite proximal tibial growth.

Although the operation to destroy the growth plate is essentially the same as for the distal femur, the approach is different, and for someone not familiar with it, this can be more difficult than it might appear. This is because of the peculiar shape of the proximal tibia, the curving shape of the physis, and the need to gain access to the proximal fibular physis.

The operation is performed under a tourniquet. If the surgeon is not familiar with this operation, it may also be helpful to identify the physeal plate of the proximal tibia before making the incision. It is easier to start with the lateral side. A sandbag can be placed under the hip on the operated side to aid in internally rotating the leg for better access to the lateral aspect of the leg. After this side is completed, the circulating nurse removes the sandbag before starting on the medial side (Figs. 6-74 to 6-80).

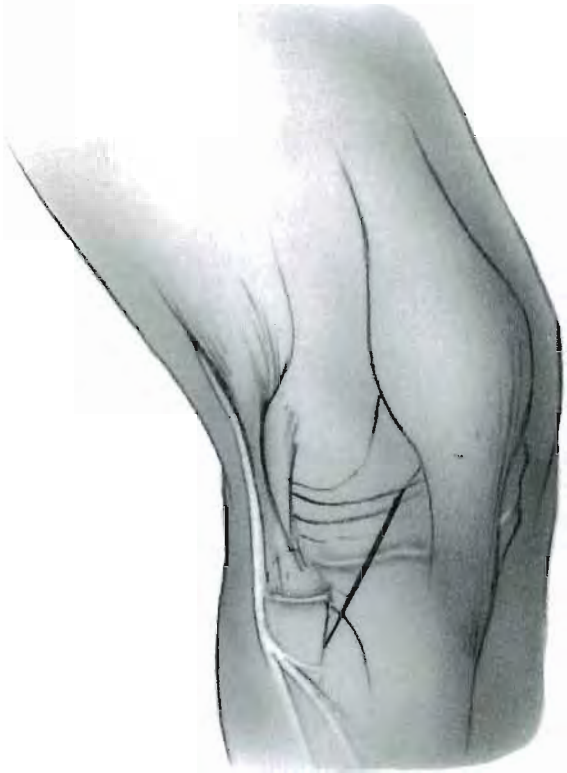

FIGURE 6-74. The physeal plate of the proximal fibula lies below and posterior to the physis on the lateral side of the proximal tibia. Because these two structures lie so closely, one incision is used. It extends from the proximal-anterior to the distal-posterior side. It begins on the prominence of the tibia and ends just below the fibular head. It is best to keep the incision anterior to the fibula because it will be approached from this direction without exposing the peroneal nerve.

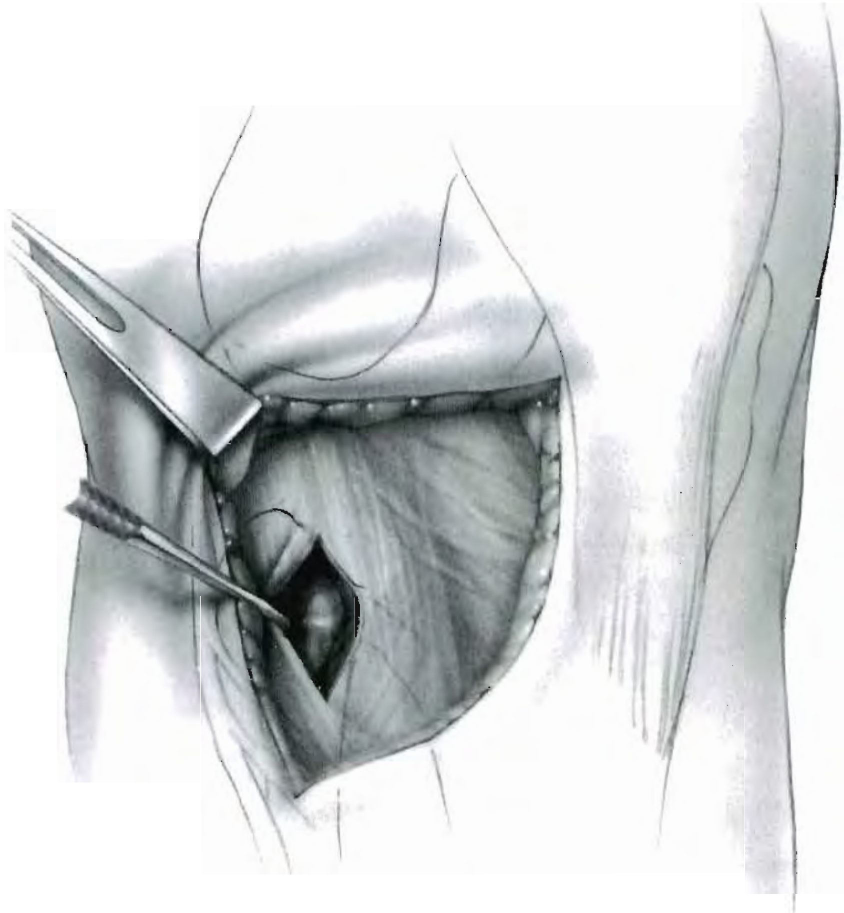

FIGURE 6-75. The fibular epiphysiodesis can be performed first. By staying on the anterior aspect of the fibular head and not moving distal to the fibular head, the peroneal nerve can be avoided. The skin flap is elevated until the fibular head is exposed. It is covered by fascia and muscle. A longitudinal incision is made directly over the anterior portion of the fibular head. This cuts the periosteum proximally and some fibers of the peroneus longus or extensor digitorum longus distally. Again, take care not to go too far in the distal direction: this is a small incision.

The periosteum is elevated in both directions. The physis is identified and, if necessary, a small H incision can be made in the periosteum to aid in exposure of the physis. A small, slightly curved rongeur is used to remove as much of the physis as possible. The periosteum is closed.

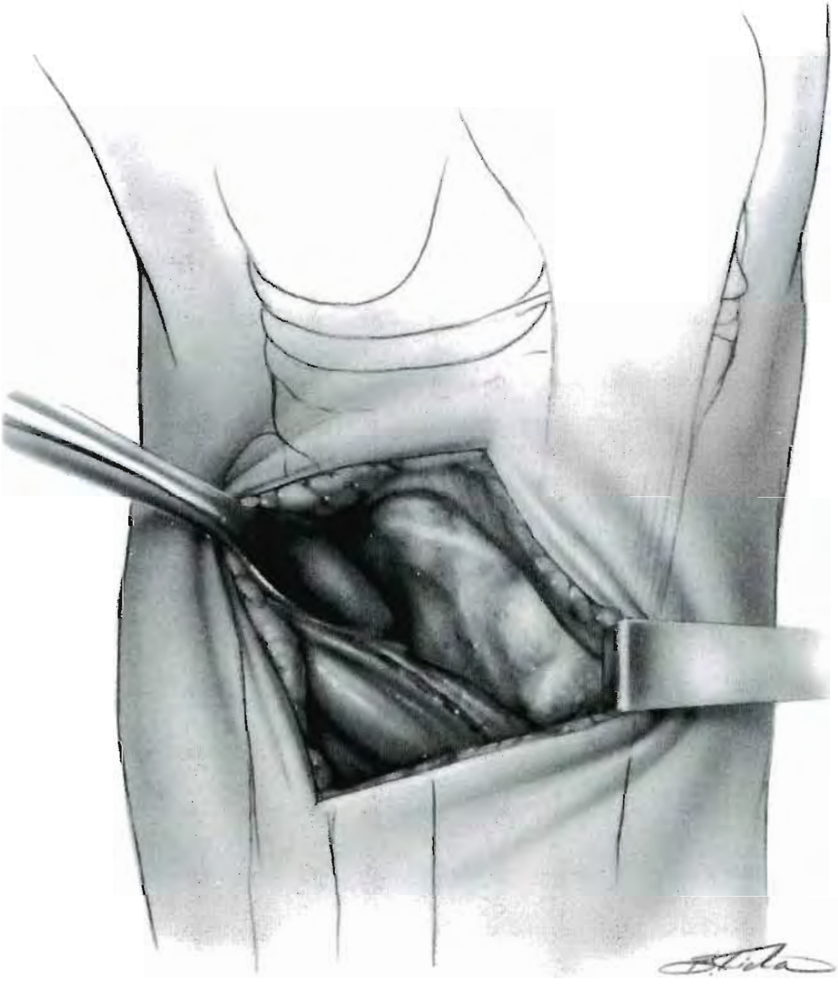

FIGURE 6-76. To expose the proximal tibial physis, a curved incision is made starting next to the tibial tubercle and following the ridge of the tibia posteriorly (see Fig. 6-69). Then, the periosteum is elevated distally along with the origin of the anterior tibial muscle. If the incision was too low on the ridge, the periosteum will also need to be elevated proximally to expose the plate.

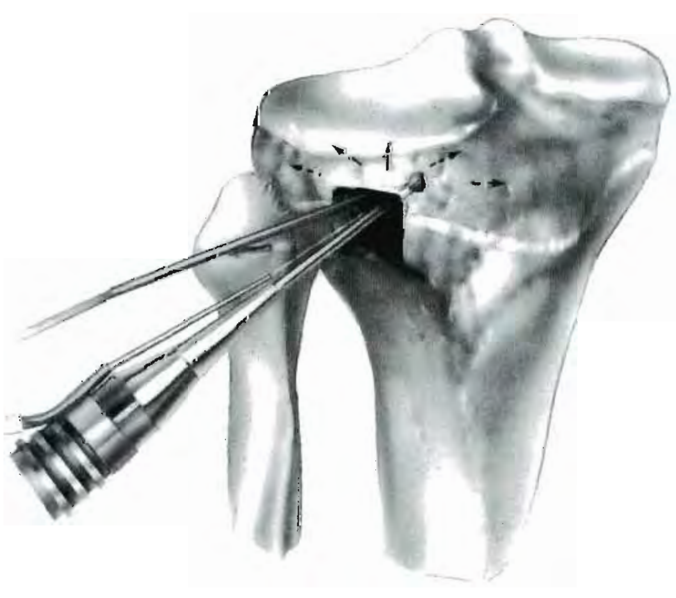

FIGURE 6-77. Using the mortise chisel, a block of bone is removed from the midportion of the lateral surface of the tibia creating a window. A high-speed, 5-mm bur is used to remove the physis. The ideal bur for this procedure is one that combines irrigation at its tip. Care must be taken in using the bur because the tough physeal cartilage is more resilient than the surrounding soft cancellous bone. The bur tends to bounce off the cartilage and remove bone. If the surgeon is not careful, a deep channel can be cut because of the assumption that the bur has removed physis when it has not. The key is to keep the white physeal cartilage always in view. A headlight or small fiber optic light can be used, but this is seldom necessary. The use of a curette to remove the plate is described in the technique of distal femoral epiphysiodesis (see Procedure 4-19).

FIGURE 6-78. As much of the plate as can be seen is removed. Cancellous bone from the metaphysis is cut with an osteotome or curette and packed into the defect, and the bone block is replaced after reversing it either 90 or 180 degrees. The periosteum is closed, followed by the crural fascia, the subcutaneous tissue, and the skin. The sandbag is removed, and the leg is allowed to rotate externally.

FIGURE 6-79. The medial incision is placed over the center of the medial side of the tibia angled in the direction of the fibers of the pes anserinus and extends from the joint line distally about 4 cm. When this incision in deepened, the periosteum of the tibia is in the proximal part of the wound, and the fascia covering the origin of the anterior tibial muscle is in the distal part. The physis lies almost directly under this insertion and must be removed to gain access to the plate.

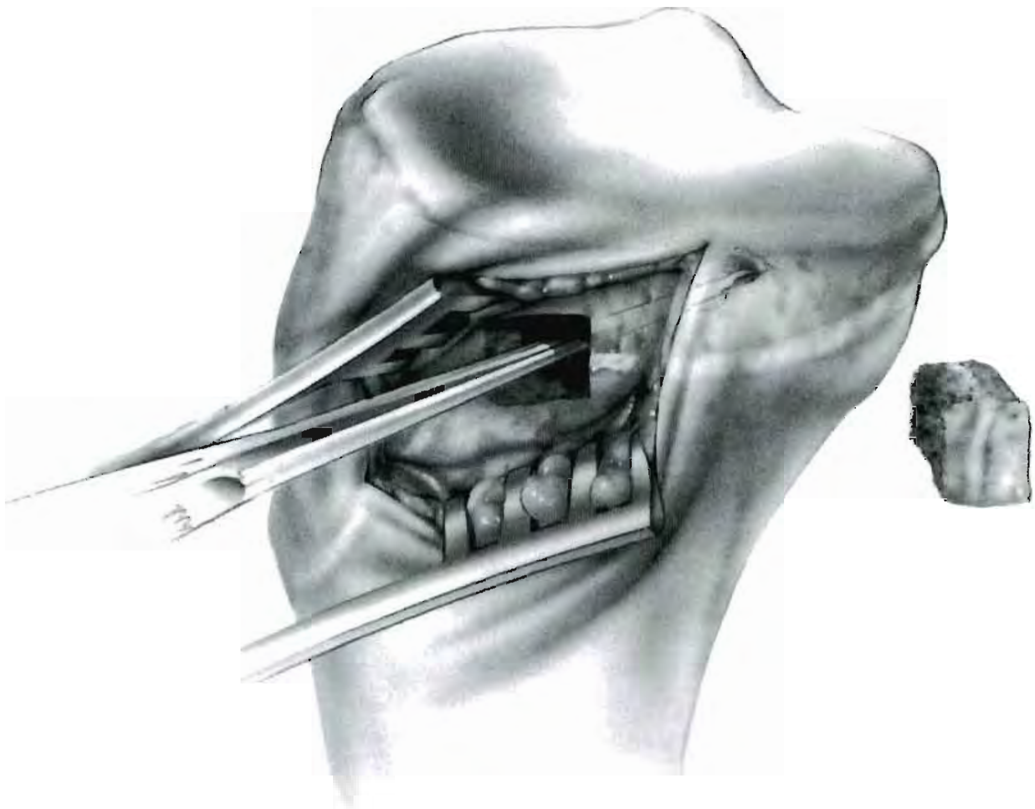

FIGURE 6-80. An incision is made in the periosteum beginning alongside the tubercle and extending proximally and then curving posteriorly about two thirds of the way posterior on the tibia. A periosteal elevator is used to elevate this periosteum and with it the origin of the anterior tibial and extensor digitorum muscles. The physis should now be visible. The physis is destroyed in the same manner as on the lateral side.

POSTOPERATIVE CARE

Despite the surgeon's perceived thoroughness, there is still considerable continuity between the epiphysis and diaphysis. For comfort, the patient may be placed in a knee immobilizer, and for safety, the patient is taught a three-point partial weight-bearing crutch gait with 25 to 50 lb of weight permitted. Because this surgery is often performed on an outpatient basis, crutch walking should be taught preoperatively. Within 3 days, the knee immobilizer is removed for range-of-motion exercises, which soon progress to quadriceps and hamstring strengthening with low weight. Healing is usually sufficient to permit full weight bearing by 6 weeks.

6.13 PERCUTANEOUS EPIPHYSIODESIS OF THE PROXIMAL TIBIA

Although the Phemister open epiphysiodesis is the standard technique, it is being replaced in general use with the percutaneous method, which is just as effective (1–3) and has a lower morbidity rate.

Because the leg is a two-bone system, the fibula is also a concern. It is advisable to arrest the growth of the proximal fibula if there are 2 years or more of growth remaining, or in any situation in which the proximal fibula is prominent.

The operation is performed under tourniquet and can usually be done on an outpatient basis. It is easier to start with the lateral side. If the fibula is to be arrested, a small incision is necessary (unless the surgeon feels capable of safely destroying the proximal fibula physis percutaneously). A sandbag can be placed under the hip on the operated side to aid in internally rotating the leg for better access to the lateral aspect of the leg. (See positioning in Procedure 4-20, on distal femoral epiphysiodesis.) If access to the medial side is necessary, the circulating nurse removes the sandbag before starting on the medial side (Figs. 6-81 to 6-85).

FIGURE 6-81. The patient is positioned as in the Phemister epiphysiodesis with a sandbag under the buttocks of the operated side to facilitate internal rotation of the leg and access to the fibula and the lateral side of the tibia. The incision used is also the same. The reason for an incision on the lateral side is that it is probably safest to destroy the proximal fibular physis under direct vision with a rongeur. If it is not necessary to arrest the proximal fibular growth, the procedure may be entirely percutaneous and done from the medial side, lateral side, or both sides. It is usually not necessary to arrest the proximal fibula if it is not unusually prominent and there is less than 2 years of growth remaining.

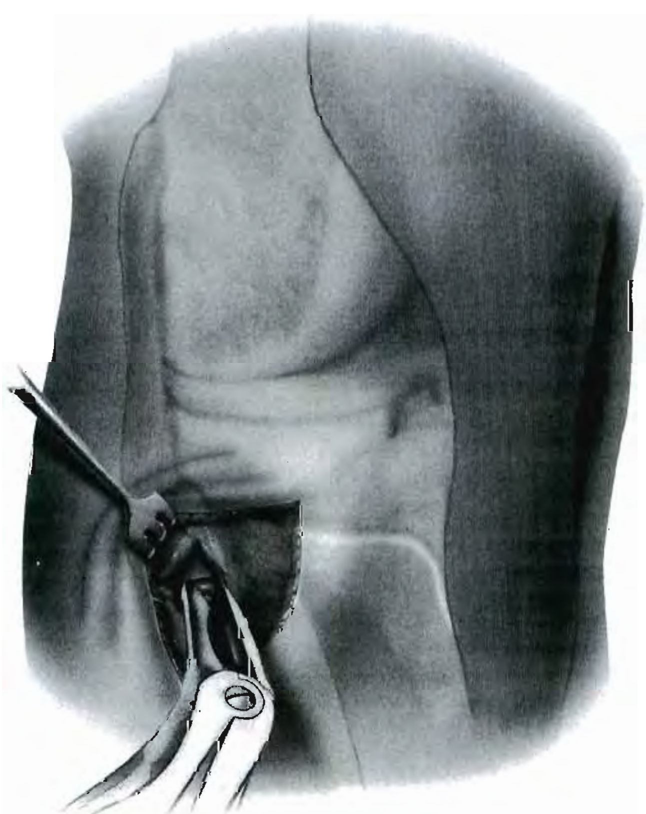

FIGURE 6-82. The proximal fibular physis is exposed on its dorsal surface. This obviates the need to expose the peroneal nerve, which curves over the dorsal surface of the fibula below the physis. Needless to say, care needs to be taken in the exposure. The periosteum is split in the pattern of an H and is elevated, giving good access to the physis. A small rongeur is used to remove the more dorsal aspect of the physis and a smaller, more pointed rongeur or a curette is used for the deeper portions. A power bur may also be used but is usually not necessary. When this is complete, the periosteum is closed.

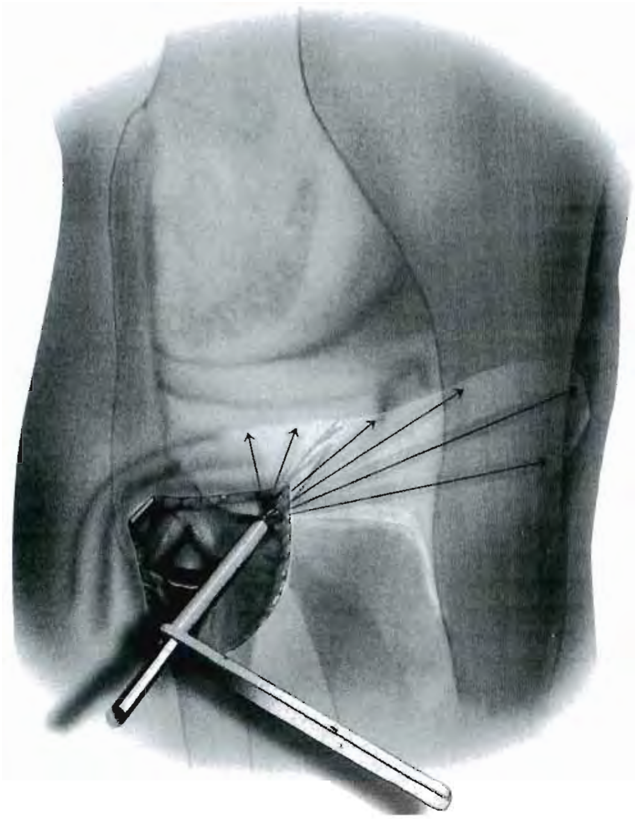

FIGURE 6-83. The technique for destruction of the tibial physis is the same as that described for percutaneous epiphysiodesis of the distal femur. A drill is advanced across the physis under image intensifier control. Several passes are made going anterior and posterior, with care taken that each time the drill is advanced, it remains in the physis and not above or below. Care need also be taken that the drill remains within the bone. The closer together these drill tracks are made, the easier will be the next step.

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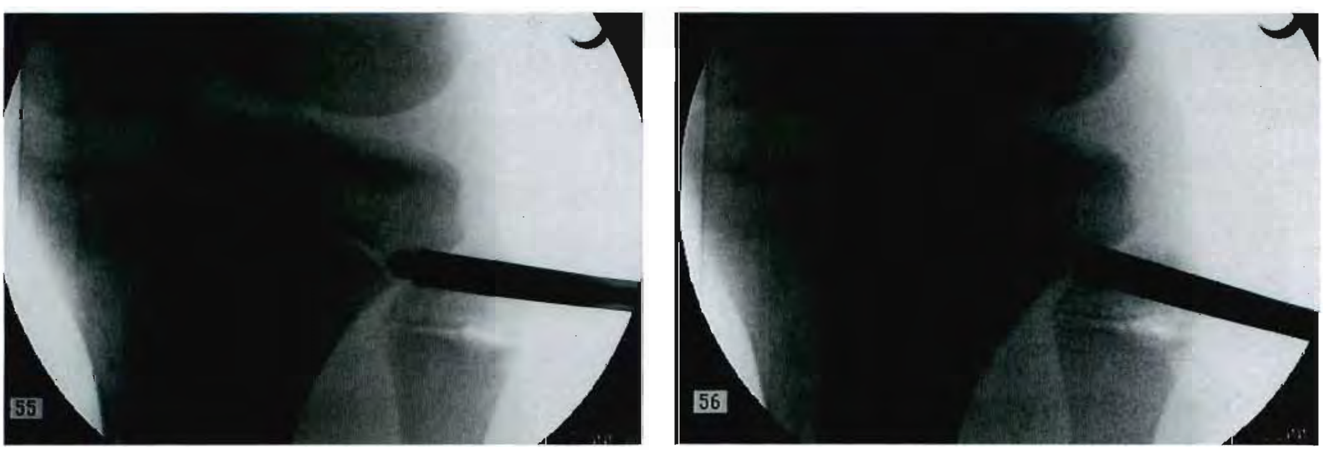

B

C

FIGURE 6-84. If the fibula was arrested with the open technique, it is a simple matter to start the drill into the bone through the wound. If not, a small stab wound is made opposite the physis. It is possible to do this from only the lateral (or medial) side in a normal-shaped physis. **A–C:** The drill is slowly advanced, checking with the image intensifier to be sure that the drill remains in the physis. This is done with each pass as the surgeon moves the drill more anteriorly and posteriorly with each successive pass.

In some cases, the physis follows an undulating course, which requires the epiphysiodesis to be done from both the medial and lateral sides. In addition, some surgeons may feel uncomfortable passing the drill completely across the physis, especially posteriorly, for fear of going outside of the bone and injuring an important structure.

FIGURE 6-85. After multiple passes with the drill, a curette is used to connect the drill holes and further remove additional physis. The curette should be checked with the image intensifier to be certain that it is removing physis and not unnecessary metaphyseal bone. Also, an effort should be made to keep the hole in the cortex as small as possible to minimize the bleeding into the soft tissues. The wound is closed with absorbable sutures. A drain is not helpful because it blocks readily with the material from the bone.

If the limb has 2 years or less of growth remaining, it is usually not necessary to arrest the proximal fibula. In this case, it is usually easier to perform the epiphysiodesis from the medial side because the border of the tibia is subcutaneous. This is the only time the operation is truly percutaneous.

POSTOPERATIVE CARE

A dressing is applied with a compression bandage if desired. A Cryo-Cuff can be helpful in eliminating swelling and may result in faster rehabilitation. The procedure is performed on an outpatient basis. The patient should be instructed to loosen any compression bandage if the foot begins to swell. Crutches may be needed for comfort during the first few days. Active quadriceps rehabilitation can be started within a few days.

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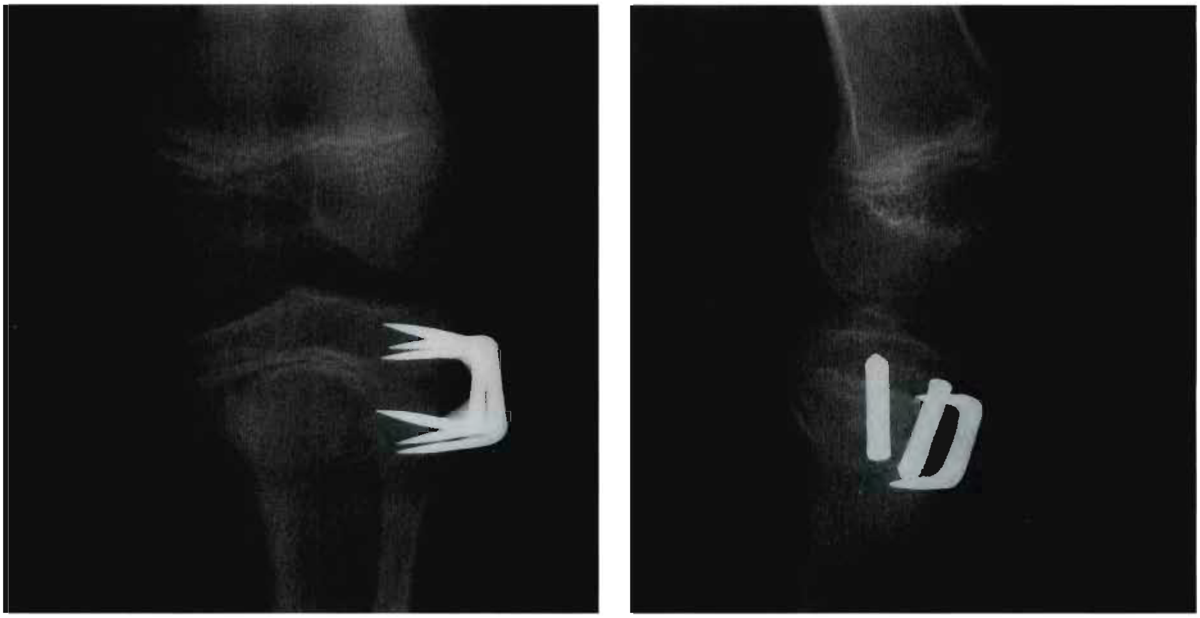
6.14 HEMIEPIPHYSIODESIS OF THE PROXIMAL TIBIA BY STAPLING TO CORRECT GENU VARUM

An epiphysiodesis performed with staples may be permanent or can be done according to the original principles proposed by Blount and Clarke (1). In this method, staples are inserted well before the end of growth and removed when correction is obtained. In this technique, a small amount of overcorrection is desirable because a rebound of growth may occur after removal.

An additional consideration is the cause of the deformity: if it continues, recurrence can be expected. Leaving the staples in for a period of 3 to 4 years may cause permanent closure of the physis (2). These points are important in considering the use of hemiepiphysiodesis in cases of adolescent or juvenile Blount's disease. Because the growth on the side opposite the growth arrest is neither normal nor predictable but is permanent, a longer period of growth than usual is needed for correction. Permanent growth arrest may cause overcorrection, and removal of staples with resumption of growth may cause recurrence of the deformity.

When circumstances are more predictable (e.g., idiopathic genu valgum), a permanent partial epiphysiodesis may be used to correct angular deformity. Bowen and colleagues (3,4) have described this technique and a method of calculating the timing of the epiphysiodesis. The epiphysiodesis must be performed so that the correction is obtained when growth is finished, much like the calculations used to determine limb length. Although the correction in this case is angular, the data used are the same growth data of Anderson and Green (5) that are use to calculate limb length (Fig. 6-86).



A B

FIGURE 6-86. The patient is positioned as for percutaneous stapling, and the incision is the same as described for that procedure. The proximal tibial physis anterior to the head of the fibula is exposed and identified on the image intensifier. Three staples are inserted, and each is confirmed in the anteroposterior and lateral projections on the image intensifier. The principles of insertion are discussed in the section on hemiepiphysiodesis by stapling to correct genu valgum in the distal femur. In the case illustrated here, not all of the staples are perfectly placed according to the principles outlined by Blount and Clarke.

POSTOPERATIVE CARE

A dressing is applied with a compression bandage if desired. A Cryo-Cuff can be helpful in eliminating swelling and may result in faster rehabilitation. The procedure is performed on an outpatient basis. The patient should be instructed to loosen any compression bandage if the foot begins to swell. Crutches may be needed for comfort during the first few days. Active quadriceps rehabilitation can be started within a few days.

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6.15 SCREW EPIPHYSIODESIS FOR ANKLE VALGUS

Ankle valgus is a deformity common to a wide variety of paralytic, chromosomal, and congenital conditions. Therefore, its correction is a common concern of orthopaedic surgeons. The technique of partial epiphysiodesis of the medial side of the physis has been used for years, but a more recent technique has gained in popularity because of its simplicity and reversibility. This technique involves the creation of a temporary tether on the medial side of the physis by means of a screw (1,2).

The surgery is recommended for children 6 years of age or older. Although not reported in the small number of cases to date, permanent arrest of the physis remains a possibility. The screw is removed when correction is achieved. Recurrence of the deformity may be expected, depending on the cause of the original deformity (Figs. 6-87 to 6-88).

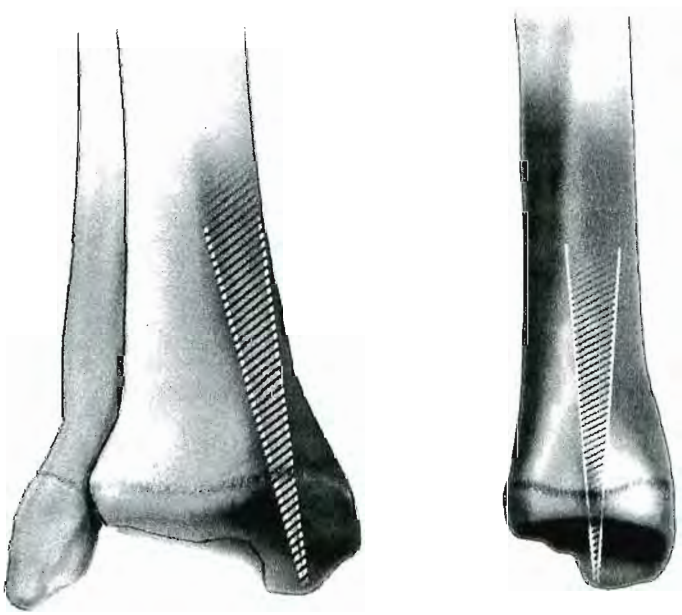
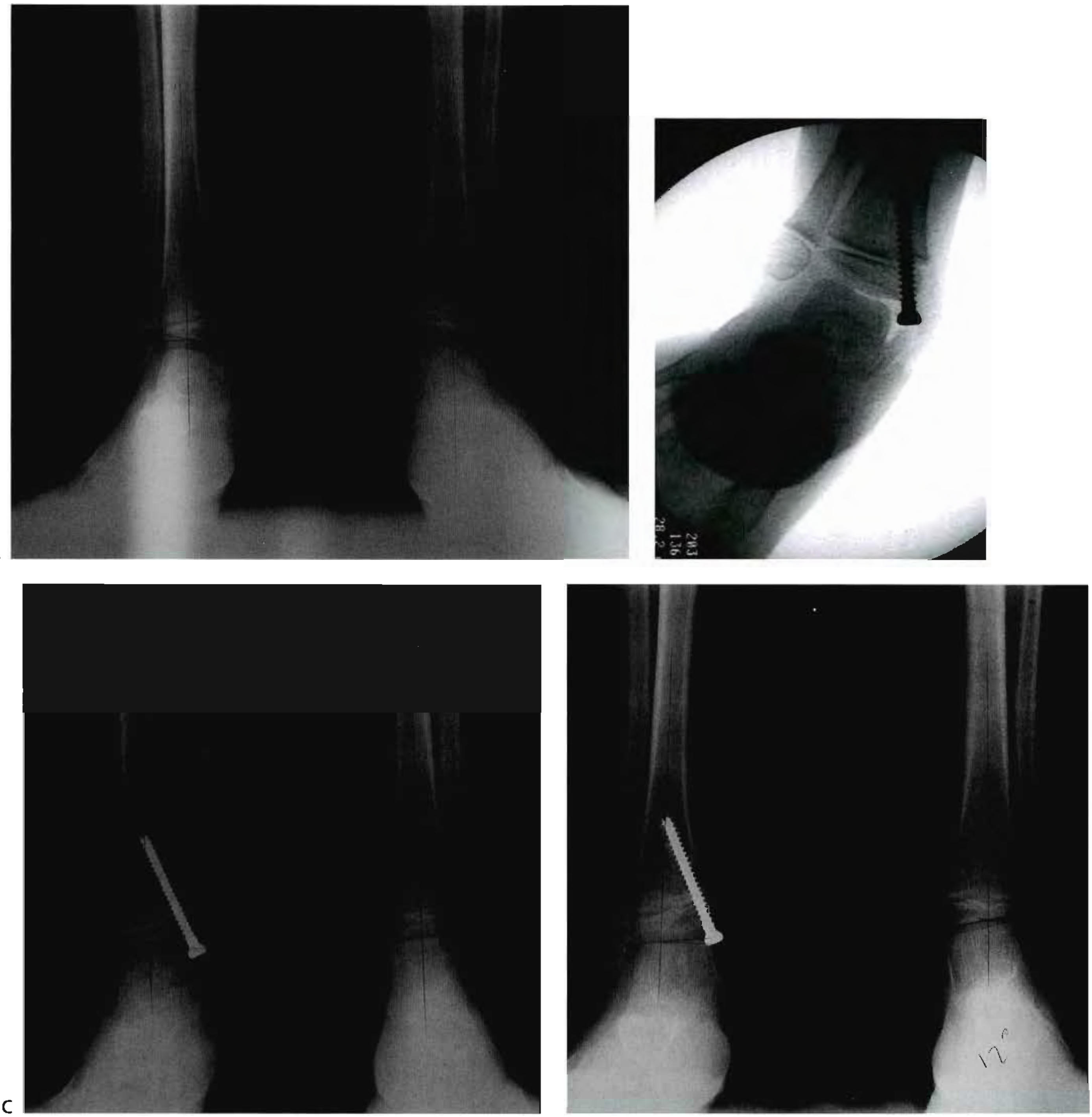


FIGURE 6-87. The patient is positioned in a sterile field under an image intensifier. A small stab wound is made over the tip of the medial malleolus, and a guide wire for a cannulated screw about 4.5 to 5 mm in diameter is inserted.

The goal is to keep the screw as close to the medial tibial cortex as possible and in the middle third of the tibia on the sagittal view. The position should be confirmed in two views with the image intensifier.

The tap is passed over the guide wire followed by a fully or partially threaded screw at least 45 mm in length. The wound is closed with a single subcuticular absorbable suture, and a small dressing is applied.



A C D

FIGURE 6-88. **A:** Radiographs of a 4-year, 10-month-old girl who had a right vertical talus corrected at 8 months of age. She has symptomatic ankle valgus measuring 13 degrees. **B:** Intraoperative placement of the screw, with a better view of the triangular epiphysis. **C:** Correction to neutral is achieved 9 months after screw placement. Note the asymmetric growth line in the tibia and the absence of any growth line in the fibula. **D:** Fourteen months after surgery, there is slight overcorrection. The screw was removed at this time. (Courtesy of Peter M. Stevens, MD, Salt Lake City, UT.)

POSTOPERATIVE CARE

The procedure is performed on an outpatient basis. The patient may resume full weight bearing. It is important to follow the patient closely so that significant overcorrection does not occur. A small amount of overcorrection may be desirable because of the rebound effect after screw removal. At the appropriate time, the screw is removed.

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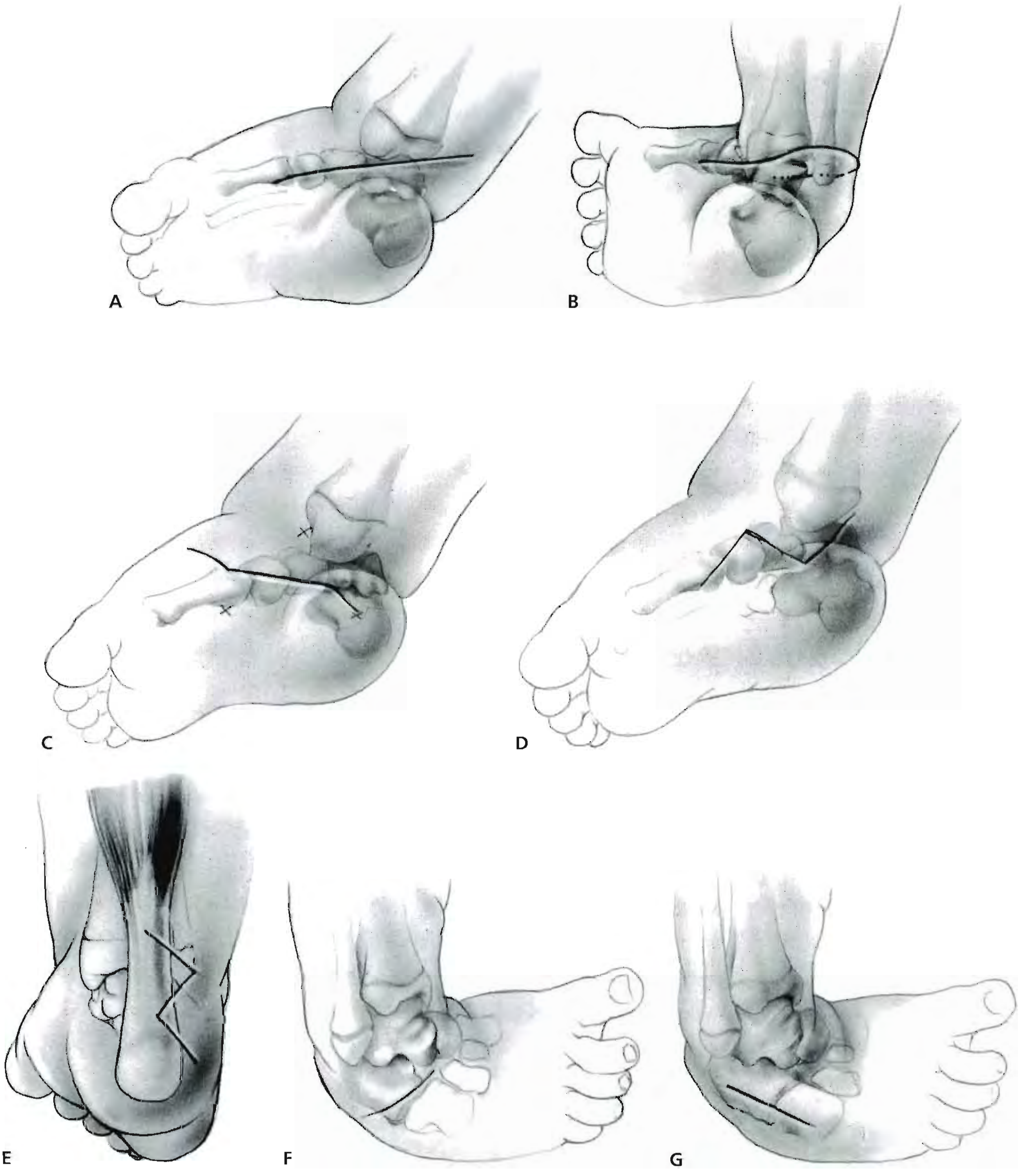
7

THE FOOT

7.1 SURGICAL CORRECTION OF CLUBFOOT

Turco (1) popularized the posteromedial release for clubfoot deformity in the United States in 1971 and followed this with a second report in 1979 (2). Since that time, there have been numerous articles on the surgical correction of resistant clubfoot deformity. A careful reading of all of these articles, however, may not convince the surgeon that one best operative procedure is known. This is due to several factors: not all clubfeet are the same and thus they do not all require the same surgery; there is no good classification that would allow a comparison of clubfeet before or after surgery; there is not always complete agreement between surgeons on the nature of the morbid anatomy of the foot (3); and the importance of incisions is often emphasized over what is done beneath the skin. In short, there remains considerable art to the surgery of resistant clubfeet.

The surgical release of resistant clubfoot is discussed as the various components of an operation that the surgeon may choose to use or omit. There is no intention to advocate a particular operation or incision, and the surgeon is left to decide what is needed for each clubfoot. The techniques that various surgeons bring to the surgical treatment of clubfoot are so numerous and without published objective evidence of superiority that no one operation can be advocated. The operative steps are described through three separate incisions, although it is recognized that some surgeons may prefer one large or two separate incisions (Figs. 7-1 to 7-18).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◀ **FIGURE 7-1.** The incisions used vary widely and are more numerous than can be described here. All of them have been used successfully, but what is done beneath the incision is far more important to the result than the incision itself.

Turco (1) described a straight incision that ran from the base of the first metatarsal, under the medial malleolus, until it reached the Achilles tendon **(A)**. He pointed out that a proximal extension of the incision along the Achilles tendon was contraindicated and that no undermining of the wound should be done. Ignoring these two admonitions has led to many wound problems.

Crawford and colleagues (4) described an incision popularized by Giannestras in Cincinnati **(B)**. This transverse incision begins on the medial side of the foot, over the naviculocuneiform joint. From there, the incision passes posteriorly to cross just beneath the tip of the medial malleolus. It continues across the back of the foot over the Achilles tendon at the level of the tibiotalar joint and continues laterally to pass over the lateral malleolus, ending at the sinus tarsi. Although many surgeons have abandoned this incision because of wound complications, just as many report using it routinely without problems.

Many surgeons prefer to use two incisions: one posterior and one medial, with a third incision laterally over the calcaneocuboid joint if this is necessary. Carroll (3) has described a medial incision with three limbs **(C)**. The center of the calcaneus, the front of the medial malleolus, and the base of the first metatarsal (marked by *X*s), form a triangle. The center part of this incision is parallel to the base of the triangle, whereas the proximal part angles toward the center of the heel, and the distal part crosses over the dorsum of the foot. The posterior incision runs from a point in the midline about 4 cm above the tibiotalar joint obliquely to a point midway between the Achilles tendon and the lateral malleolus.

A useful incision that we use was learned from Campos de Pas and his staff in Brazilia, Brazil **(D, E)**. It consists of a separate medial and posterior zigzag incision. The first limb of the medial incision begins above and behind the medial malleolus and extends forward and downward toward the sole of the foot. The second limb angles distal and dorsal to end over the region of the navicular. The third limb extends distal and plantar to end at the base of the first metatarsal. The posterior incision is also composed of three limbs. Placing this incision on the lateral side of the Achilles tendon preserves a larger skin bridge between the two incisions and does not limit the exposure of the medial structures. The first limb begins along the posterolateral side of the calcaneus and angles proximally to the lateral border of the Achilles tendon. Two more limbs of equal length extending proximally complete the incision. The advantage of the zigzag incision is that much more side-to-side exposure can be gained with a shorter incision, and as the foot is corrected, the tension on the incision is largely eliminated. With this posterior incision, it is possible to reach from the posterior tibial tendon medially to well past the peroneal tendons laterally.

If the surgeon does not use the Cincinnati incision and desires to open the calcaneocuboid joint from the lateral side, he or she has two choices. An oblique incision in the skin lines can be made directly over the calcaneocuboid joint **(F)**. If this incision is used, the surgeon must be sure of its placement directly over the joint, or exposure becomes difficult. The second option is a curvilinear incision perpendicular to the calcaneocuboid joint **(G)**. This has the advantage of easier exposure and heals with surprisingly little scarring.

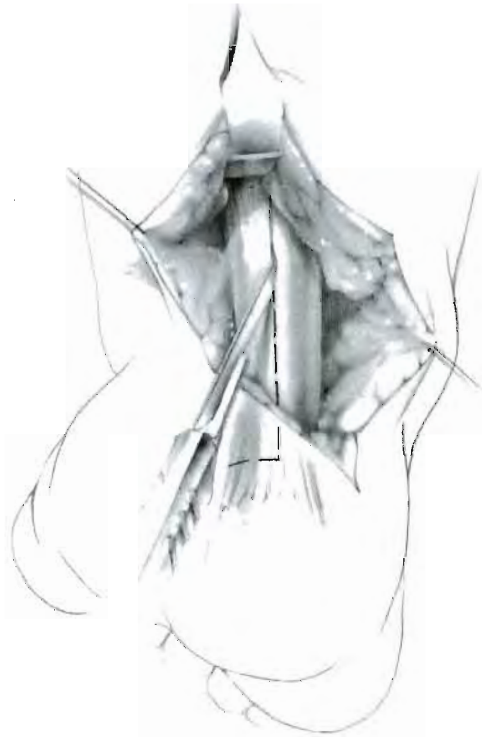


FIGURE 7-2. The patient is positioned prone. The foam head cradle used by anesthesiologists to support the head serves as an excellent support for the prone infant. It can be raised with a folded sheet underneath it to allow better access to the foot.

The skin is divided sharply down to the Achilles tendon. It is important to preserve the sheath of the tendon. This is best accomplished by leaving the sheath attached to the subcutaneous tissue. Therefore, the incision in the skin and subcutaneous tissue is carried directly down onto the tendon, passing through its filmy sheath. Then, the tendon is exposed circumferentially by gently teasing its sheath away with a small elevator. A large amount of proximal exposure can be achieved by placing the blade of a Senn retractor proximally and pulling upward while "toeing in" on the retractor.

It is possible to divide the tendon in a Z fashion. This starts proximally with a cut in the middle of the tendon. It should be sufficiently long because it is often surprising how much length is needed in a severe clubfoot. When the knife reaches the calcaneus, it is turned medially to detach the medial half of the tendon from the calcaneus. The medial half is detached to lessen the varus force. With the Senn retractor elevating the skin proximally, the lateral half of the tendon is detached proximally. Both halves are dissected free. The proximal half can be curled under the skin and subcutaneous tissue proximally where a tunnel was formed. A suture can be passed through the distal half, attached to a small hemostat, and wrapped in a moist sponge to hold it out of the way.

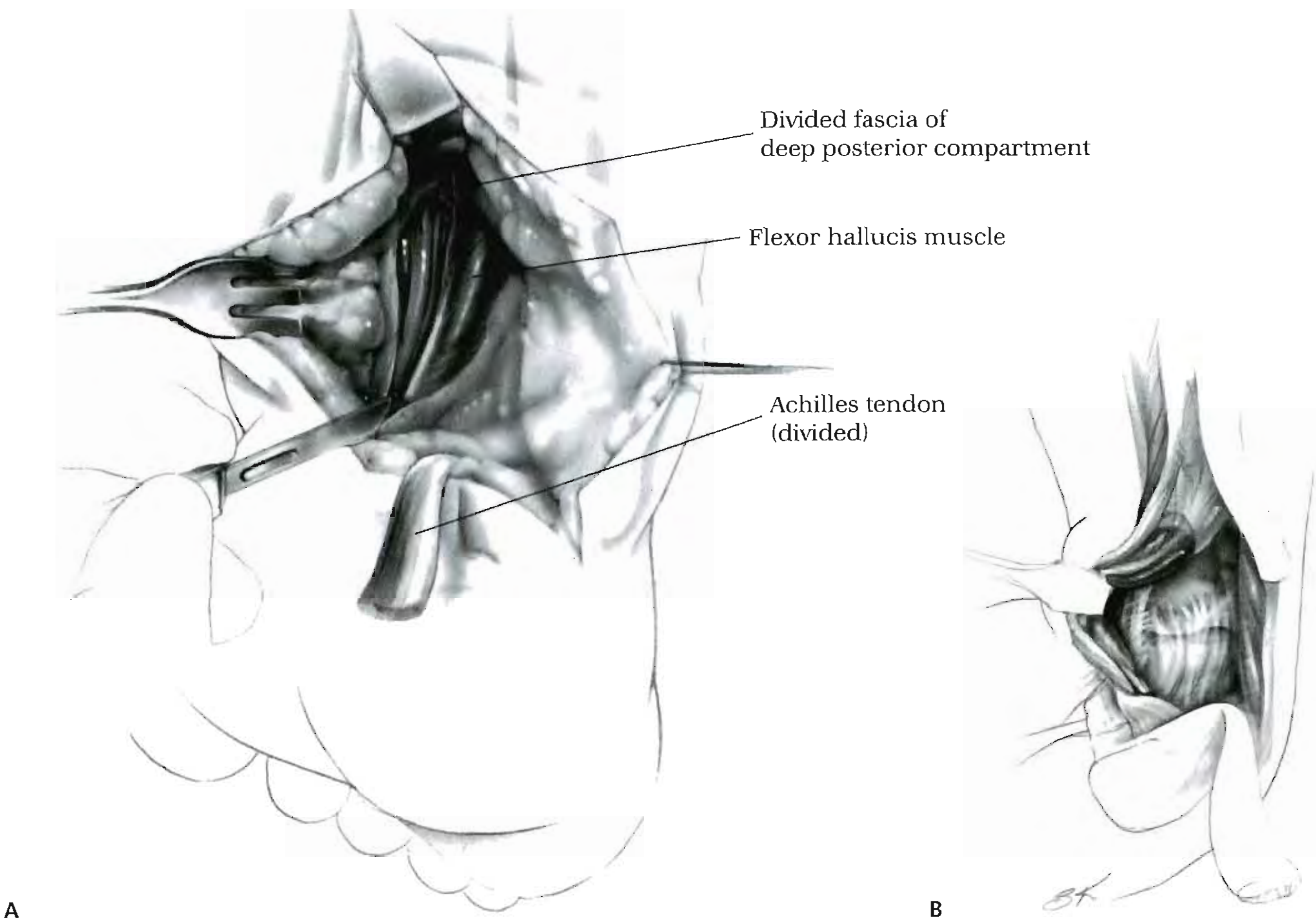


FIGURE 7-3. The next step is to open the deep posterior compartment. The surgeon may be tempted to do this by spreading with a scissors or hemostat, but this is unnecessarily destructive and can only lead to poor healing and scarring. The posterior compartment is a distinct anatomic compartment and can be opened by incising it with a knife. Starting proximally, the fat under the Achilles tendon is sharply incised in a straight line. As this incision is deepened, the fascial boundary of the compartment is encountered and, beneath it, more fat in the posterior compartment. Often, after this incision is completed, the anatomic structures in the posterior compartment come instantly into view **(A)**. In addition, in the severe clubfoot, the normal anatomic relationships may not remain. In such cases, the incision may come down directly over the posterior tibial nerve, as illustrated here. Note the flexor hallucis longus just lateral to the nerve. This structure is the first landmark to identify in the posterior compartment and is easily recognized as the only tendon passing behind the medial malleolus in which the muscle belly extends this low. This is easily remembered as the only muscle with "beef at the heel."

A small periosteal elevator is used to dissect beneath this muscle, staying in close contact with the posterior capsule. This dissection is continued around the medial side of the ankle as far as the posterior aspect of the medial malleolus. The dissection is facilitated by opening the sheath of the flexor hallucis longus distal to the medial malleolus to allow this muscle to be displaced. The neurovascular bundle is elevated with the fatty tissue and does not need to be disturbed. If a plantar release will be performed later in the procedure, it is easiest to dissect the neurovascular bundle out at this point to facilitate its exposure from the medial incision. A Senn or House retractor can be used to retract all these structures, giving a clear view of the posterior capsules from the midline to the medial malleolus **(B)**. Allowing the foot to go into plantar flexion makes this exposure even easier.

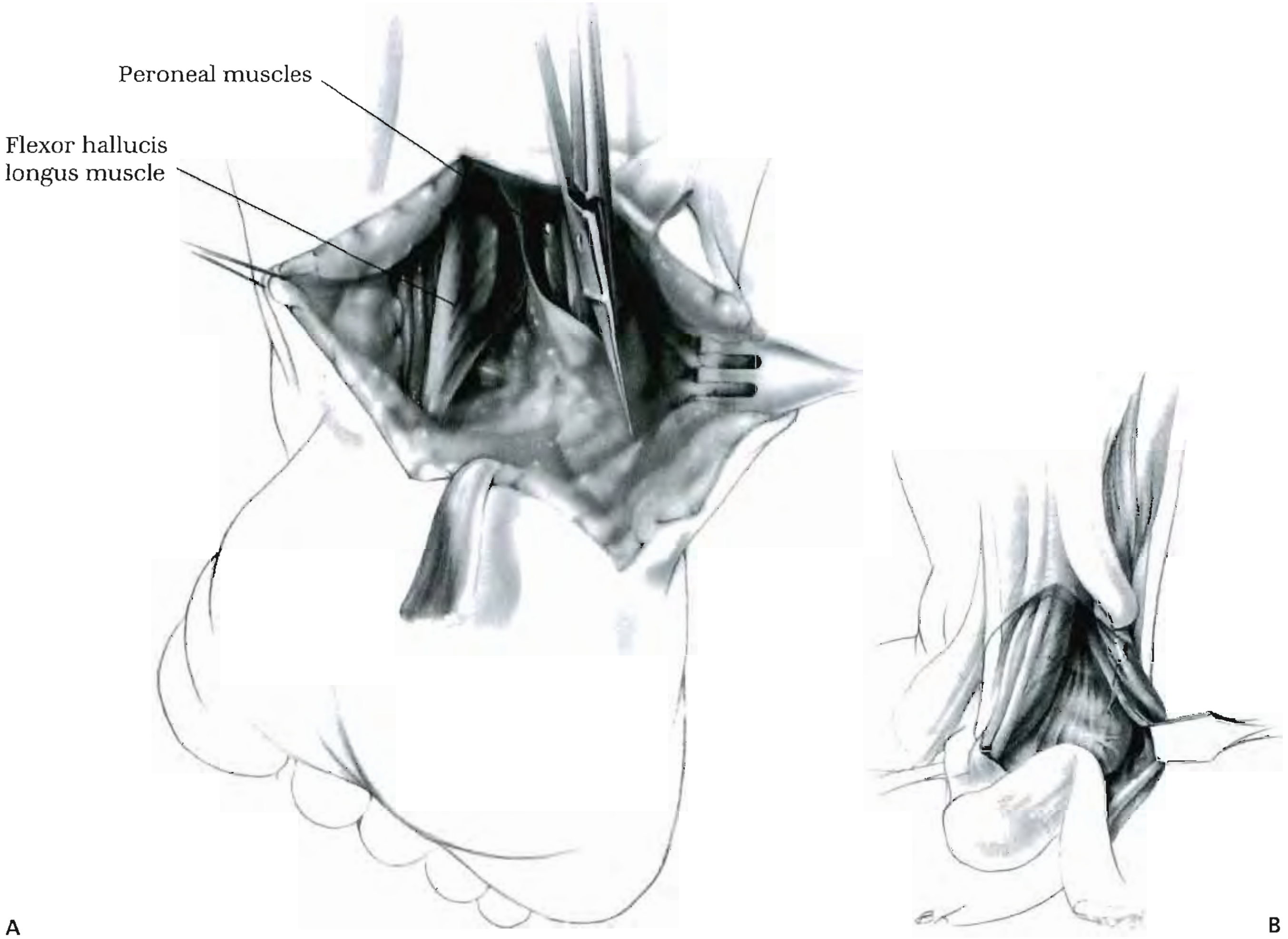


FIGURE 7-4. The lateral side of the capsules must now be exposed in the same manner. This is most easily accomplished by incising the fascia over the peroneal muscle bellies. These muscles are enveloped in fat and fascia lateral to the flexor hallucis longus, whose muscle belly is shown exposed along the neurovascular bundle. After the muscle tissue is identified, a scissors is used to open this fascial envelope around the peroneal muscles and tendons **(A)**. This incision should be carried to the point where the peroneal tendons curve under the lateral malleolus so that these tendons can be retracted sufficiently to permit a complete division of the calcaneofibular ligament, which lies beneath the peroneal tendon sheath **(B)**. This completes the exposure of the posterior aspect of the tibiotalar and subtalar joint.

FIGURE 7-5. The next step is to open the posterior joints. In a severe clubfoot, the posterior edge of the calcaneus may be in direct contact with the posterior border of the tibia, obscuring the talus. To facilitate this exposure, the fibrofatty tissue and capsule over the posterior aspect of the joint are sharply excised with a knife. This should expose the talocrural and subtalar joints at the same time. A scissors can be used to extend the capsular incision medial and lateral.

The tibiotalar joint can be identified by palpation and inspection while the foot is flexed and extended. The fibrofatty tissue is first excised with a knife, and then the scissors is inserted with one blade in the joint and the other outside the joint. The capsule is opened around the medial side until the flexor digitorum longus muscle is identified. Two notes of caution: be sure the neurovascular structures are retracted, and go slowly behind the medial malleolus to avoid dividing the flexor digitorum longus and posterior tibial tendons. The peroneal tendons are now retracted, and the incision in the capsule is continued around the lateral side. As the foot is dorsiflexed, the dome of the talus comes into view. Cutting the calcaneofibular ligament usually makes the largest difference in the amount of dorsiflexion that is obtained.

FIGURE 7-6. The subtalar joint can now be opened if the surgeon wishes to do so. The subtalar joint is found close to the tibiotalar joint posteriorly. Use the scissors to open this capsule and extend the incision in the capsule medially and laterally. On the medial side, caution must be used to avoid cutting the flexor hallucis tendon that runs along the medial aspect of the subtalar joint. With care, this can be retracted, allowing the subtalar joint to be opened as far medially as the tibiotalar joint.

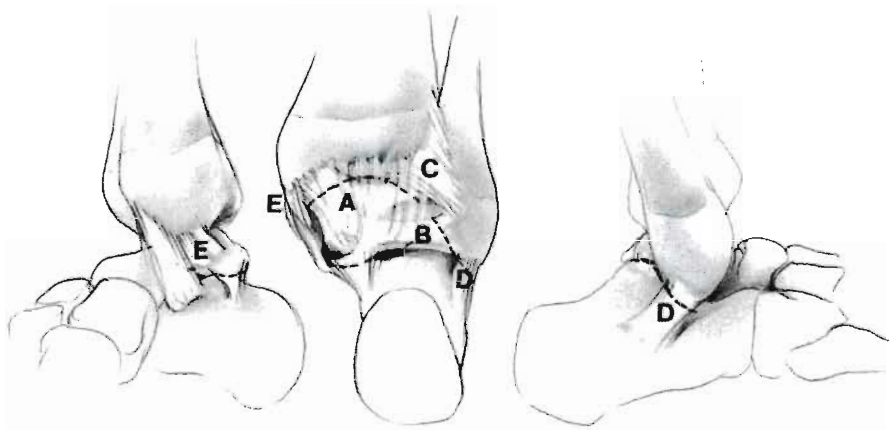


FIGURE 7-7. Although many illustrations of clubfoot surgery show the ligaments of the posterior capsule as distinct structures, the surgeon rarely sees them this way because they are merely condensations of the continuous posterior capsule. Occasionally, the posterior fibulotalar ligament and the calcaneofibular ligament stand out, the latter appearing like a tendon. The geographic cuts in the posterior capsule of the tibiotalar and subtalar joints divide the ligaments as shown: the posterior tibiotalar ligament **(A)**, the posterior talofibular ligament **(B)**, the talofibular ligament **(C)**, the calcaneofibular ligament **(D)**, and the deltoid ligament **(E)**.

The deltoid ligament consists of several parts. One part of the deltoid ligament, referred to as the *deep deltoid ligament* (anterior tibiotalar part of the deltoid ligament), is attached to the talus and, in the opinion of many surgeons, should not be divided to avoid the complication of lateral subluxation of the talus. Division of this part of the deltoid ligament is avoided by stopping the capsulotomy of the tibiotalar joint at the posterior aspect of the medial malleolus. If it is desired to divide this portion of the deltoid ligament as a part of the operation, as is done in the procedure described by Goldner (5), it should be repaired.

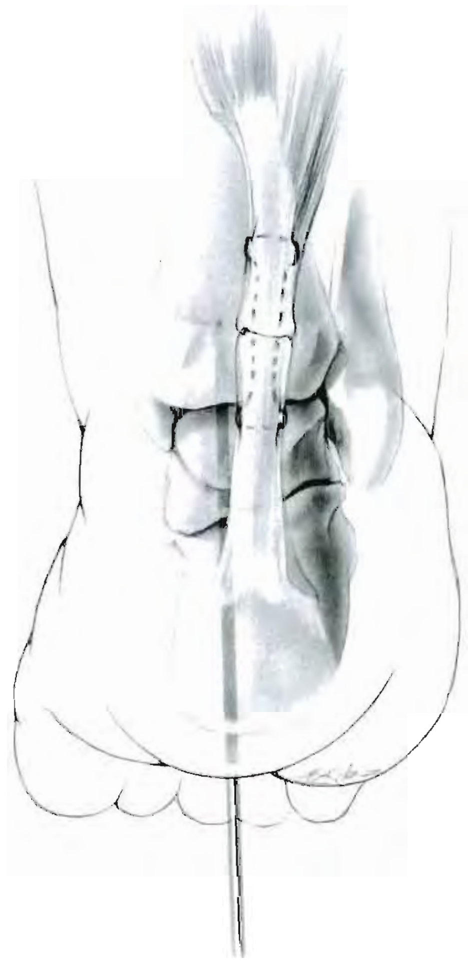


FIGURE 7-8. Repair of the Achilles tendon is all that remains to be done posteriorly. This should be done after the completion of the entire release and after the foot is reduced and fixed with Kirschner wires. The tendon may be repaired end to end with a Kessler type of stitch or side to side. The repair should be under modest tension to avoid unnecessary weakening of the gastrocnemius muscle.

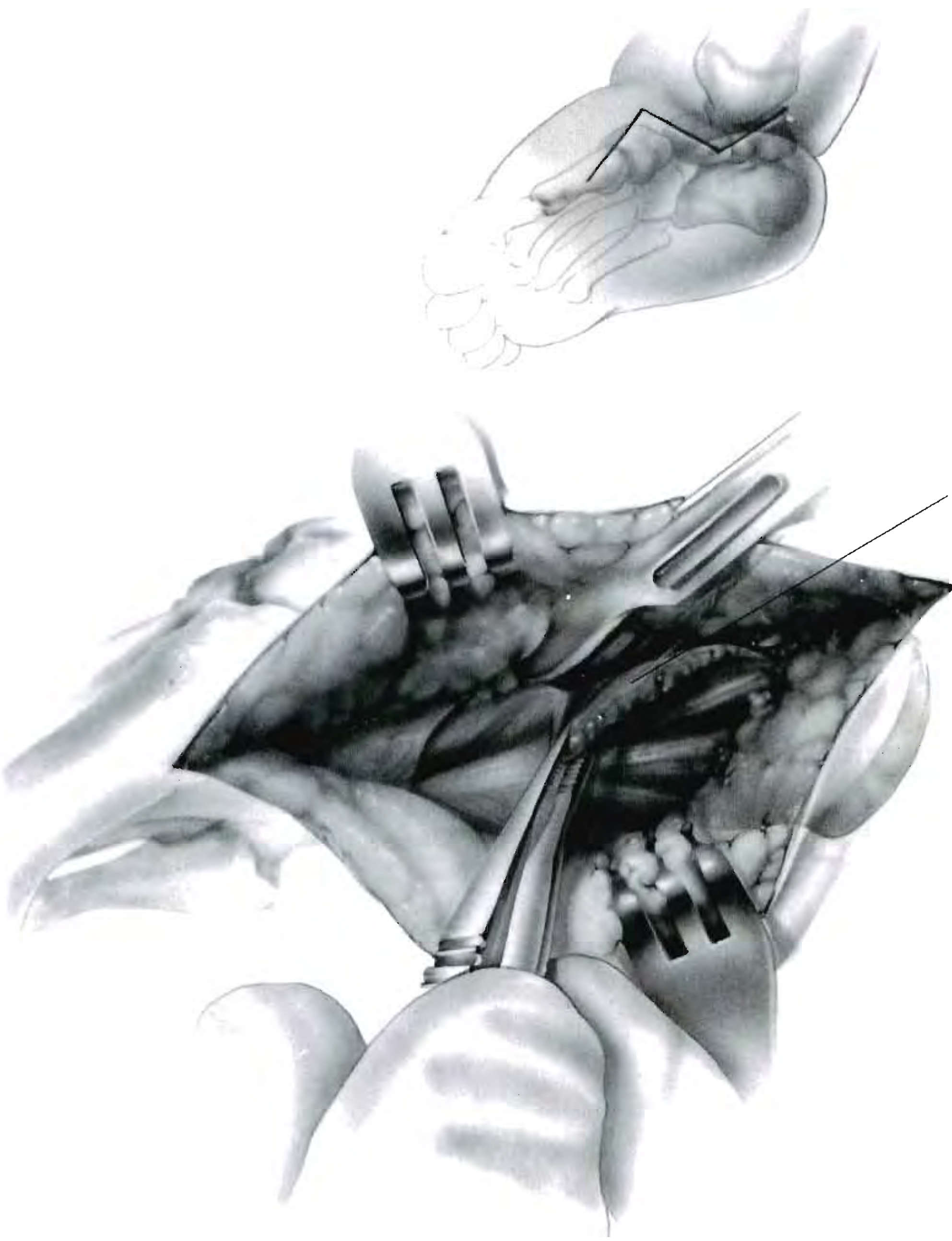
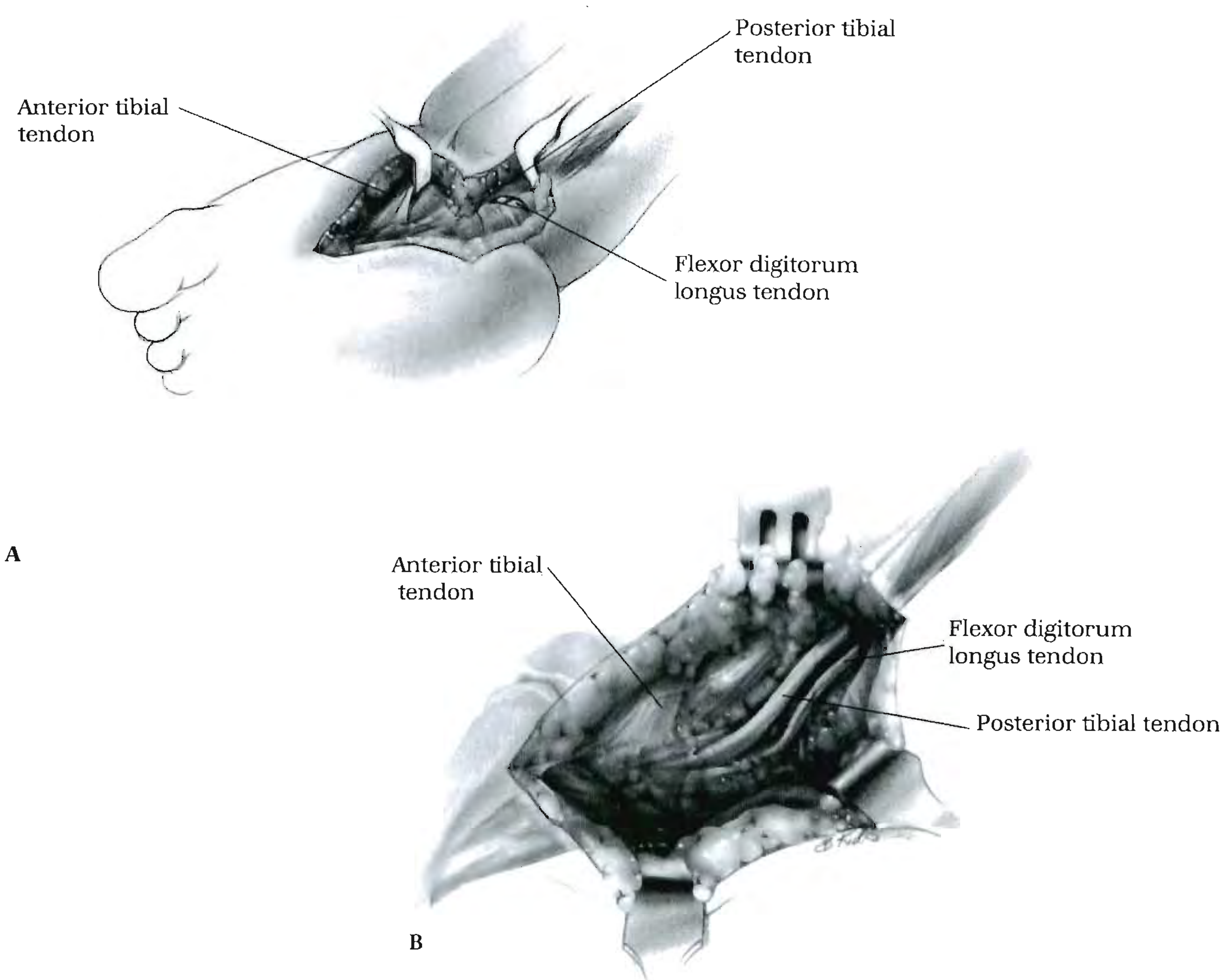


FIGURE 7-9. Despite the fact that this is called a *medial release,* much of the operation occurs on the sole of the foot and a lesser part on the dorsum. The key to this part of the operation is the exposure, and the key to this exposure is the abductor hallucis muscle, which Henry has called the door to the cage (6). The cage is that space formed by the arch of the skeleton.

After the skin incision is made, it is deepened to the belly of the abductor hallucis muscle. The dorsal edge of this muscle is then identified and detached all the way back to its insertion on the medial tuberosity of the calcaneus. This muscle is hinged downward with a small periosteal elevator that dissects it off the underlying fascia. Be careful when detaching the posterior insertion of the abductor hallucis because the neurovascular bundle will run beneath the muscle in this region. At this point in the dissection, little of the important anatomy is visible because it is all hidden beneath the fascia. The next step is to expose all of the essential anatomic structures.



Posterior tibial tendon
Anterior tibial tendon
Flexor digitorum longus tendon
A
Anterior tibial tendon
Flexor digitorum longus tendon
Posterior tibial tendon
B

◀ **FIGURE 7-10.** The dissection on the dorsal surface of the foot is the easiest. This part of the dissection is necessary only to open the dorsal capsule of the talonavicular joint and therefore does not have to be extensive. This dissection can be done either with a knife or by spreading with the scissors. The subcutaneous fat is lifted off the deep fascia covering the bones. The only important structure that needs to be identified is the anterior tibial tendon. This dissection is beneath this tendon, staying directly on the bony structure of the dorsum of the foot close to the ankle. Do not unnecessarily divide the small blood vessels that are seen in this area; all that is needed is enough exposure to divide the dorsal capsule of the talonavicular joint **(A)**.

To gain access safely beneath the fascia covering the structures on the sole of the foot, first identify the posterior tibial and the flexor digitorum longus tendons that run behind the medial malleolus. A small, carefully made, transverse incision extending posterior from the tip of the medial malleolus will cut open their sheaths without cutting the tendons **(A)**. The sheath of the flexor digitorum longus tendon that lies just posterior to the posterior tibial tendon is opened first with a scissors. This sheath will guide the scissors beneath the navicular, where the master knot of Henry will be divided. The dissection of the flexor digitorum should be continued distal to the region beneath the metatarsals. The fascia is much thinner after passing the master knot.

The posterior tibial tendon will be dorsal. It is much shorter, seeming to end in the tuberosity of the navicular. Because the navicular is so close to the medial malleolus in an uncorrected clubfoot, the novice may think that this tendon is missing or may unknowingly transect it at its insertion **(B)**.

The medial plantar nerve from the posterior tibial nerve will run almost parallel to the flexor digitorum longus tendon in the sole of the foot and will be just volar to it. The medial plantar branch of the posterior tibial nerve can be followed proximally to help identify the neurovascular bundle just posterior to the flexor digitorum longus tendon behind the medial malleolus.

At the completion of this stage of the dissection, the following structures are visible: most volar is the medial plantar branch of the posterior tibial nerve, just dorsal to it and paralleling its course is the flexor digitorum longus, crossing this tendon transversely at the master knot of Henry is the flexor hallucis longus tendon, and splaying out over the tuberosity of the navicular is the insertion of the posterior tibial tendon. If the flexor digitorum longus tendon is retracted, the plantar ligaments, the peroneus longus tendon coming to insert on the base of the first metatarsal, and the medial side of the calcaneocuboid joint can all be exposed.

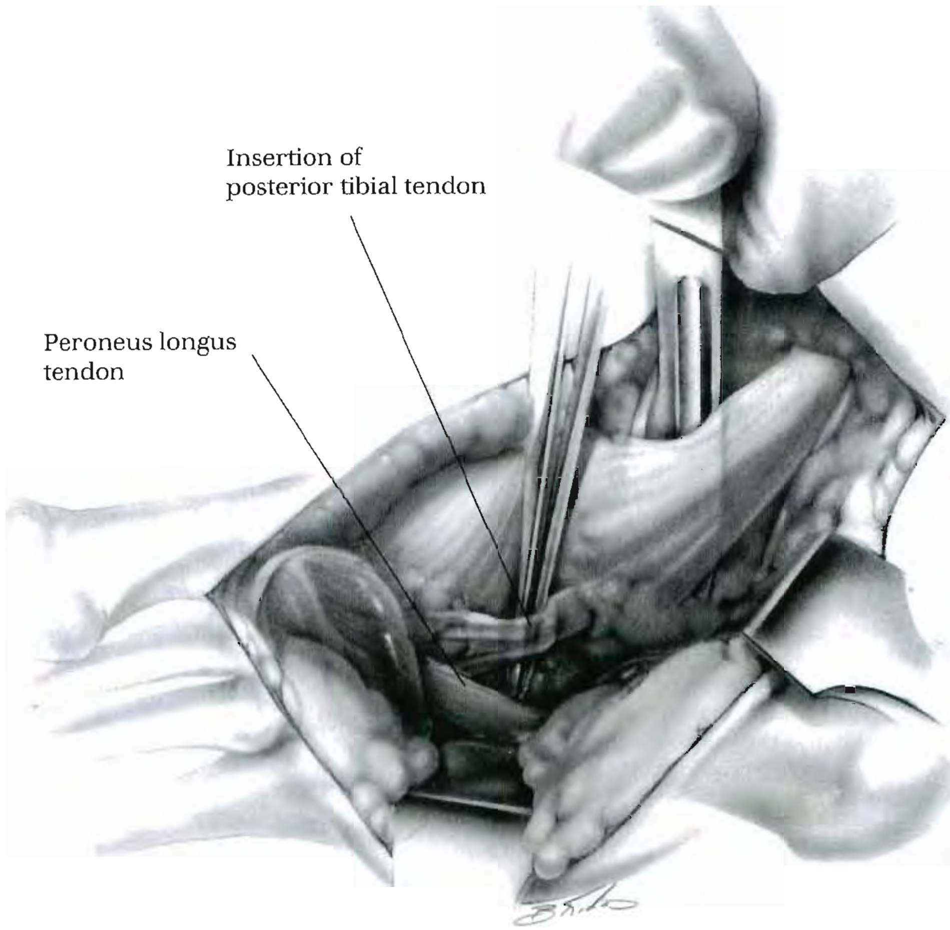
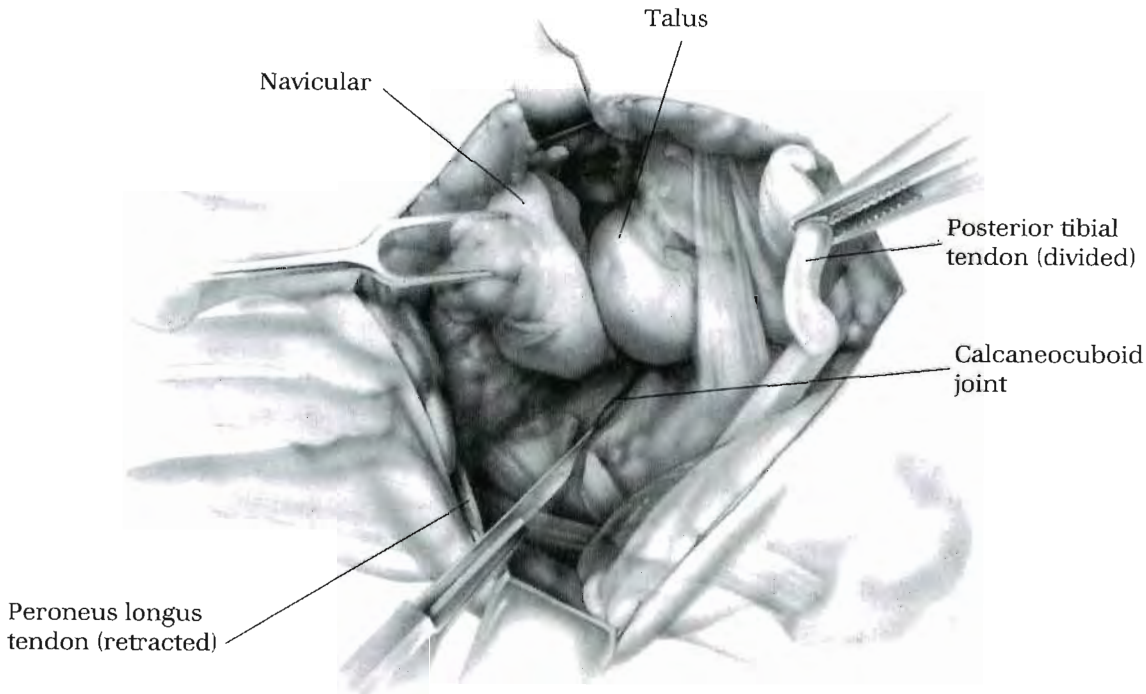


FIGURE 7-11. The posterior tibial tendon is now lengthened. This is necessary to gain release of the talonavicular joint as well as to lengthen the tendon.

The posterior tibial tendon can be lengthened in a Z fashion behind the medial malleolus, through either the medial incision or the posterior incision. Another method is to detach it from its insertion. To provide for the extra length of tendon that is required to lengthen the tendon, one of its insertions distal to the tuberosity of the navicular is identified and detached. These insertions are not easily seen. One major insertion passes down to the sustentaculum tali, whereas another insertion is an almost straight continuation of the posterior tibial tendon that runs beneath the cuneiform bone to the base of the first metatarsal. This one seems preferable.

An extension of the posterior tibial tendon is exposed by removing the fascia over it with a small, sharp periosteal elevator. At the same time, and by the same method, the peroneus longus tendon, which is coming from the lateral side of the foot to insert into the base of the first metatarsal, should also be identified. (For clarity, it is shown here as if retracted, but it will overlap the extension of the posterior tibial tendon.) This allows the distal insertion of the posterior tibial tendon to be divided without danger of cutting the peroneus longus tendon. This extension of the posterior tibial insertion is divided as far distally as possible. It is much smaller than the broad insertion of the posterior tibial tendon, which is now detached from the tuberosity of the navicular, but it is sufficient to reattach the tendon.



A

FIGURE 7-12. (A) With the posterior tibial tendon detached, it should be easy to identify the talonavicular joint, and it would be easy in a normal foot. In a clubfoot, it must be remembered that the navicular is displaced medially, causing it to lie on the medial side of the neck of the talus and closer than normal to the medial malleolus **(B)**. In addition, the space between the tuberosity of the navicular and the medial malleolus is filled with dense, fibrous tissue. This tissue can be excised with a knife if the surgeon knows the anatomy. Leave a small portion attached to the navicular for reattachment of the posterior tibial tendon. (*Figure continues*).

B

C

FIGURE 7-12. ***(Continued)***

A scissors is used to open the talonavicular joint. This joint is found by directing the scissors distally toward the first metatarsal between the neck of the talus and the navicular **(B)**. The error is to cut transversely across the foot as if the anatomic relationship between the navicular and the talus were normal. This is especially dangerous if done with a knife because it is not difficult to divide the cartilaginous neck of the talus. At the same time, the surgeon should be careful to avoid opening the naviculocuneiform joint. This will further devascularize the navicular and tends to destabilize the navicular, permitting it to rotate out of position and creating a significant "recurrence." The navicular is easily retracted by inserting a sharp double-pronged skin hook. This exposes the joint and aids in cutting the dorsal and volar capsule. (Much of the capsule in this drawing has been removed for clarity, but this should not be done during the surgery.)

The dorsal aspect of the talonavicular joint is easy to open; however, the volar aspect usually remains tight even after the capsule is cut. To free it, the plantar calcaneonavicular (spring) ligament and the anterior portion of the deltoid ligament inserting into the navicular (tibionavicular ligament) must be divided. Because these ligaments are condensations of the capsules, they will be divided when the capsules between the talus and the navicular dorsally and the calcaneus and the cuboid volar are opened. This can be done with a scissors or a knife when the surgeon is certain that he or she has identified the joint.

Volar and lateral to the talonavicular joint and almost in line with it is the medial side of the calcaneocuboid joint **(C)**. This medial capsule can be opened, but it is unlikely that sufficient capsule will be opened from the medial side to permit much mobility of this joint.

Because the peroneus longus tendon crosses the most volar and lateral aspect of this joint, it should be retracted. Shown in **A** is the retracted peroneus longus tendon; it is seen in its more normal relationship in Figure 7-11. The medial capsule of the calcaneocuboid joint, like all of the other capsules, can be opened safely with a scissors, although some experienced surgeons prefer to use a knife. The lateral aspect of the capsule can be divided by passing a small, sharp periosteal elevator or similar instrument through the joint and pushing this repeatedly through the lateral capsule while palpating the lateral aspect of the joint through the skin with the opposite hand.

If desired, the remainder of the subtalar joint capsule can be divided. If the navicular does not slide around the head of the talus but instead opens like a book, it may be necessary to open the lateral side of the calcaneocuboid joint and remove bone from the lateral side. Release of the plantar fascia is another step that aids in the proper reduction of the navicular on the talus.

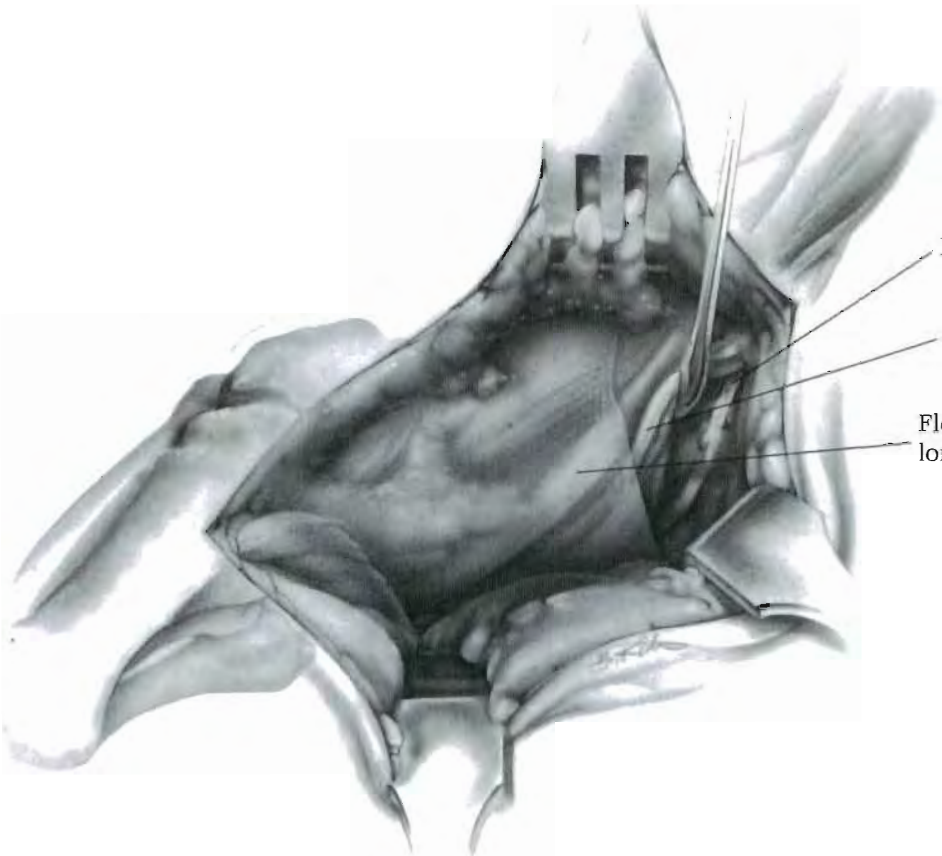


FIGURE 7-13. Another component of the medial release is the division of the plantar fascia and muscles at their insertion into the calcaneus, as described by Carroll (3). This part of the operation is done posterior to the neurovascular structures. The medial plantar nerve is identified easily in the neurovascular bundle. The lateral plantar nerve must also be identified. This can be done by following the medial plantar branch proximally until the lateral plantar branch is found. It will lie posterior to the medial plantar branch and, if followed for a short distance, will have a course that is more volar and lateral. Both of these branches and the vascular structures are retracted distally, exposing a fatty space behind them and above the plantar structures that are to be divided.

FIGURE 7-14. A plane is developed between the volar aspect of the plantar fascia and the subcutaneous tissue extending to the lateral border of the foot. A heavy Mayo scissors is inserted from the medial to lateral side with one blade in this plane and the other in the fatty space behind the neurovascular structures and above the plantar fascia and muscles. These structures can be divided at their insertion into the calcaneus.

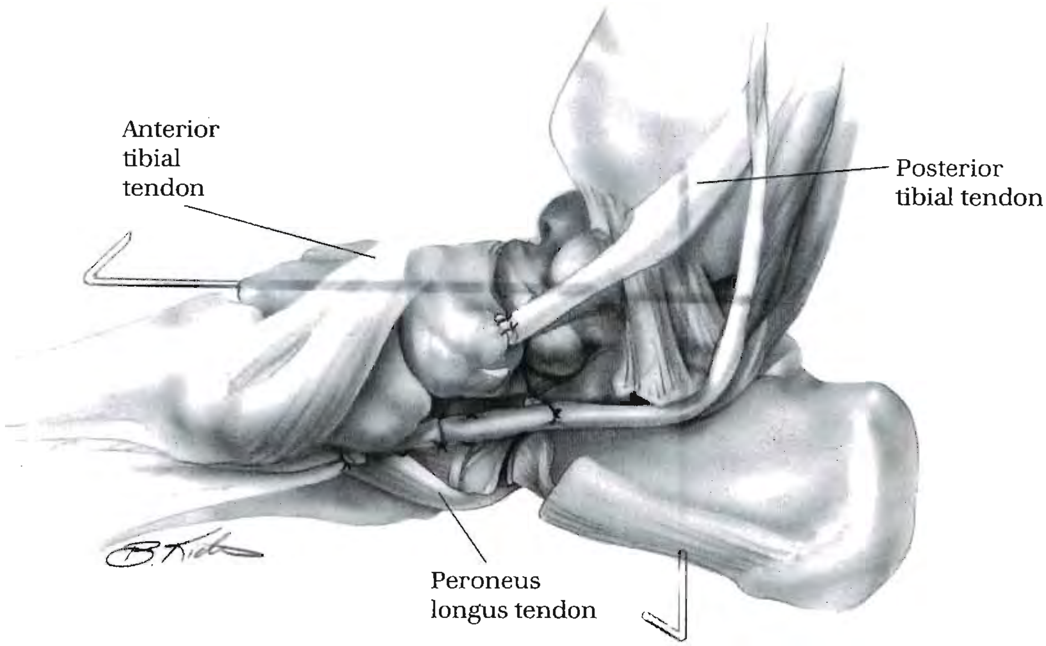


FIGURE 7-15. After the release is completed to the surgeon's satisfaction, the correction of the foot can be secured with two small Kirschner wires. The talonavicular joint is reduced first and transfixed with a smooth wire. This may be passed from distal to proximal or proximal to distal, starting through the posterior exposure. During this step, take care to see that the navicular is not displaced dorsally in relation to the head of the talus by keeping the foot dorsiflexed. The wire should not protrude from the talus posteriorly. It should remain protruding through the skin on the dorsum of the foot, where a short bend is placed in it. This way it can be removed in the office.

With the ankle held in neutral, one wire is passed or drilled through the skin of the heel, through the calcaneus and the talus, and into the tibia. The wire is cut off, leaving a short piece to be bent over.

If the surgeon wishes to obtain radiographs of the foot to verify the correction, they are done at this point. The posterior tibial tendon is reattached to the navicular. The flexor hallucis longus and the flexor digitorum longus are interconnected in the sole of the foot. They usually are both tight after correction of the foot, and some release is necessary. If the flexor hallucis is cut, the flexor digitorum longus is no longer tight. The surgeon, however, may not feel comfortable with this technique. A technique for lengthening these tendons is described.

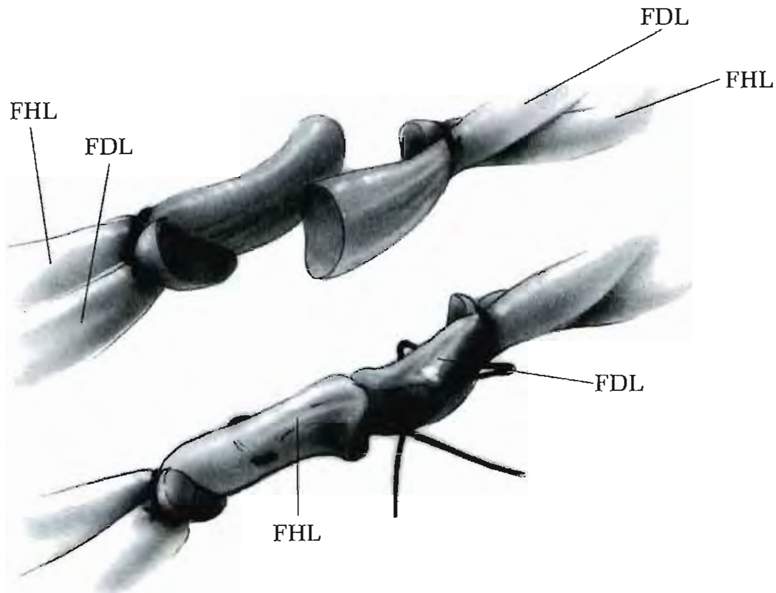


FIGURE 7-16. The flexor hallicus longus (FHL) and the flexor digitorum longus (FDL) need to be lengthened. If they are not, when the ankle is dorsiflexed, they will cause severe flexion of the toes. Although these tendons can be lengthened through the posterior incision, this can also be accomplished in the sole of the foot. As these two tendons are dissected in the sole of the foot, they will be seen to cross with a variable amount of interconnection. This is the reason they often move simultaneously.

To achieve this lengthening, the two tendons—the FDL and the FHL—are sutured together, both proximally and distally. Then the tendons are divided: one just proximal to where they are sutured together distally, and the other just distal to where they are sutured together proximally. These resulting cut ends then are sutured together under the appropriate tension. This is done most easily after the ankle and talonavicular joint are correctly positioned and transfixed with Kirschner wires.

Fine absorbable sutures used to close the skin do not cause undue reaction and obviate the need for removal. A small suction drain can be placed that runs from the posterior operative field, under the medial skin bridge into the medial wound, and out through the skin distal to the medial incision. This will greatly reduce the postoperative swelling.

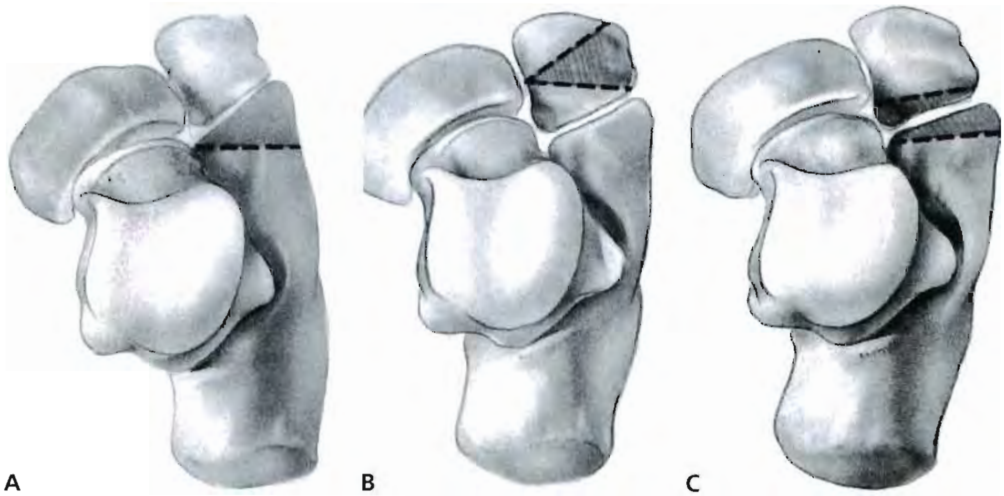


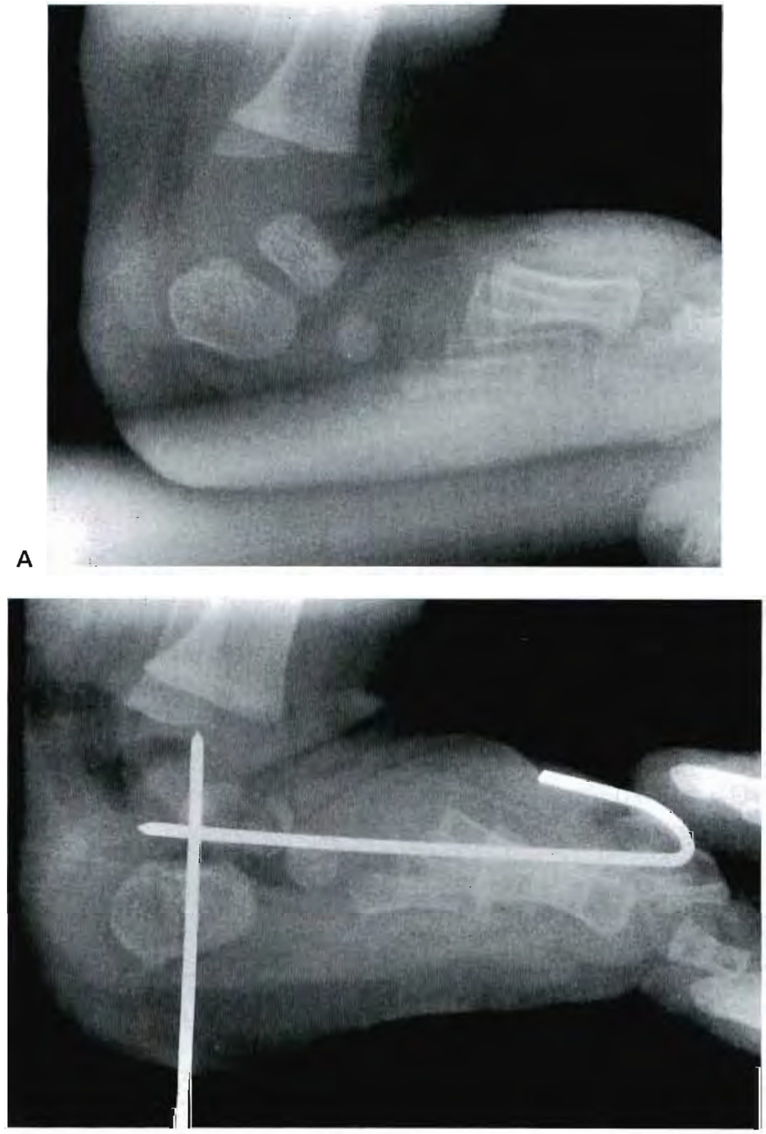
FIGURE 7-17. If a lateral release is required, the calcaneocuboid joint can be exposed by use of the Cincinnati incision or either of the other two incisions described.

After dividing the subcutaneous tissue, the muscle of the abductor brevis muscle is visible. This muscle is detached proximally and reflected distally to expose the calcaneocuboid joint. The tendon of the peroneus brevis will run over the volar aspect of the joint and should be freed and retracted volarly.

Although numerous methods have been described to shorten the lateral column of the foot, there are three that receive the widest use. The Lichtblau procedure is based on the assumption that adaptive changes in the calcaneocuboid joint are what prevent adequate reduction (7). With the medial displacement of the navicular, the lateral side of the calcaneus overgrows, and the result is a calcaneocuboid joint that is angled in such a way that the cuboid cannot be laterally displaced on the calcaneus **(A)**. The operation, which is recommended for children older than 2 years of age, excises a laterally based wedge from the distal end of the calcaneus. The resulting fibrocartilaginous joint functions well and remains asymptomatic.

Goldner (5) achieves the shortening of the lateral side of the foot by resecting a wedge of bone from the cuboid bone. This preserves the joint surfaces and is more effective than decancellation of the bone **(B)**. This operation can be used at any age, if deemed necessary by the surgeon.

The final method of achieving lateral column shortening is that described by Evans (8), who called attention to the lateral column of the foot. This operation excises a portion from each side of the calcaneocuboid joint. The defect created by the wedge is held closed by staples and is intended to result in fusion **(C)**. The operation is not recommended before the age of 4 years; before that age, too much of these bones is cartilage, and fusion will not result.



A

B

FIGURE 7-18. A: Lateral radiograph of a 4-month-old child with uncorrected clubfoot. **B:** Postoperatively, the parallelism between the talus and the calcaneus has been corrected. The pins are shown in place. The surgeon chose not to transfix the talotibial joint.

POSTOPERATIVE CARE

There are so many dearly held beliefs about what is important in the postoperative management of the clubfoot that we can only relate what we do and why (with no more scientific certitude than a surgeon who does something different).

Before closure of the wound, some steps should be taken to minimize the bleeding in the foot because this can cause considerable swelling, which may necessitate splinting or removal of the cast. We each use a different technique. One prefers to insert a small Silastic drain running from the posterior wound through the medial wound and out of a small stab wound distal to the medial incision. This drain is removed the day after surgery. The other of us releases the tourniquet and achieves wound hemostasis before closure. At the conclusion of surgery, the patient is placed in a long-leg cast with the knee bent 90 degrees. This allows a loose-fitting cast to be applied without danger of slipping off. At 6 weeks, this cast and the pins are removed in the office. There is no manipulation of the foot during the initial 6 weeks because full correction is gained at the operating table and secured with the wires. The use of the two zigzag skin incisions running longitudinally to the direction of tension, along with the broad medial area of intact skin, prevents any undue tension on the wound.

After removal of the pins, a short-leg cast is applied and maintained for an additional 4 weeks. After the cast is removed, there are several alternatives. One of us does no further treatment. Another option is the use of reverse last shoes set at 20 degrees of external rotation on a 6-inch Fillaeur bar. The reverse last shoes are intended to maintain the forefoot correction, whereas the bar promotes inversion and eversion along with some dorsiflexion and plantar flexion as the child flexes and extends the legs. These are used for 3 to 4 months. A third option is the use of an ankle-foot orthosis in an overcorrected position used as a night splint.

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7.2 RESECTION OF CALCANEONAVICULAR COALITION

Mitchell and Gibson (1) reported on excision of calcaneonavicular bars that remain symptomatic after conservative treatment as an alternative to the usual treatment of triple arthrodesis. A subsequent report by Cowell (2) helped to popularize this approach, and following reports have validated the success of this operation (3–6). Between 80% and 90% of patients who have excision can expect an acceptable result. Some surgeons believe that talar beaking represents arthritis of the talonavicular joint and thus a contraindication to this surgery. It has been pointed out, however, that this change is actually extraarticular and probably a result of the excessive motion at this joint, producing traction on the ligaments. It would appear from the reported results that this is not a contraindication to this procedure (Figs. 7-19 to 7-23).

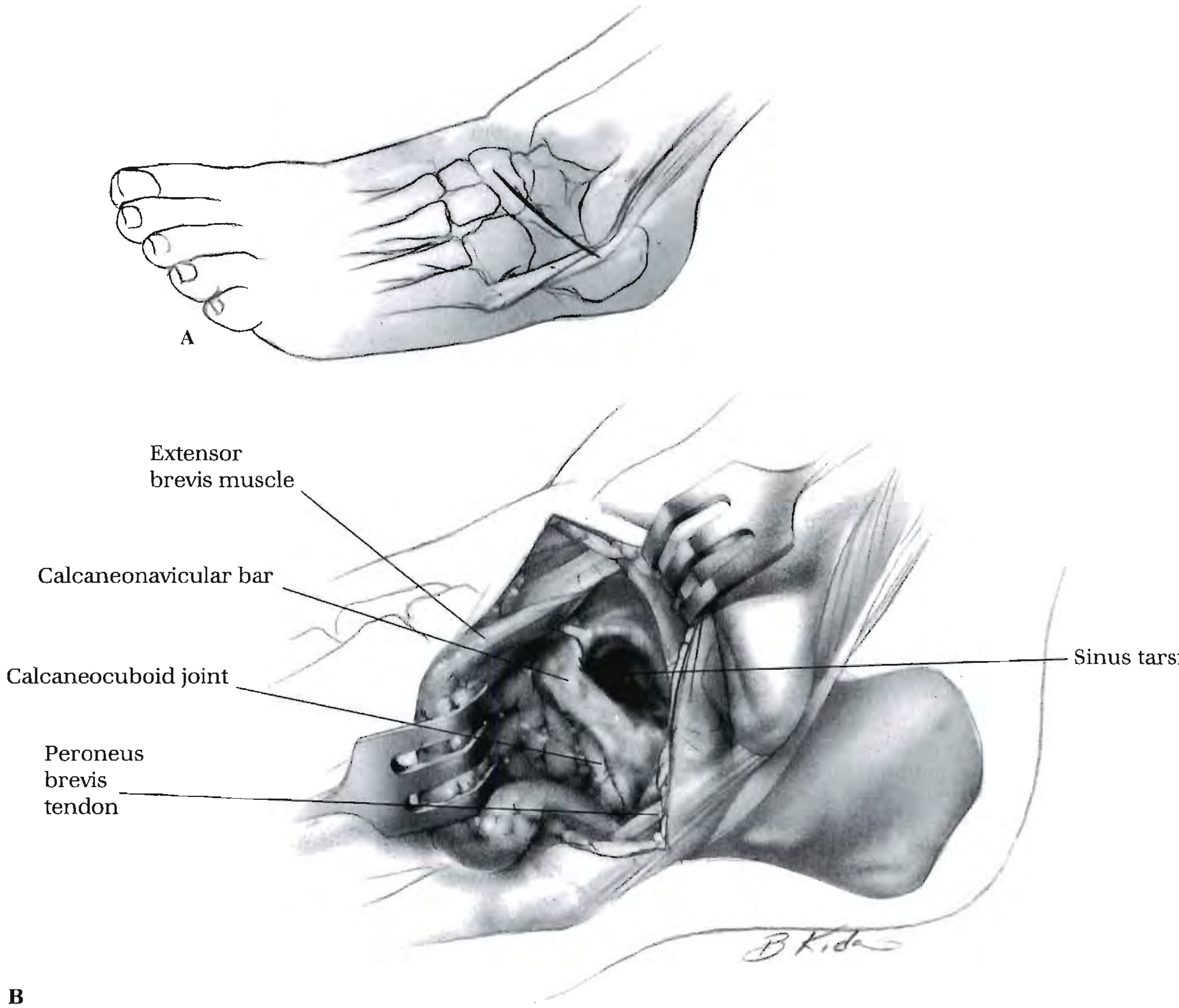

FIGURE 7-19. The calcaneonavicular bar is approached through the Ollier incision on the lateral side of the foot. The incision should extend from the extensor tendons to the peroneal tendons in a skin crease over the coalition **(A)**. It is important that the initial incision be made through the entire layer of skin, subcutaneous tissue, and fascia overlying the extensor brevis muscle without undermining the wound edges. This is very thin skin that must be handled with care.

After the fascia of the extensor brevis muscle is opened, it is elevated proximally off the muscle itself. This leads to the fibrofatty tissue in the sinus tarsi. It is not necessary to remove all of this tissue but rather only the most distal portion that covers the distal surface of the calcaneus and the talus. After exposing the origin of the extensor brevis muscle, an incision is made into this fibrofatty tissue. This incision is made deep into the sinus tarsi. These portions of the fibrofatty tissue and the extensor brevis muscle are dissected distally as a unit, exposing the distal talus and calcaneus, the bar connecting the distal end of the calcaneus and the navicular, and the proximal portion of the cuboid **(B)**.

FIGURE 7-20. A hemostat can be placed on the fibrofatty tissue to retract it and the extensor brevis muscle out of the way without damaging the muscle that will later be used to fill the area where the bar is excised. At this point, the anatomy should be easily visible, showing the coalition. An understanding of the normal anatomy is important at this point in planning the excision. If too much is excised, the joints will be violated. If too little is excised, motion will not be restored, and the bar may reform. The most common error is to excise too little bone from the medial side of the bar. It is important that the piece of bone excised be trapezoidal and not triangular.

A $^1/_4$-inch straight osteotome is used to excise the bar. Good exposure of the sinus tarsi, where the calcaneus and the talus are in close approximation, will aid in directing the osteotome in the correct direction. If the surgeon is unsure, an image intensifier may be used.

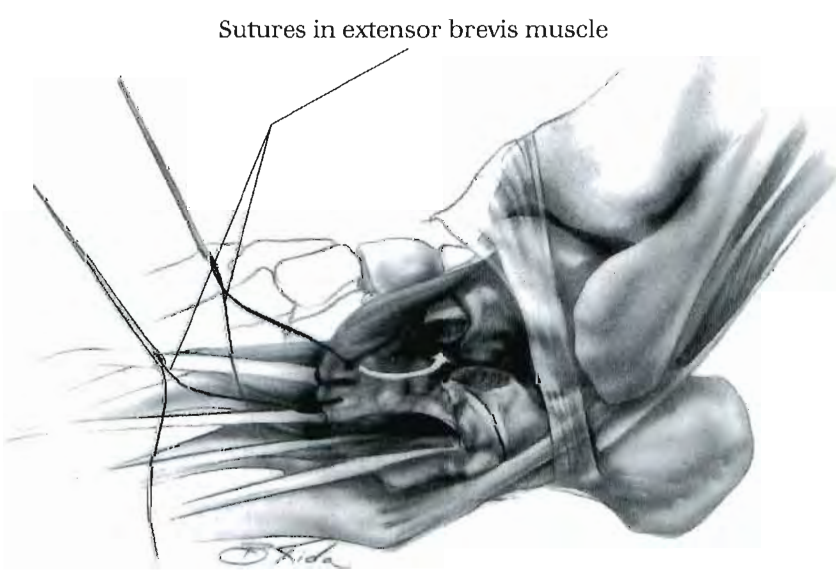

FIGURE 7-21. After the bar is excised, the surgeon should be able to see a distinct gap separating the anterior aspect of the calcaneus and the navicular. In addition, examination of the foot should confirm that subtalar motion is restored. It should be possible to displace the origin of the extensor brevis muscle into this gap between the calcaneus and the navicular that was created by removal of the bar. The excess of fibrofatty tissue that is not needed can be cut off and discarded.

A heavy absorbable suture is threaded through the end of the extensor brevis muscle, and a long, heavy, straight Keith needle is threaded onto each end of the suture.

FIGURE 7-22. The two straight Keith needles are passed through the gap that was left by the excision of the bar and out through the skin on the medial side of the foot. As the needles emerge, they are passed through a small piece of sterile foam and a sterile button.

A forceps is used to guide the muscle deep into the defect while the suture is pulled through and tied over the button on the medial side of the foot. This should result in the muscle being interposed between the cut ends of the calcaneus and navicular.

The wound is closed with interrupted absorbable sutures in the deep layer of muscle fascia and subcutaneous tissue that was carefully preserved at the beginning of the operation. The skin is closed with care to evert the skin edges. A short-leg cast is applied.

A

B

C

FIGURE 7-23. A: Oblique radiograph of the foot of a 10-year-old girl with 1 year of foot pain demonstrating an incomplete calcaneonavicular coalition. **B:** Note the incomplete coalition in the opposite asymptomatic right foot. **C:** One year after resection of the coalition, no reformation of the bar has occurred.

POSTOPERATIVE CARE

Cowell (2) has recommended removal of the cast after 10 days. At this time, the foam pad and button are cut free from the pull-through suture. Active and passive exercises are begun to increase the range of motion in the subtalar joint. Progressive weight bearing is started using a three-point partial weight-bearing crutch gait. As the patient tolerates it, the weight is increased until full nonassisted weight bearing is resumed.

References

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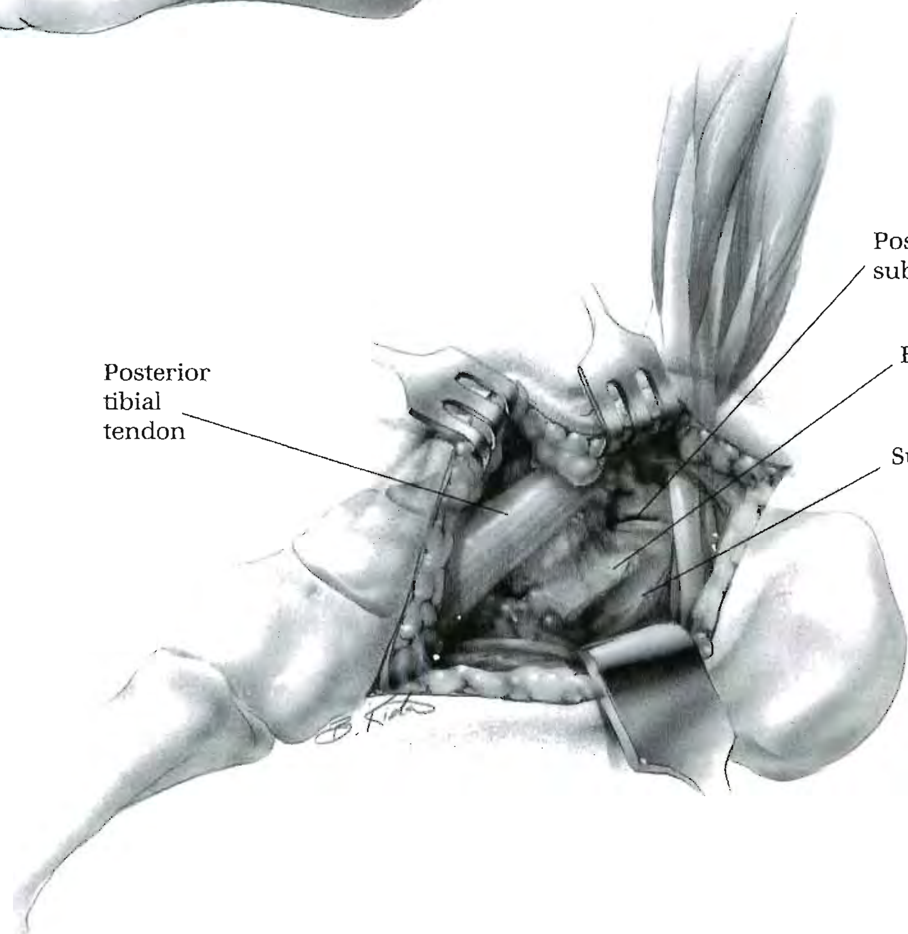
7.3 EXCISION OF TALOCALCANEAL COALITION

Historically, excision of persistently symptomatic talocalcaneal coalition has not been popular because of the uncertainty of a successful outcome (1–3); however, several reports have documented greater success with this procedure (4–6). This may be due in part to the use of computed tomographic scanning to determine the extent of joint involvement before undertaking surgical excision. Exactly how much of the joint can be involved and how successful a result can be achieved are not known. Scranton (4) does not recommend excision if more than 50% of the joint is involved (Figs. 7-24 to 7-27).

A



B

FIGURE 7-24. A slightly curved incision about 6 to 7 cm in length is made over the sustentaculum tali following the course of the flexor digitorum longus tendon **(A)**. The incision should extend from the prominence of the navicular to the area posterior to the posterior facet of the subtalar joint. If muscle fibers of the abductor hallucis are encountered, they are reflected plantarward. The flexor retinaculum, which overlies the sustentaculum tali, must be opened to allow the flexor digitorum longus tendon, along with the neurovascular bundle, to be retracted plantarward. The flexor hallucis longus tendon, which runs just beneath the sustentaculum tali, can also be retracted out of the way. The posterior tibial tendon can be identified running above the sustentaculum tali.

At this point, the coalition will not be apparent because it lies beneath the periosteum and the sheath of the flexor digitorum longus **(B)**.

FIGURE 7-25. To expose the coalition and define its anterior and posterior boundaries, an incision is made in the periosteum slightly to the dorsal side of the prominence, which is the sustentaculum tali and the middle facet coalition. The periosteum, including the sheath of the flexor digitorum longus tendon, is elevated off of the bony prominence and reflected volarly. This should be done with care because, although this periosteum is often thin, it will be necessary to approximate it later to hold the fat graft in place. This dissection should be carried far enough anteriorly and posteriorly to identify normal joint space. The medial aspect of the coalition and its anterior and posterior boundaries are now identified. The lateral extent of the coalition can be judged from the preoperative computed tomographic scans. It is a good idea, at this point, to test the motion of the subtalar joint. Some slight motion may be observed in the normal parts of the joint that are exposed. This will be useful for comparison after excision of the coalition.

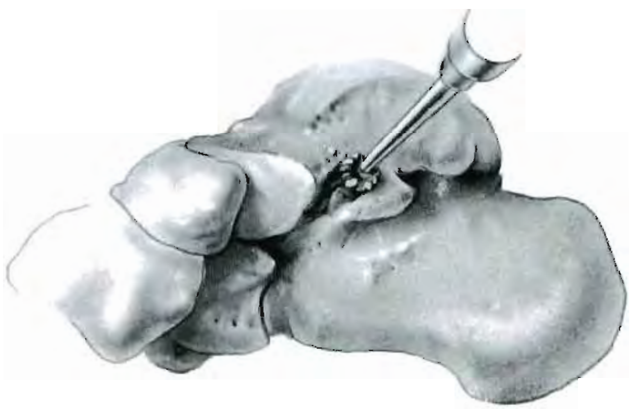


FIGURE 7-26. To begin the excision of the coalition and preserve as much of the sustentaculum as possible, it is helpful to define the exact location of the coalition within the bony mass. To accomplish this, a small osteotome can be used to shave off thin layers of bone until the fibrous or cartilaginous coalition is identified. This is only possible when the coalition is not completely ossified. If it is completely ossified, its removal can be guided by the normal joint surfaces distal and proximal.

Using a small rongeur or a power bur, the coalition is excised. The excision should not be unnecessarily wide, and as much of the sustentaculum tali as possible should be preserved. The removal of bone is continued until joint cartilage is seen anteriorly, posteriorly, and laterally from the excision. At this point, subtalar motion should be improved markedly.

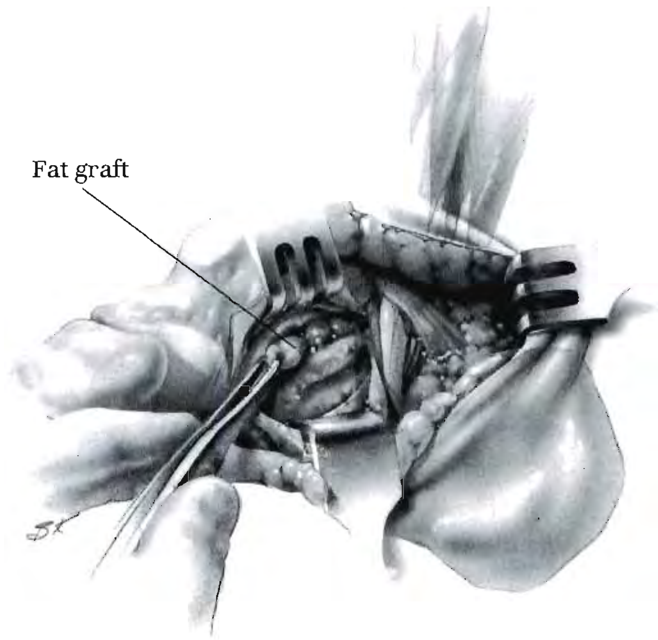


FIGURE 7-27. The final step is to interpose fat between the two bony surfaces. This can be obtained most easily from the area on the dorsal surface of the calcaneus between the posterior facet and the Achilles tendon. This is the reason for the posterior aspect of the incision.

A small amount of fibrofatty tissue is excised from this area. The bony surfaces can be sealed with bone wax to lessen the bleeding that might tend to displace the fat graft. The fat is carefully pushed into the defect created by the excision, with care taken to ensure that it reaches the depth of the excision. It is held in place by approximating the periosteum with small sutures.

The tendons can be returned to their sheath, which can be approximated with fine absorbable sutures. The subcutaneous tissue and the skin is closed, and a short-leg cast is applied.

POSTOPERATIVE CARE

The patient remains non–weight bearing for 3 weeks to avoid extrusion of the graft. At that time, the cast is removed and the patient is started on a three-point, partial weight-bearing crutch gait for an additional 3 weeks. Exercises to increase the range of motion of the ankle and subtalar joints can be taught.

References

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7.4 OSTEOTOMY OF CALCANEUS FOR VALGUS

Numerous osteotomies of the calcaneus to correct heel valgus have been described. The most popular osteotomy was that described by Dwyer (1,2). Wound problems resulting from the opening wedge and collapse of the graft have limited the use of this procedure, however. These potential problems are solved, and the same goals are achieved by the medial displacement osteotomy of the calcaneus. The operation was first described by Koutsogiannis (3) but attributed to Pridie (Figs. 7-28 to 7-33).

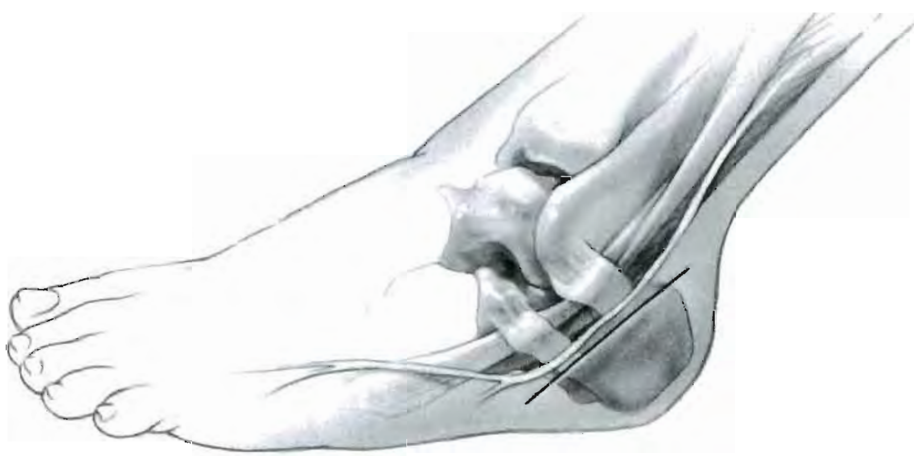


FIGURE 7-28. A straight incision is made over the lateral side of the calcaneus. The incision is posteroinferior to the peroneal tendons. It should be long enough to allow exposure of the inferior and dorsal surface of the calcaneus, which actually means that it does not have to be very long. It is important to avoid damage to the sural nerve, which runs slightly inferior to the peroneal tendons.

FIGURE 7-29. The incision should reach the periosteum of the calcaneus with a minimum of undermining. It should be possible to slide a small retractor (e.g., a Homann or Chandler retractor) over both the dorsal surface of the calcaneus anterior to the Achilles tendon and under the plantar aspect of the calcaneus. The large curved Crego elevator is useful for dissection of the periosteum on the far side of the calcaneus and also as a retractor. A straight incision is made in the periosteum, and it is elevated for about 5 mm on each side of the incision. The capsule of the posterior facet of the subtalar joint should be seen but not disturbed. This ensures that the osteotomy is far enough distal to prevent creation of too small a fragment of the calcaneus.

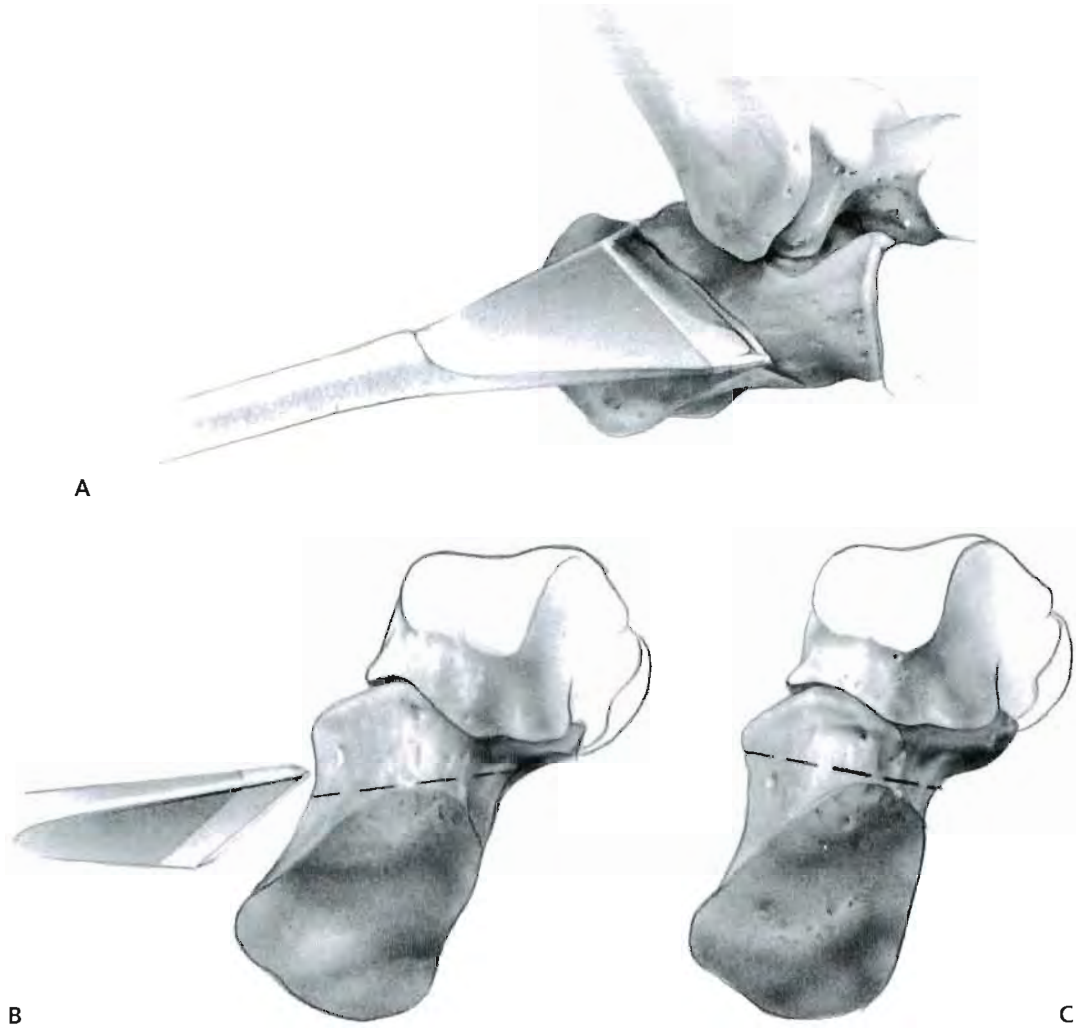
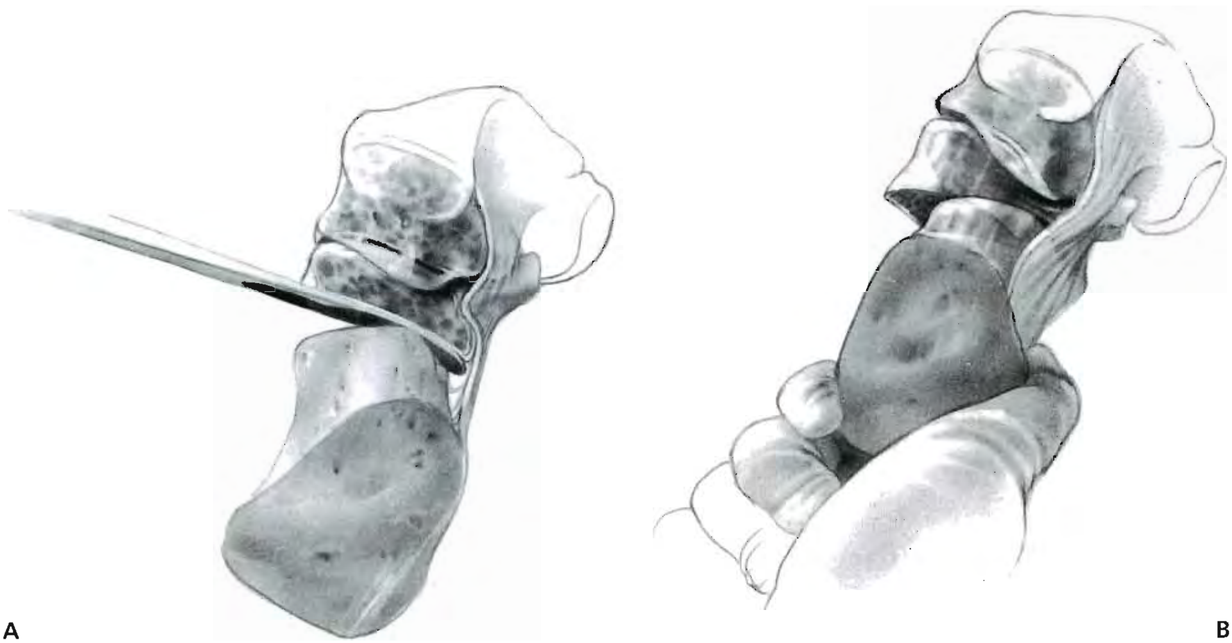


FIGURE 7-30. The osteotomy may be made with either a power saw and copious irrigation, with a broad 1.5-inch osteotome, or better, with a chisel. The placement and direction of the osteotomy is important. The osteotomy should remain about 1 cm beneath the capsule of the posterior facet of the subtalar joint. The osteotome should be positioned obliquely, parallel with the posterior facet of the subtalar joint **(A)**. As the osteotome is driven across the calcaneus, it should remain in the transverse plane or angle slightly toward the subtalar joint **(B)**. When it angles away from the subtalar joint, the fragment tends to bind as it is displaced, making displacement much more difficult **(C)**. This is analogous to the 10-degree cephalad slope that is used in the Chiari pelvic osteotomy.

Caution must be used in completing the osteotomy through the medial cortex because of the proximity of the posterior tibial vessels and nerve. Ensure that the inferior and superior cortices of the calcaneus are divided first. Then divide the most plantar aspect of the medial cortex and proceed toward the dorsal aspect, which is where the neurovascular bundle is separated from the periosteum only by a thin fascial layer. While dividing the medial cortex, be certain that there is no pressure behind the lateral malleolus that would hold the neurovascular structures against the bone.



A B

FIGURE 7-31. The large weight-bearing portion of the calcaneus can be displaced. It is usually necessary to displace it at least half of the width of the calcaneus. At first, this will not seem possible, but with a little perseverance, it can be accomplished. A broad stout osteotome or periosteal elevator can be inserted to pry the two fragments apart **(A)**. This tends to tear the periosteum and separate it from the medial cortex. Strong repeated manipulation of the fragment also tends to separate the periosteum by stripping it from the bone **(B)**. Because the Achilles tendon and the plantar fascia hold the fragments together when taut, the foot should be held in plantar flexion for all of the manipulations. If a very large amount of displacement is needed, it may be necessary to divide the periosteum. A small lamina retractor can be used to separate the fragments and provide better access while at the same time stretching the medial periosteum taut. Because of the proximity of the neurovascular bundle, we use an osteotome for this rather than a sharp knife. Finally, the long plantar ligament can be divided in a similar fashion.

FIGURE 7-32. The foot is plantarflexed, and the loose fragment of calcaneus is pushed medially. Be certain that it does not displace dorsally. The foot is dorsiflexed to push the osteotomy surfaces together and maintain the displacement.

To ensure that the displacement is maintained, a heavy, smooth, Steinmann pin is drilled from the posterior aspect of the calcaneus distally across the osteotomy site. The pin is cut off, leaving enough protruding through the skin so that it can be removed easily in the office.

It will not be possible to close the periosteum. The deep fascia and the skin are closed with interrupted sutures, taking care not to damage the sural nerve, and a short-leg cast is applied. The portion of the Steinmann pin that protrudes should be well padded in cast padding apart from that used for the foot. This will prevent its being bound to the cast with resulting excessive motion at the pin–skin interface as the foot moves.

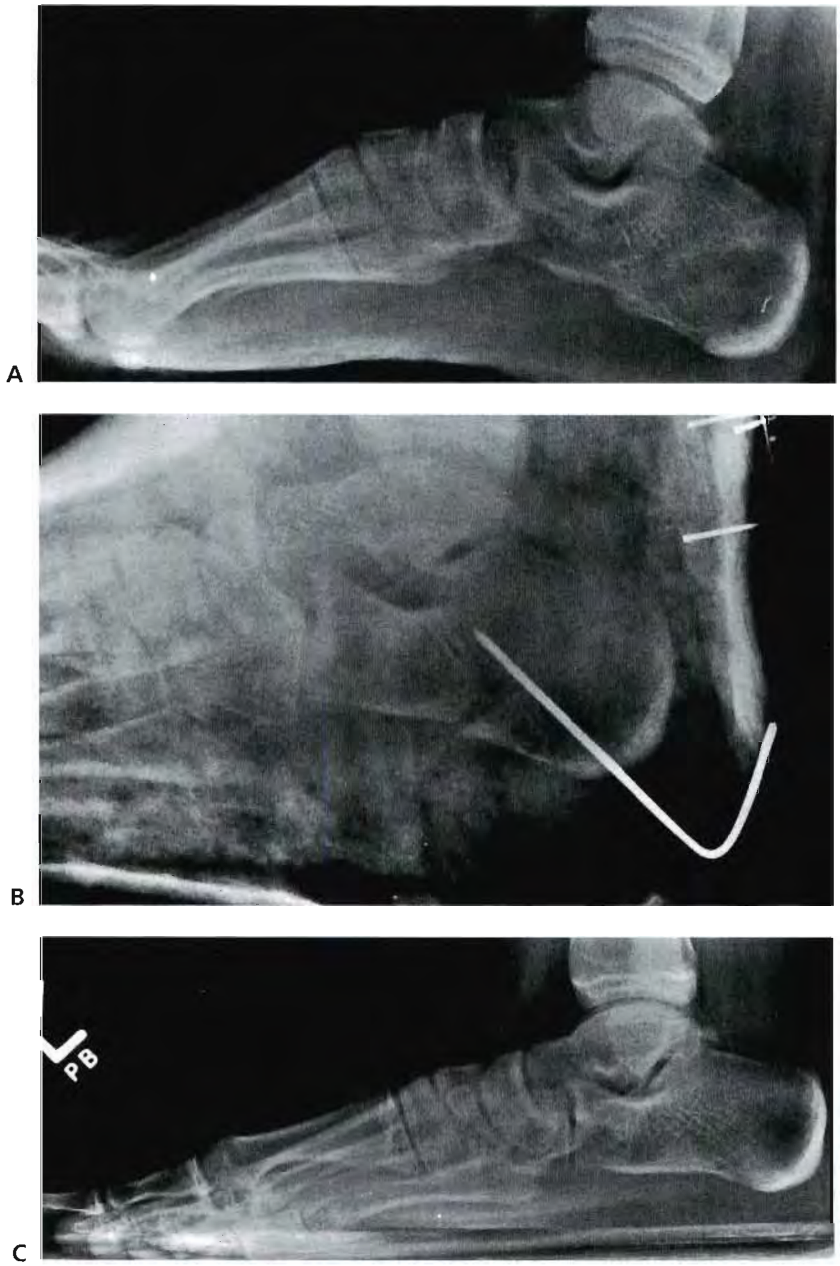


FIGURE 7-33. A: Preoperative lateral radiograph of the foot of a 13-year-old girl with severe painful flat feet. Because of her inability to wear orthotics with her usual shoe wear and only moderate relief with orthotics, she requested surgical correction. **B:** The immediate postoperative radiograph demonstrates the pin holding the displacement. A larger pin could have been used, and it could have been inserted further. The pin was withdrawn at 2 weeks and the cast changed. **C:** The healing is complete at 6 weeks.

POSTOPERATIVE CARE

The patient is non–weight bearing on the operated foot for 2 weeks. The cast is removed in the office, and the pin is removed from the bone. A short-leg walking cast is applied for 4 weeks while the patient gradually resumes full weight bearing. Six weeks after surgery, there should be radiographic evidence of complete healing, and immobilization is discontinued.

References

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7.5 CALCANEAL LENGTHENING OSTEOTOMY FOR THE TREATMENT OF HINDFOOT VALGUS DEFORMITY

Evans (1) described an operation in which an osteotomy was performed in the distal portion of the calcaneus, and the calcaneus was lengthened by inserting a tibial graft into the osteotomy. He observed patients in whom he had excised the calcaneal cuboid joint for correction of clubfoot who subsequently developed a calcaneovalgus deformity. In his first case, he corrected this by taking down the calcaneocuboid arthrodesis and inserting a graft to restore more length to the lateral column of the foot. The results were good, and he applied this to other conditions characterized by a valgus hindfoot, such as polio, rigid flatfoot, including tarsal coalitions, and severe symptomatic valgus feet. He believed this procedure should be contraindicated in paralytic conditions, such as cerebral palsy and spina bifida.

Mosca (2) has broadened the indications to include patients with cerebral palsy, spina bifida, and skewfoot. He often combined these procedures, when appropriate, with Achilles tendon lengthening, opening-wedge osteotomy of the first cuneiform bone, and tibial osteotomy. In several cases, he added a release or plication of the talonavicular joint. Mosca further elaborated on the technical details of the operation.

The patient who is a candidate for this procedure usually has symptoms from pressure from weight bearing on the sagging talar head. The foot is in valgus with relative abduction of the cuboid on the calcaneus. The anteroposterior radiograph shows lateral migration of the navicular on the head of the talus, the opposite of what is seen in varus (Figs. 7-34 to 7-41).

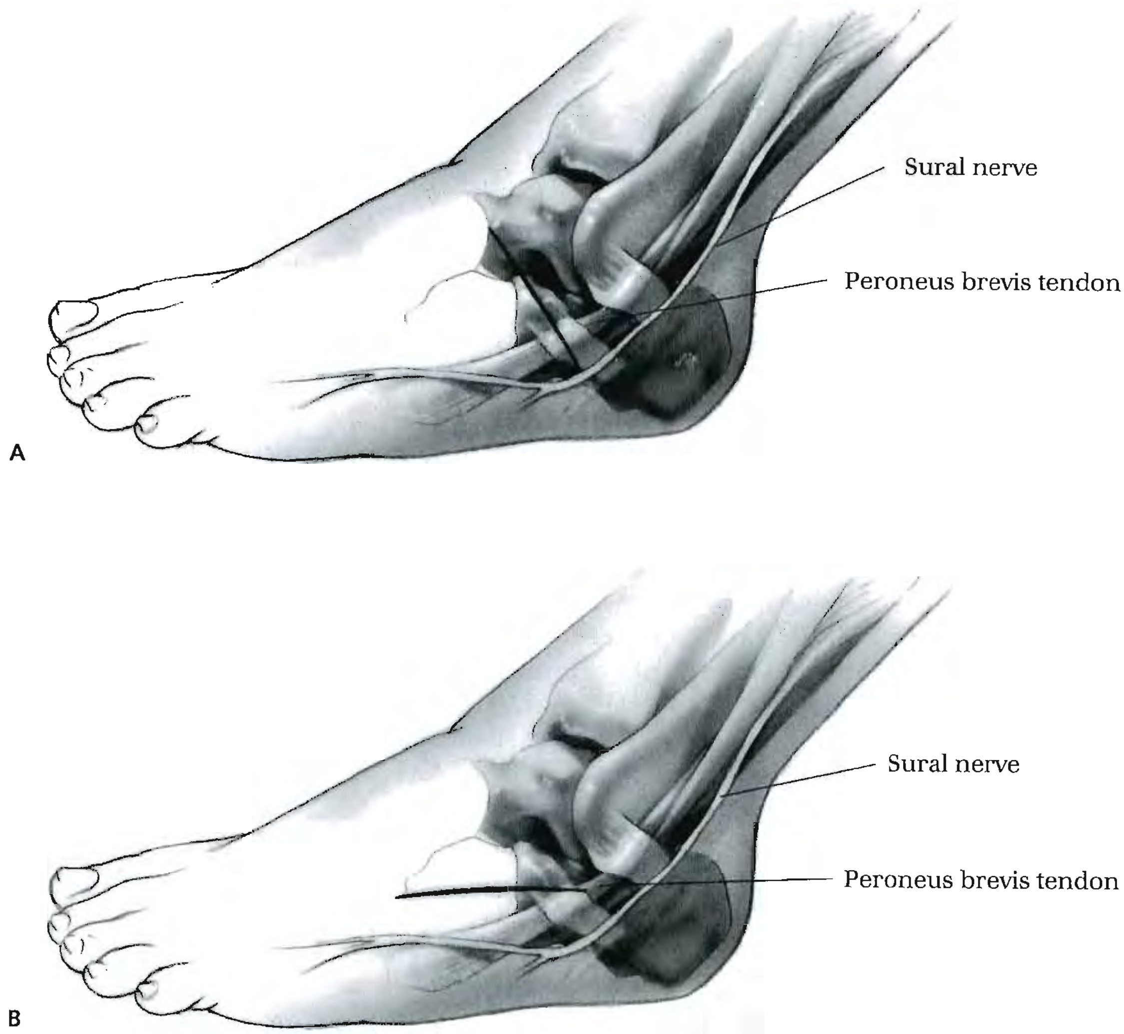

FIGURE 7-34. The incision can be either an oblique Ollier type of incision that crosses the talar beak **(A)** or a transverse incision directly above the peroneal tendons, as originally described by Evans (1) **(B)**.

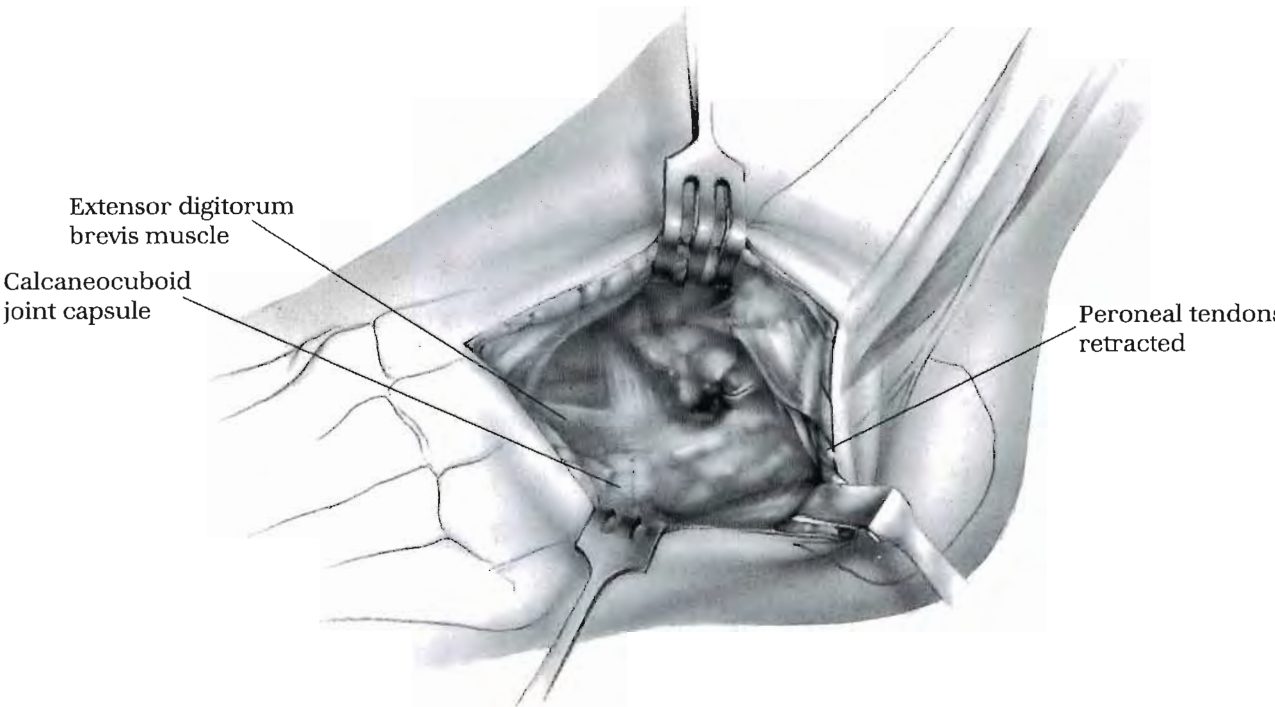

FIGURE 7-35. After the incision is deepened through the skin, the peroneal tendons in their sheath are identified. The peroneal sheath is opened, and the tendons are freed so that they can be retracted out of the way. The calcaneocuboid joint should be identified by its landmarks but not opened; its capsule is important in providing stability to the distal fragment.

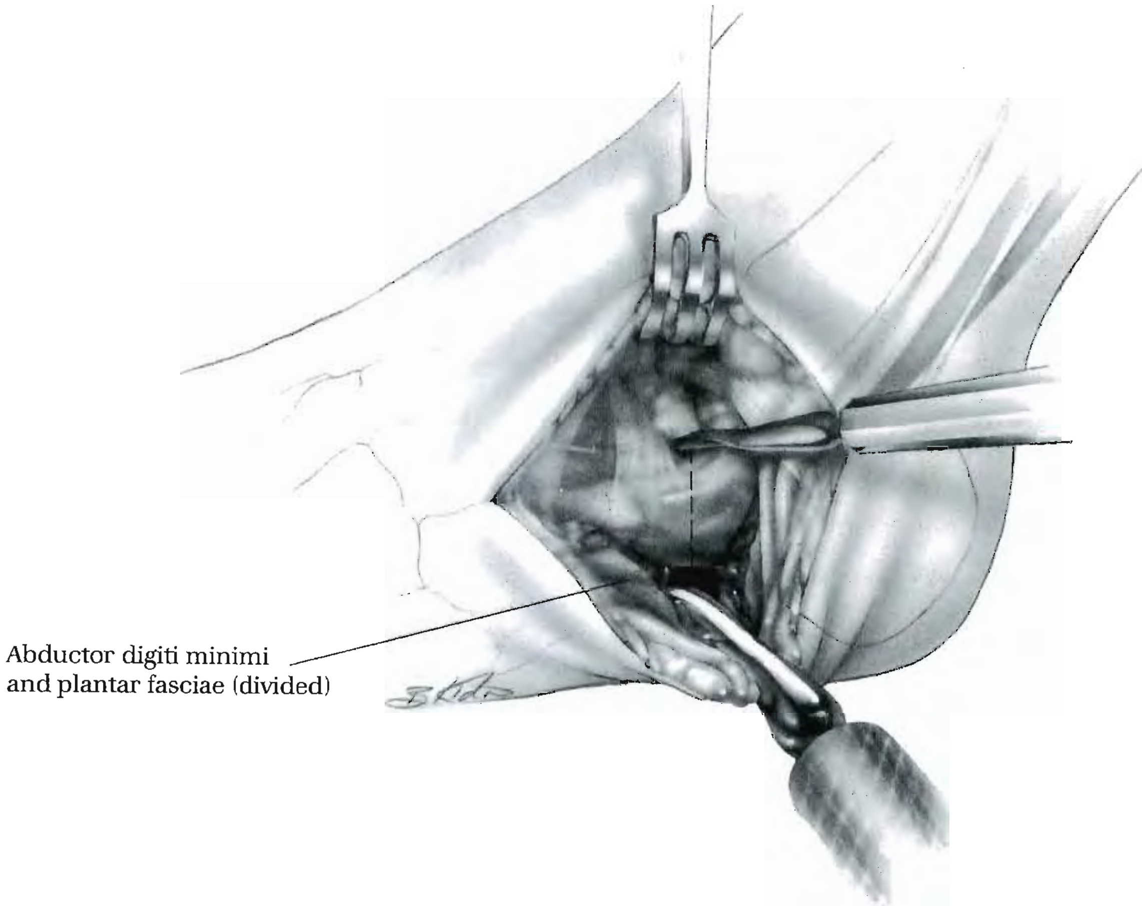

FIGURE 7-36. A point about 1.5 cm behind the calcaneocuboid joint is identified as the site for the osteotomy. The soft tissue is freed from the undersurface of the calcaneus. This is facilitated, as is distraction of the osteotomy, by dividing the most lateral plantar fascia and the abductor digiti minimi muscle. Next, incise the fascia along the floor of the sinus tarsi (the dorsum of the calcaneus). With a small periosteal elevator, elevate the fibrofatty tissue so that the elevator reaches the medial side.

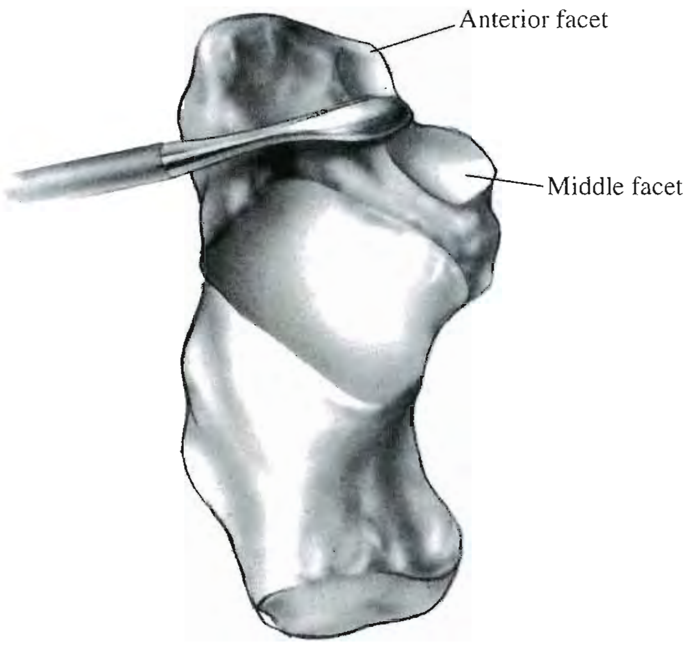

FIGURE 7-37. Although the starting point of the osteotomy is easily seen, the exit point on the medial side is not. Mosca (2) believes that this exit point should be between the anterior and middle facets of the subtalar joint. To identify this, slide a Freer elevator across to the medial side, feeling the sustentaculum tali or the middle facet. Probing distally, the surgeon will find an interval between the anterior and middle facets. Note that the plane of this osteotomy is neither perpendicular to the lateral border of the foot nor parallel to the calcaneocuboid joint.

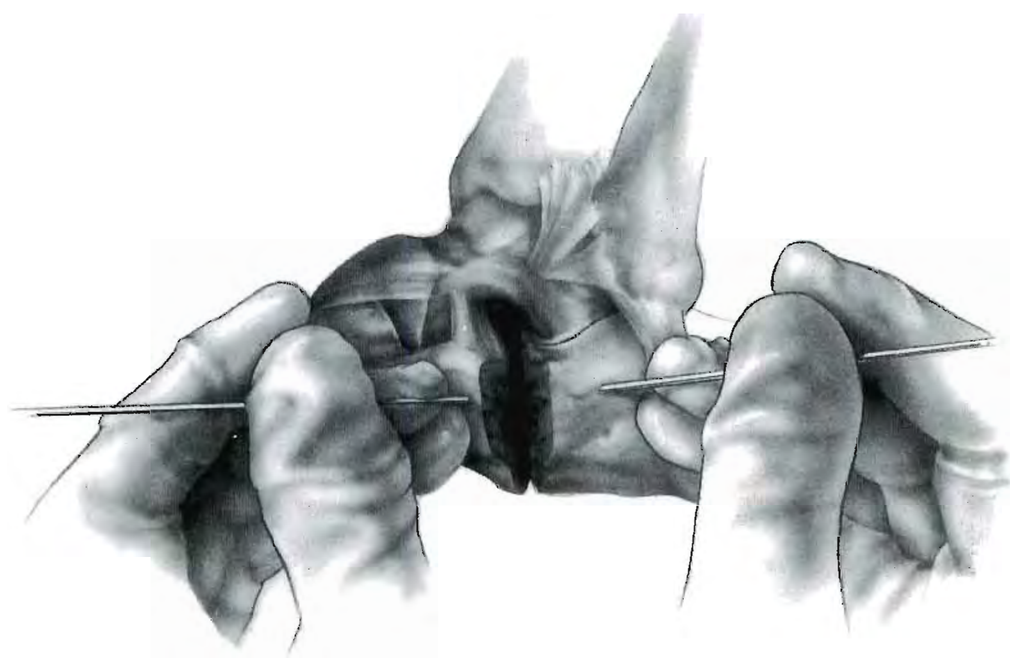

FIGURE 7-38. Two small Chandler retractors are now used, one under and the other over the top of the calcaneus, to mark and expose this area. Two smooth Steinmann pins are placed on either side of the proposed osteotomy. These will orient the surgeon and, more importantly, are necessary to manipulate the fragments. The osteotomy is now performed with an osteotome or oscillating saw. Spreading and rotating with the two Steinmann pins demonstrates that the osteotomy is complete.

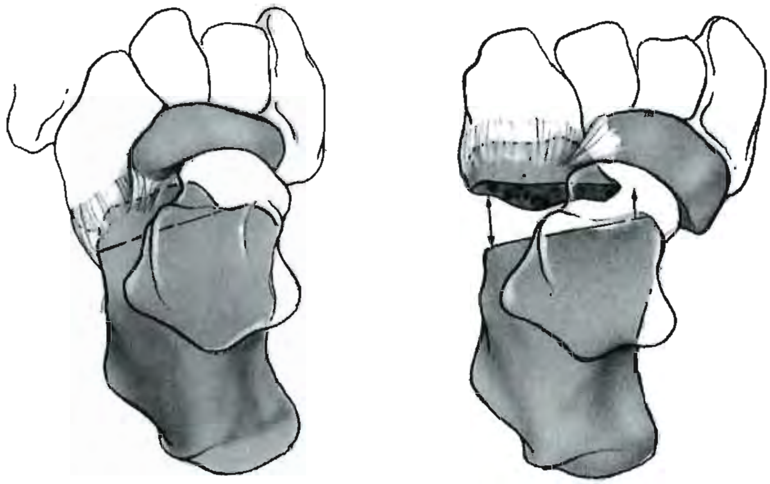

FIGURE 7-39. To assess the size of the graft to be inserted, a lamina spreader can be used. With it in place, the foot is inspected to be certain that the desired amount of correction will be gained. Release of the talonavicular joint with capsular plication may be necessary. If questions remain, a radiograph should be obtained to demonstrate that the navicular is reduced medially on the head of the talus.

In obtaining the graft and opening the osteotomy site, it is important to realize that the graft will be trapezoidal and that the center of rotation is not the medial cortex of the calcaneus but rather a point closer to the talar head. Note how the navicular moves medially as the osteotomy is opened. If this joint is not mobile, a medial release will be required to restore mobility.

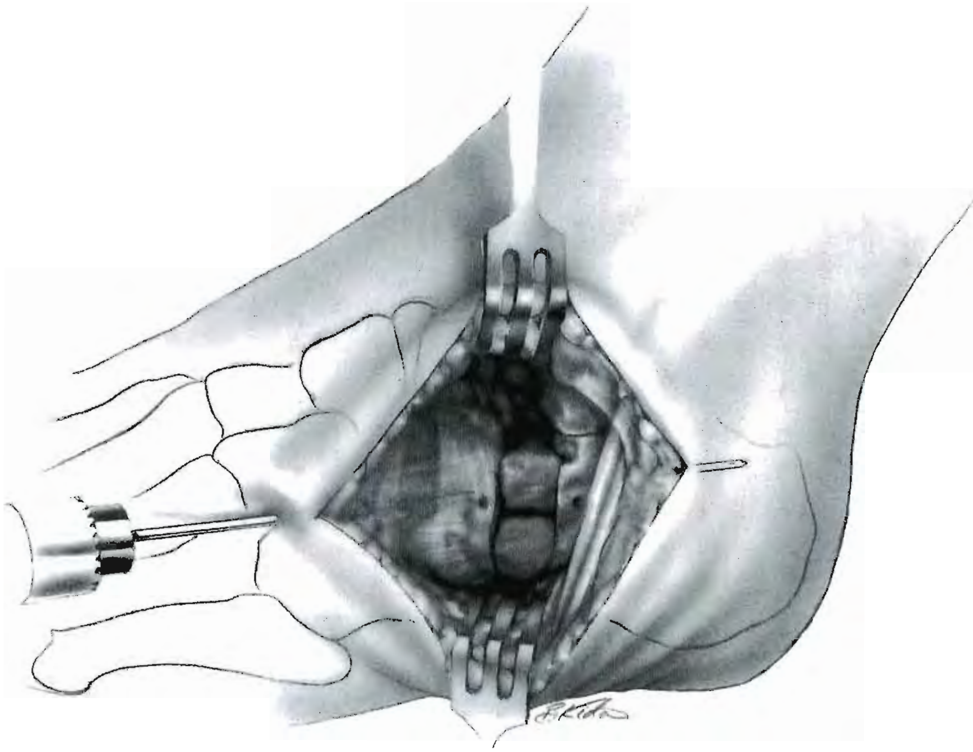

FIGURE 7-40. The osteotomy is held open by the two Steinmann pins while a trapezoidal tricortical iliac graft is inserted. This should be placed so that the cortex of the graft is in contact with the cortex of the calcaneal fragment to give stability to the osteotomy. Depending on the size of the graft, one or two pieces may be necessary. The first is placed more plantarward and the second dorsally.

Care should be taken to ensure that the distal fragment of the calcaneus does not subluxate dorsally. To prevent this, the smooth Steinmann pin that will be used to fix the graft is inserted first as far as the distal calcaneal fragment. The osteotomy site is opened, and the graft is inserted. Then, the Steinmann pin is advanced through the graft and into the proximal calcaneal fragment.

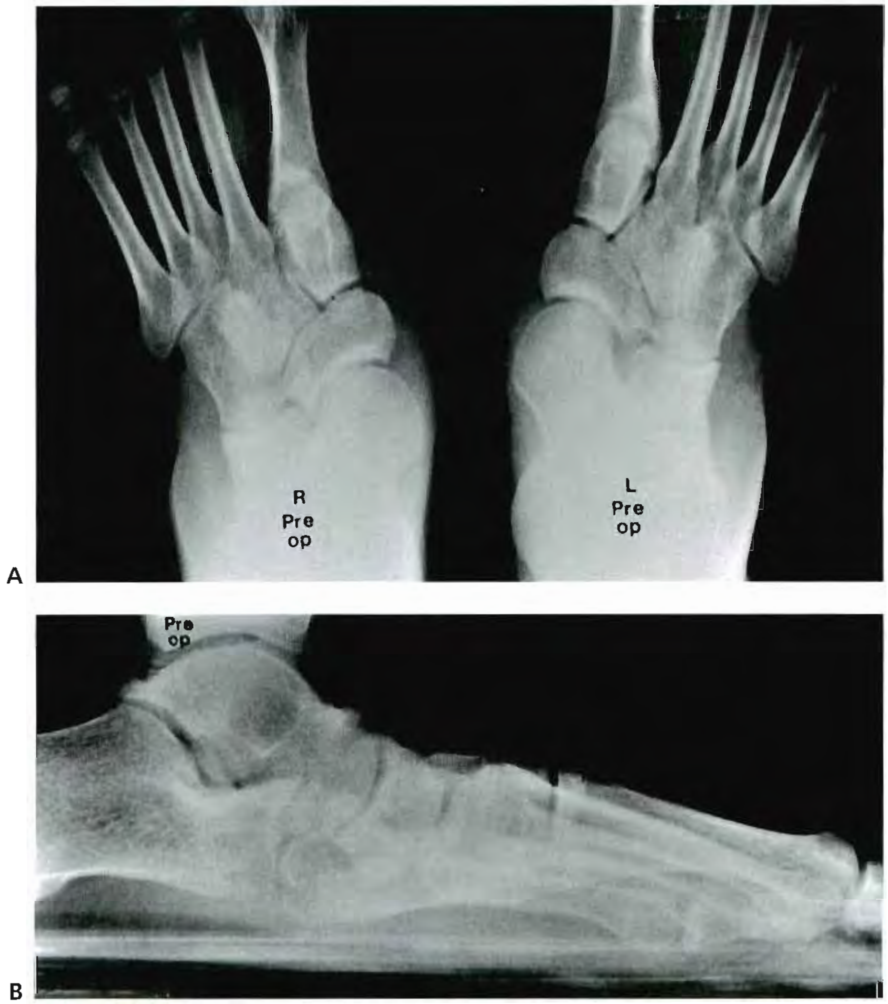

FIGURE 7-41. Standing anteroposterior **(A)** and lateral **(B)** radiographs of a 15-year-old girl with severe flexible flat feet and significant foot pain unrelieved by nonoperative methods.

C

D

FIGURE 7-41. ***(Continued)***
Standing anteroposterior radiographs after correction of the right foot and before correction of the left foot demonstrate the correction of the navicular on the talus that is achieved with lengthening of the calcaneus **(C)**. A standing lateral radiograph **(D)**, taken at the same time, demonstrates the correction of the talar sag.

POSTOPERATIVE CARE

The grafts take about 8 weeks to heal. If desired, the pin can be removed in the office after 4 weeks and the cast changed. Weight bearing is not permitted during the time it takes for the grafts to heal.

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7.6 DOUBLE TARSAL OSTEOTOMY TO CORRECT FOREFOOT ADDUCTION

Residual adduction and supination are often a problem after clubfoot correction. The deformity is commonly referred to as the "bean-shaped foot." The symptoms are difficulty with rigid shoe wear and walking on the lateral border. This procedure is not indicated if the navicular is lateral on the talus and there is heel valgus because the closing wedge osteotomy of the calcaneocuboid joint will only aggravate the hindfoot problem. This operation represents an alternative to repeat soft tissue surgery in the the older child (4 to 11 years old) with this deformity.

Another indication for the use of this operation is the older child with a residual metatarsus adductus who demonstrates the medial sloping distal facet of the first cuneiform. This deformity is not visible on radiographs until the bone is well ossified, usually at 3 or 4 years of age. Often, in this situation, only the opening osteotomy of the cuneiform bone (the Fowler procedure) is indicated because the heel may tend toward valgus.

In the past, these deformities were often treated by metatarsal osteotomies or tarsometatarsal capsulotomies (Hyman-Herndon procedure). More recently, however, these operations have been used less frequently because they either fail to provide the desired correction or result in painful stiff joints.

The origin of this double tarsal osteotomy is obscure. We first learned of it through orthopaedic surgeons who trained at Duke University with Dr. Leonard Goldner and heard it referred to as the *Durham procedure.* The procedure represents a combination of two operations: the opening-wedge osteotomy of the first cuneiform bone, described in 1959 by Fowler and colleagues (1), and a shortening of the lateral column of the foot by some means. The concept of shortening the lateral column of the foot in the clubfoot deformity is not new. Solly (2) described decancellation of the cuboid bone in 1857. In 1961, Evans (3) described wedge resection of the calcaneocuboid joint with fusion, and in 1973, Lichtblau (4) described resection of the anterior portion of the calcaneus.

The first written description found of the described operation (5) was used to correct persistent metatarsus adductus and varus following clubfoot correction with recurrence of this forefoot deformity. A subsequent report by McHale and Lenhart (6) evaluates the results of this procedure in seven feet but does not discuss the origins of it (6) (7-42 to 7-49).

FIGURE 7-42. The operation is started on the lateral side of the foot. A bolster is placed beneath the buttocks, turning the leg internally to facilitate the approach to the cuboid. The incision may be either oblique, following the skin lines directly over the cuboid, or curvilinear over the bone.

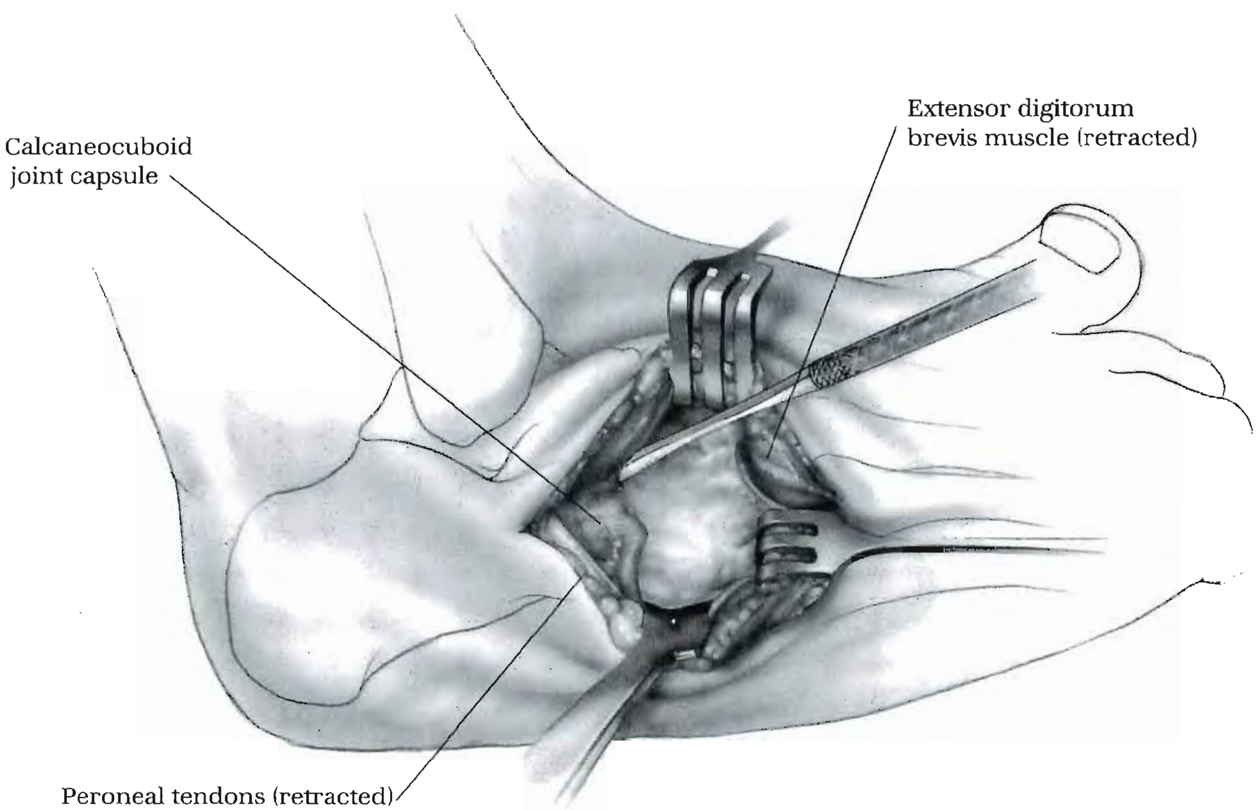

FIGURE 7-43. After opening the skin, the peroneal tendons are identified, freed from their sheath, and retracted plantarward. The soft tissues are freed dorsally and plantarward to expose the cuboid bone, keeping the joint capsules intact. The periosteum of the cuboid is incised from the dorsal to plantar side and elevated toward the joint surfaces. This exposes the section of bone to be removed.

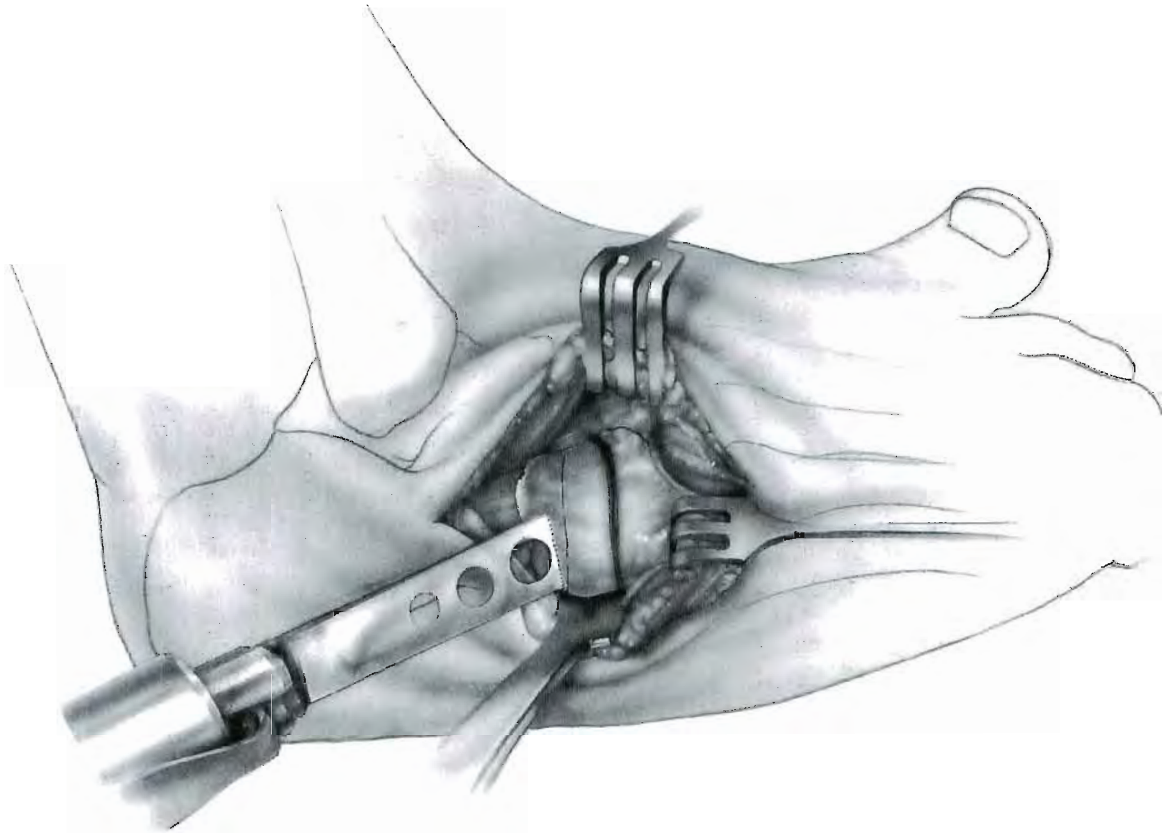

FIGURE 7-44. Using a microsagittal saw, a laterally based wedge of bone of the desired size is removed. It is important to go through the medial cortex of the bone so that the osteotomy will be mobile and easy to close. The wound is left open and the bolster removed to provide better access to the cuneiform bone on the medial side of the foot.

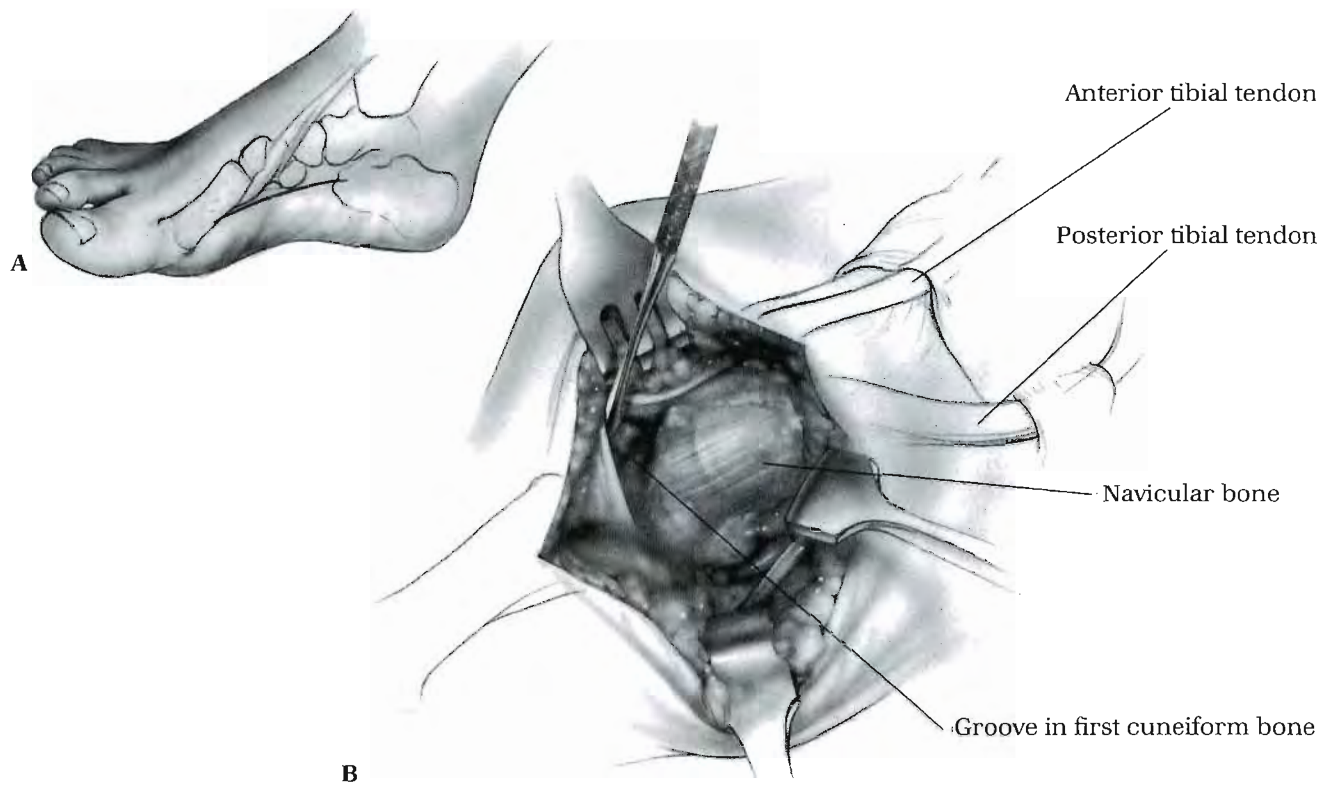

FIGURE 7-45. A straight linear incision is made directly over the first cuneiform bone **(A)**. As the dissection is deepened, the anterior tibial tendon will be identified coursing over the first cuneiform bone. This tendon can be dissected free without disturbing any of its essential attachments. Start on the inferior aspect of the tendon and reflect it dorsally. This usually allows adequate exposure. In the idiopathic type of forefoot adduction, this tendon will appear to have cut a groove of variable depth into the bone **(B)**. Continue to dissect the cuneiform bone (subperiosteally if and where possible) until both the proximal and distal joints are identified positively, while trying to preserve intact the joint capsules and while the plantar and dorsal aspect are exposed. Because of the peculiar shape of the first cuneiform bone in this condition, it may be wise to check the path of the proposed osteotomy with the image intensifier.

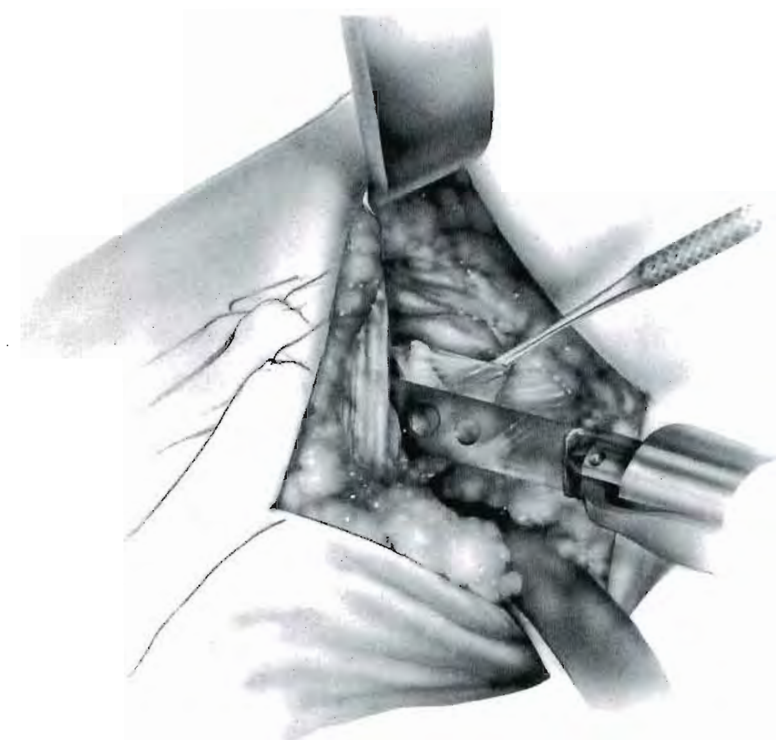

FIGURE 7-46. Using the microsagittal saw, make a single osteotomy cut in the first cuneiform bone. Be aware of the sloping joint surface, and if necessary, pass a small dissector into the naviculocuneiform joint to mark its plane. After completing the osteotomy, insert a blunt instrument to spread apart the fragments and ensure their mobility.

FIGURE 7-47. The graft that was taken from the cuboid is now inserted into the osteotomy of the first cuneiform. If there is difficulty opening this osteotomy sufficiently to insert the graft, place a Kirschner wire into each fragment to open the osteotomy. It may be necessary to release the abductor hallucis tendon if it is tight or produces adduction of the great toe after the graft is inserted. If the bone is large enough, a small lamina spreader will work well. When the bone is in place, it should be relatively secure; however, with any activity, there is the danger that it may extrude. Therefore, it is secured with a Kirschner wire passed through the base of the first metatarsal, the distal fragment, the graft, and the proximal fragment.

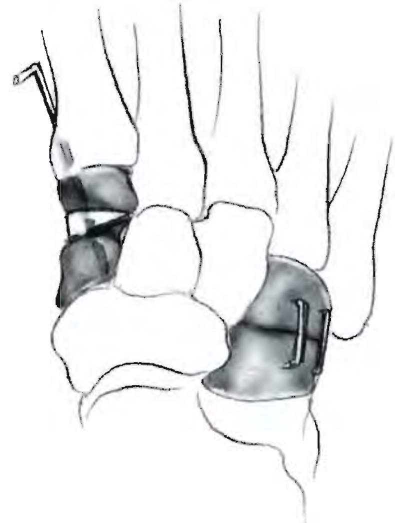

FIGURE 7-48. The cuboid osteotomy is inspected. If this osteotomy has not closed, it can be manipulated closed and held with one or two small staples or a Kirschner wire.

A B

FIGURE 7-49. A: Anteroposterior radiograph of a 5-year-old boy with persistent forefoot adduction 4.5 years after clubfoot correction. **B:** At the time of cast removal, 6 weeks after surgery, the medially based wedge of bone graft inserted into the medial side of the first cuneiform bone is seen, as is the closing wedge osteotomy in the cuboid bone. The clinical correction is greater than appears on these radiographs, which vary in their projection.

POSTOPERATIVE CARE

After closing and dressing the wounds, the patient is placed in a short-leg cast. Weight bearing is not permitted. The cast is removed after 6 weeks, when healing should be sufficient to resume weight bearing. The pin is removed in the office when the cast is removed.

References

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2. Solly S. Case of double talipes varus in which the cuboid bone was partially removed from the left foot. Med Chir Trans 1857;40:119.
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7.7 PLANTAR RELEASE AND FIRST METATARSAL OSTEOTOMY FOR CAVUS FOOT

Although correction of cavus deformity of the foot was common in the treatment of patients with the residuals of poliomyelitis, it is now a much less common procedure. Cavus deformity of the foot is usually seen as the result of a variety of conditions, such as degenerative neurologic diseases with Charcot-Marie-Tooth disease, relapsed clubfoot, traumatic neurologic injury, and idiopathic cavus foot. In addition to consideration of muscle imbalance, possible progression, and other factors related to the etiology, the most important factors to consider when choosing the treatment are the components of the deformity and their rigidity.

The operation described here is the procedure that we find indicated most often in the treatment of cavus deformity. Its successful application assumes one very important factor: the hindfoot must be flexible. It must not have a fixed varus deformity. The calcaneus must be able to move to neutral or preferably beyond into valgus. Most cavus feet appear to have a varus deformity in stance. This may be due to a depressed first metatarsal, which creates what might best be described as a fixed pronation of the forefoot. In stance, the first and fifth metatarsal heads can contact the floor only if the heel is in varus. The flexibility of the heel, that is, its ability to move into valgus, can be demonstrated by the Coleman block test (1).

Although percutaneous division of the plantar fascia has often been recommended, this is not sufficient for most feet with significant cavus deformity. In most feet, it is necessary to release not only the plantar fascia but also the origin of the intrinsic muscles of the foot from the calcaneus and the plantar ligaments. Although many approaches have been recommended, the most versatile is the plantar dissection (2). An osteotomy of the first metatarsal can be accomplished through a distal extension of the incision. The results of this procedure have been described (3) (Figs. 7-50 to 7-57).

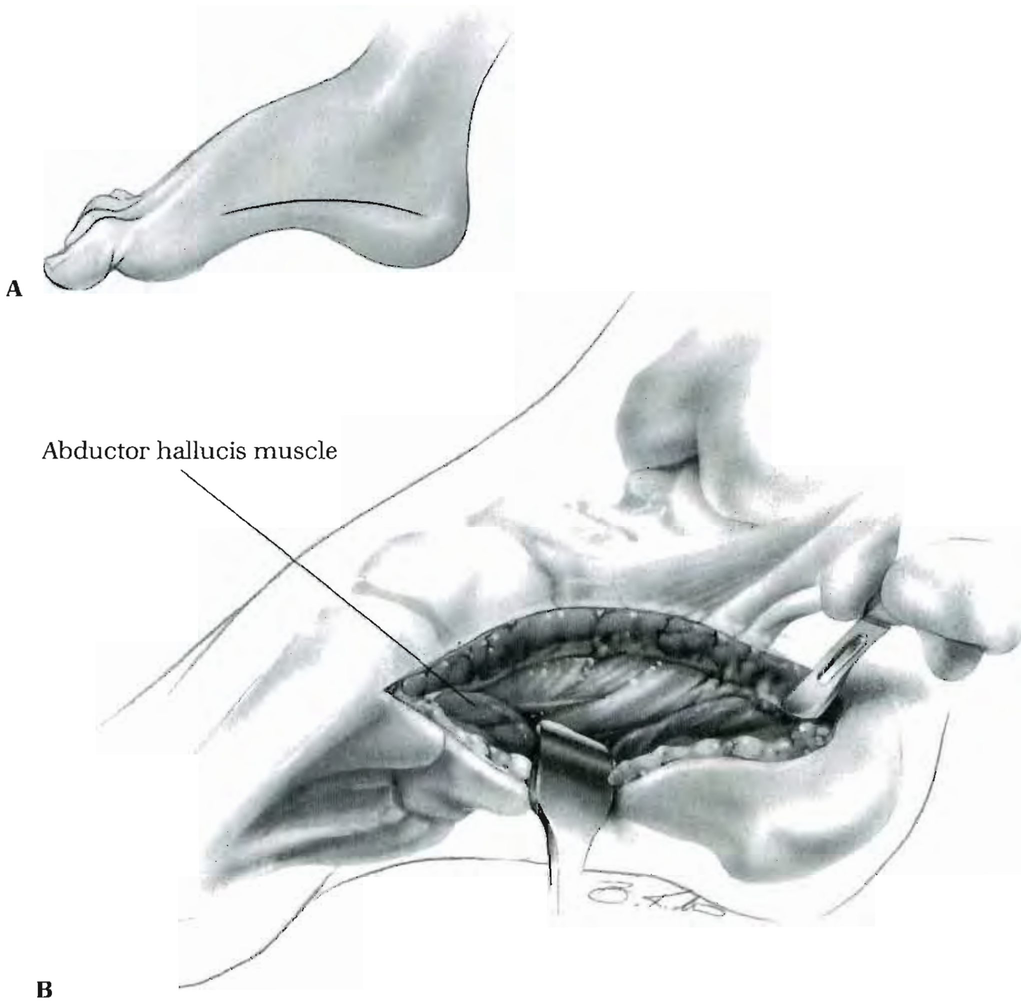

FIGURE 7-50. A curvilinear incision is made along the medial side of the foot from the midportion of the first metatarsal to the posterior tuberosity of the calcaneus **(A)**. This incision should be placed just dorsal to the plantar skin, which is usually distinguishable from the thinner skin that covers the dorsum of the foot. The incision is carried directly through the skin and subcutaneous tissue without undermining until the belly of the abductor hallucis muscle is encountered. The dorsal flap of skin and subcutaneous tissue is then elevated to expose the dorsal edge of the abductor hallucis muscle.

The dorsal edge of this muscle is detached by sharp dissection and reflected plantarward. It is important to carry the detachment far enough posteriorly so that the origin of the abductor hallucis muscle is detached from the medial tuberosity of the calcaneus **(B)**. Care should be taken here not to cut too deeply to avoid damage to the neurovascular bundle. After this muscle is completely reflected, all of the structures of the foot that are to be divided lie shrouded beneath the deep fascia.

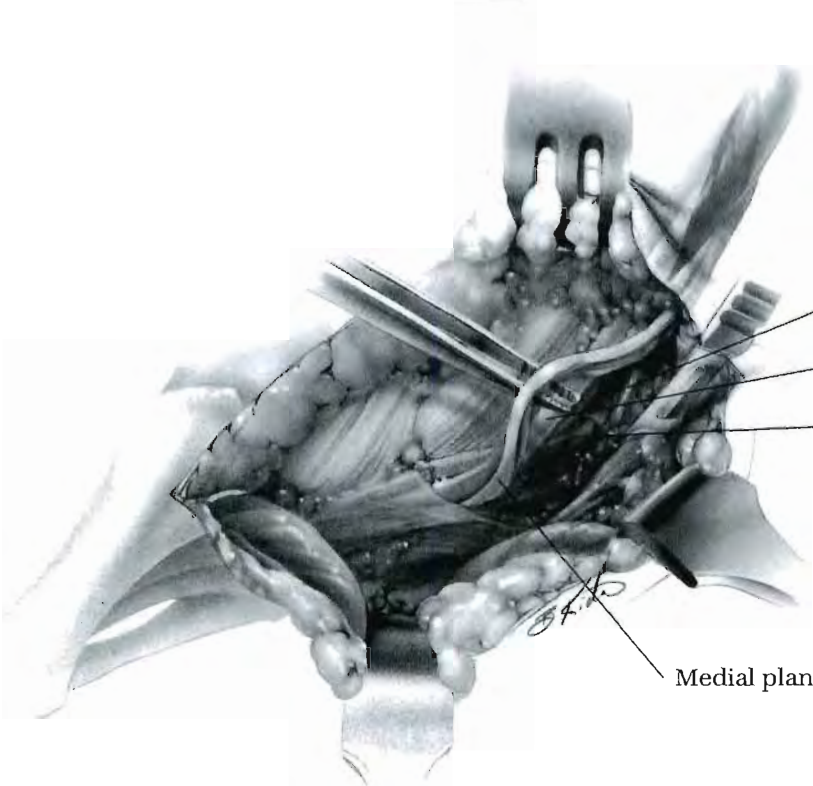

FIGURE 7-51. The structures that are to be protected are dissected free in the following order. First, the flexor digitorum longus is identified just posterior to the tip of the medial malleolus. A small transverse incision in this region will enter the sheath of both the flexor digitorum longus and the posterior tibial tendon, which lies just anterior to it. The sheath of the flexor digitorum longus is opened distally, cutting the master knot of Henry and allowing this tendon to be retracted out of the way.

Next, the neurovascular bundle is located posterior to the flexor digitorum longus. The posterior tibial nerve is dissected until its bifurcation into the medial and lateral plantar branches is identified. The lateral plantar branch will come off the posterior tibial nerve and run laterally toward the plantar aspect of the foot. If this lateral plantar branch is not identified, it may be cut inadvertently. The medial plantar branch (on the forceps) and the posterior tibial artery and its accompanying veins are dissected distally so that they too may be retracted along with the flexor digitorum longus.

At this point, additional muscle attachments to the medial tuberosity of the calcaneus may be divided under direct vision. Also, note the tendon of the flexor hallucis longus running under the tendon of the flexor digitorum longus. This tendon will be released when the master knot of Henry is divided. With all of these structures identified and retracted out of the way, a plane on the dorsal surface of all of the muscles inserting into the calcaneus can be developed by blunt dissection.

FIGURE 7-52. A plane is now developed between the plantar fascia and the subcutaneous skin of the heel pad. This must extend from the medial to the lateral side of the foot.

FIGURE 7-53. With the medial and lateral plantar nerves retracted distally and dorsally, a heavy scissors can be used to divide all of the large muscle originating from the medial and plantar surface of the calcaneus. This will include the abductor hallucis, the flexor digitorum brevis, the abductor digiti minimi, and the quadratus plantae (flexor accessorius). One blade of the scissors is passed in the plane that was developed between the plantar fascia and skin, and the other blade is passed over the dorsal surface of the muscles in the interval posterior to the retracted artery, nerves, and tendons. The surgeon should feel the blades of the scissors near the lateral skin. After these structures are divided, a finger can be passed into the gap to be sure that no tight attachments are left.

FIGURE 7-54. A broad periosteal elevator is used to dissect this mass off of the bone. This should be done extraperiosteally. Care should be taken to ensure that the long plantar ligament is not missed. It may be necessary to divide this with a knife. Through this extensive exposure, the calcaneocuboid ligament and the calcaneonavicular ligament may also be divided. This is achieved most easily by opening the volar capsules of these joints.

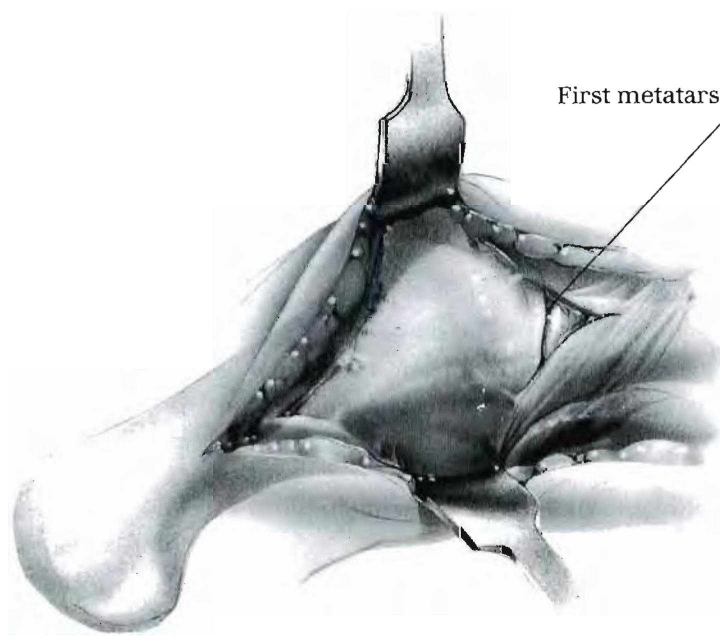

FIGURE 7-55. The proximal portion of the first metatarsal is exposed in the distal aspect of the incision. The periosteum is incised on the dorsomedial aspect of the bone, and the proximal portion is exposed subperiosteally. Two small Hohmann retractors are place to protect the soft tissues.

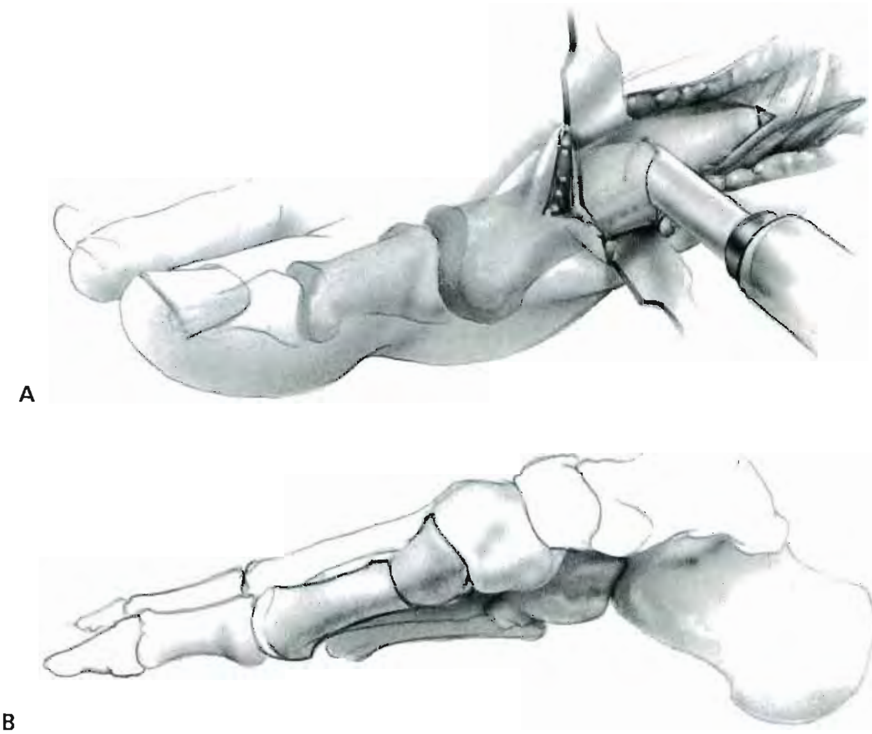

FIGURE 7-56. A dome-shaped osteotomy is made so that the distal fragment can be rotated dorsally. This may be done with a special saw that is designed to make cresentic cuts or by connecting properly placed drill holes with an osteotome. The dorsal corner of the distal fragment is removed so that rotation of the distal fragment is not obstructed **(A)**. Alternatively, the osteotomy can be made dorsolaterally so that a biplanar correction of the metatarsal is done. When the desired position is achieved, it can be fixed with a smooth Kirschner wire that is left protruding through the skin for easy removal when healing is complete **(B)**.

Before closure, a small suction drain is placed throughout the length of the wound. A short-leg cast is applied with the foot in the position of correction that can be obtained without great force.

A

B

FIGURE 7-57. **A:** Preoperative standing lateral radiograph of a 15-year-old boy with bilateral cavus feet due to Charcot-Marie-Tooth disease. His heel would correct into valgus. **B:** Six weeks after plantar release and first metatarsal osteotomy, there is sufficient healing of the osteotomy to allow weight bearing.

POSTOPERATIVE CARE

If full correction is not obtained at the time of surgery, which is the usual case, plans should be made to change the cast periodically during the first 6 weeks to obtain further correction. Correction of the cavus should not put any stress on a properly placed incision. Care should be taken not to push up on the first metatarsal if an osteotomy has been performed. Weight bearing can begin as soon as tolerated if no osteotomy has been performed or after 6 weeks if one has been performed. The wire fixing the osteotomy should be removed before weight bearing. If required, tendon transfers may be done at the same time as the plantar release. If lengthening of the Achilles tendon is required, however, this should wait 6 weeks or until the cavus is maximally corrected. If the Achilles tendon is lengthened at the same time, it will not be possible to apply a corrective force to the plantar structures.

References

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7.8 DORSAL TARSAL WEDGE OSTEOTOMY FOR CAVUS DEFORMITY

Removal of a dorsally based wedge from the tarsal bones to correct a fixed cavus deformity with its apex in the midfoot has been described by Cole (1). It is best used only when the problem is bilateral because it shortens the foot. This disadvantage is offset by preservation of the metatarsal-tarsal joints distally and the talonavicular and calcaneocuboid joints proximally. Because this operation corrects only the cavus deformity, the absence of fixed-heel varus is a prerequisite. The operation should be preceded by a plantar release.

There are variations on this procedure. Jhass (2) has described a similar osteotomy that removes the wedge distally, excising the metatarsal-tarsal joints. A common variation is that described by Japas (3). The results of the Cole procedure have been reported (4) (Figs. 7-58 to 7-63).

FIGURE 7-58. The operation may be performed through either one long midline incision or two separate incisions, one over the dorsomedial aspect of the navicular and first cuneiform bone and the second over the cuboid bone in line with the fourth metatarsal. In the severe cavus foot, the single incision makes it difficult to reach the lateral extent of the cuboid bone. The incision must extend from the dorsal aspect of the talar neck distally as far as the middle of the metatarsals. Through this incision, the entire area of the osteotomy can be exposed subperiosteally without interference from the anterior or posterior tibial tendons. It is also easier to see the osteotomy through this single incision.

FIGURE 7-59. After the skin and subcutaneous tissue are divided, the interval between the extensor tendons to the second and third toes is developed. The neurovascular bundle lies between the extensor tendons to the second and great toes. In developing this interval, care should be taken to interrupt as few vessels as possible. The arcuate artery coming off the dorsalis pedis artery will run laterally at the level of the tarsal-metatarsal joints. If this is identified, an effort to preserve it should be made.

FIGURE 7-60. After this interval is developed, the periosteum is incised from the talonavicular joint to the tarsal-metatarsal joint in line with the incision. Sharp dissection is used to detach the periosteum from the region of the joint capsules, and a periosteal elevator is used to separate the periosteum from the bones. Persistence is needed to develop the medial and lateral extents of the exposure. Medially, the dissection should go completely around the joint of the navicular and first cuneiform bone; laterally, it should go completely around the cuboid bone. This dissection will expose the joints between the navicular proximally and the cuneiform bones distally. Most of the cuboid bone should be exposed, but the joints proximal and distal to it do not need to be entered. Sufficient bone on each side of these joints should be exposed to permit the correct size of wedge to be removed.

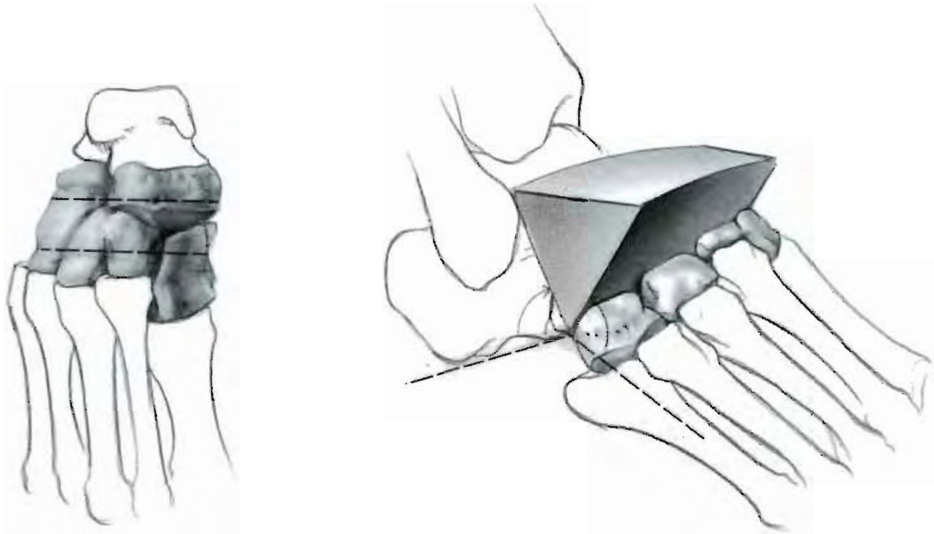
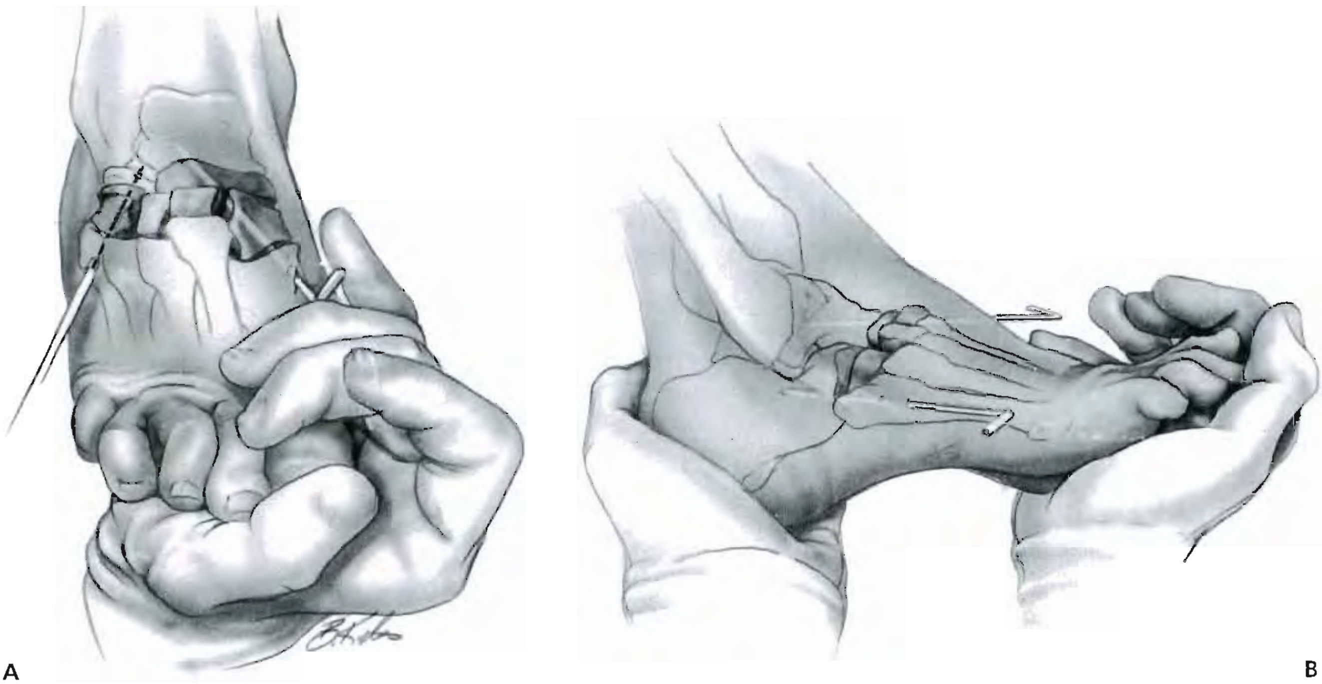


FIGURE 7-61. The osteotomy is performed using a large $^1/_2$-inch osteotome or chisel. The proximal cut is made first, encompassing the distal portion of the navicular and a portion of the cuboid bone. This cut is estimated to be perpendicular to the hindfoot axis. The distal osteotomy is made in the proximal portion of all three cuneiform bones and the distal portion of the cuboid bone. It is made perpendicular to the axis of the forefoot. Note that unlike the remainder of the osteotomy, the joints on either side of the cuboid bone are not entered. Rather, the wedge is removed entirely from the cuboid bone. To avoid excessive shortening of the foot, the osteotomies should be fashioned so that no gap of bone is present at the apex of the wedge.



A B

FIGURE 7-62. The osteotomy is closed by elevating the forefoot **(A)**. It is possible to rotate the distal segment, if desired. Often, the first metatarsal will be more depressed than the others. This can be corrected by externally rotating the forefoot; however, care should be taken not to produce an unintended malrotation.

The osteotomy can be fixed with either two Steinmann pins or staples. The dorsal surface of the cuneiform bones is usually higher than the navicular, and this may make staple fixation more difficult. Secure fixation with Steinmann pins is not as easy as it may first appear **(B)**. It is easy for the medial pin to pass too far plantarward. The medial pin is inserted first. It must start in the first metatarsal at an oblique angle directed dorsally and laterally. The pin can be started at this oblique angle more easily if a small stab wound is made over the starting point and a small hole is made in the first metatarsal with a drill. This will prevent the Steinmann pin from slipping. This pin should engage the first metatarsal, the first cuneiform bone, the navicular, and the talus. The lateral pin is started distal to the flare at the base of the fifth metatarsal and is aimed medially and slightly dorsally, crossing the cuboid bone and entering the calcaneus. The ends of the pins are left protruding outside of the skin.

The periosteum is usually tattered at this point, but it should be approximated as best it can. A small, flat silicone drain can be place in the wound, although there is not a lot of dead space. A well-padded, nonwalking short-leg cast is applied.

A C B

FIGURE 7-63. Anteroposterior **(A)** and standing lateral **(B)** radiographs of a 15-year-old boy with rigid symptomatic idiopathic cavus feet. The heel is neutral in stance. The anteroposterior view 6 weeks after midfoot osteotomy shows the pins before removal **(C)**. The bone that was resected can be seen by comparing this radiograph to **A**. The pins were removed, a short-leg cast applied, and weight bearing begun. Healing was complete 12 weeks after surgery.

POSTOPERATIVE CARE

The foot is kept elevated for the first few days. The patient is then ambulated with a three-point, non–weight-bearing crutch gait for 6 weeks. After 6 weeks, the cast and the pins are removed in the office. A short-leg walking cast is applied, and the patient is permitted full weight bearing for an additional 4 to 6 weeks, at which time healing should be complete.

References

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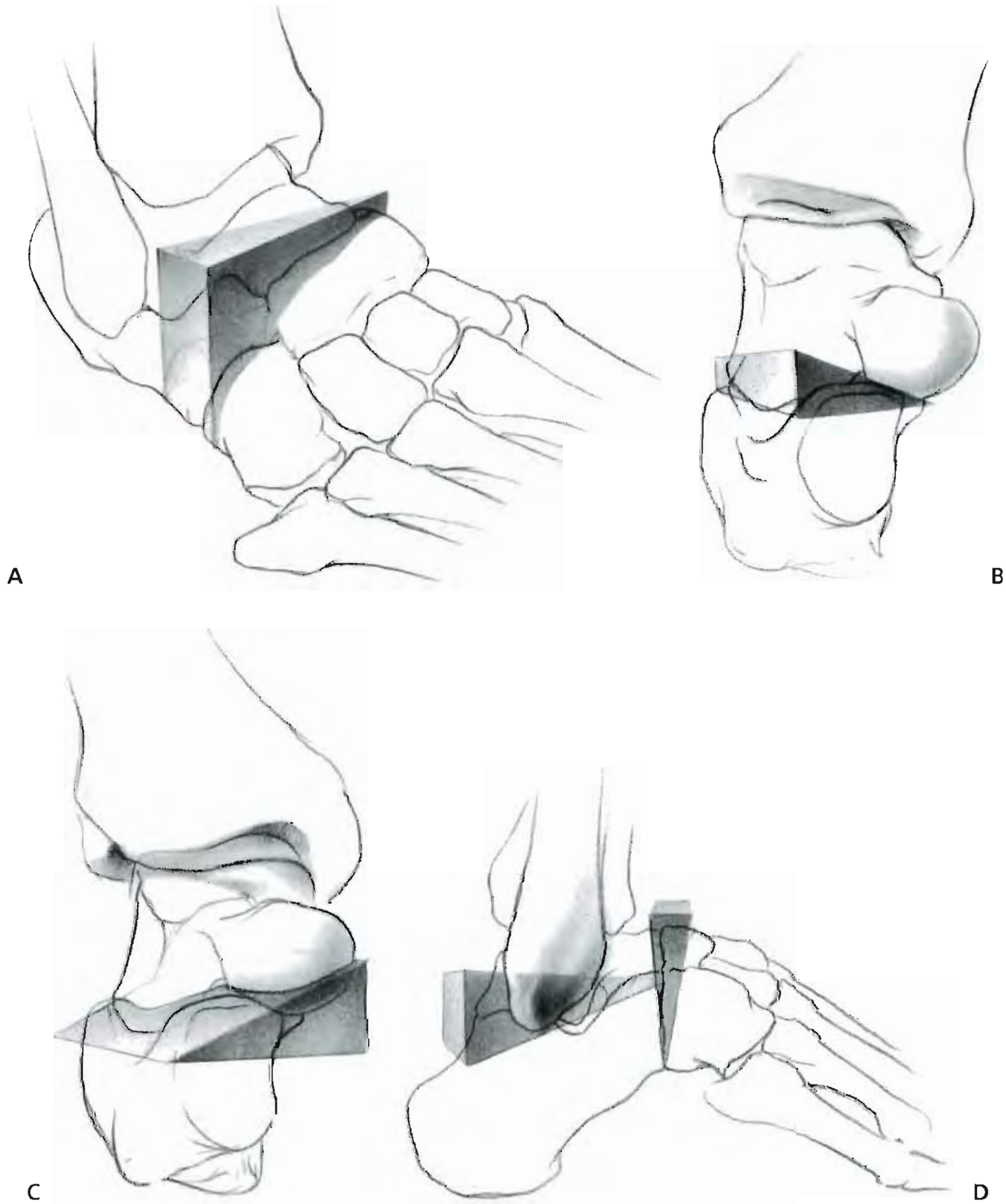
7.9 TRIPLE ARTHRODESIS

The operation commonly known as *triple arthrodesis* is attributed to Hoke (1). As originally described, he resected the head and neck of the talus after resecting the talocalcaneal joint. The foot was displaced posteriorly, and the resected bone was reshaped and reinserted. Duncan and Lovell (2) reported on 109 cases of the Hoke triple arthrodesis in which the head and neck of the talus were removed and replaced, as originally described, with the addition of calcaneocuboid joint resection. Ryerson (3) originally described the triple arthrodesis. In this classic operation, he added resection of the calcaneocuboid joint to resection of the talonavicular and talocalcaneal joints. He did not remove the head and neck of talus. Lambrinudi (4,5) described a resection of bone that is designed to correct a dropped-foot deformity. Several reports evaluate these procedures in patients with poliomyelitis (6), residual of clubfoot (7), progressive neuromuscular disease (8), and arthrogryposis (9).

The operation is deceptively simple. The three aforementioned joints are resected, separating the foot into three movable segments: the forefoot, the calcaneus, and the talus and ankle mortise. If the correct wedges of bone are resected, the position of the foot will be correct when the bony surfaces are apposed. In practice, this can be a difficult task.

The operation should be performed within 1 year or at most 2 years of skeletal maturity. In the young child, much of the bone is composed of cartilage. Resection of enough cartilage to obtain good bony apposition is difficult in the young child. In addition, this resection slows the growth of the resected bones. This growth arrest, combined with an operation that in itself shortens the foot, may result in unacceptable shortening of what may already be a short foot (Figs. 7-64 to 7-70).


A
B
C
D

◀ **FIGURE 7-64.** The surgeon should give some thought to the wedges of bone to be removed and, in particular, the amount of bone to be removed before beginning the operation. We have never found it helpful to plan precise wedges with cutouts after the operation has begun, however. Visualizing the actual foot at surgery and making the osteotomy cuts to create the wedges, as described in the subsequent discussion, seems much more practical and accurate. A slightly different technique for deformities that are not so great as to require resection of bone is to remove the joint surfaces with osteotomes and curettes until there is sufficient mobility to gain the desired correction.

The most common deformity for which triple arthrodesis is performed is fixed varus deformity. To correct this deformity, a laterally based wedge of bone is removed from each of the joints to be resected. Conceptually, two wedges of bone at right angles to each other are removed. The wedge that will allow correction of the forefoot will excise the talonavicular and calcaneocuboid joints. To achieve correction to a neutral position, the distal cut is perpendicular to the long axis of the forefoot, and the proximal cut is perpendicular to the longitudinal axis of the calcaneus **(A)**. When these two surfaces are opposed, the forefoot should be straight.

To correct the varus of the hindfoot, a laterally based wedge must be removed from the subtalar joint. To correct the heel to a neutral position, the proximal cut from the undersurface of the talus should be perpendicular to the long axis of the tibia (or parallel with the ankle mortise), whereas the distal cut from the superior surface of the calcaneus should be parallel with the bottom of the heel **(B)**. When these two surfaces are opposed, the heel should be in neutral.

A triple arthrodesis for fixed valgus deformity is among the most difficult. This is because medially based wedges created using the same principles described earlier must be removed from the lateral side **(C)**. This task is simplified if all of the joints are widely opened by extensive capsulotomies and cutting the interosseous ligament of the subtalar joint. A small laminectomy retractor can be used to hold the joints open.

Calcaneocavus deformity is the most uncommon indication for triple arthrodesis. In this circumstance, a posteriorly based wedge is removed from the subtalar joint, which allows correction of the calcaneus. A dorsal wedge is removed from the talonavicular and calcaneocuboid joints to allow the forefoot to be dorsiflexed **(D)**.

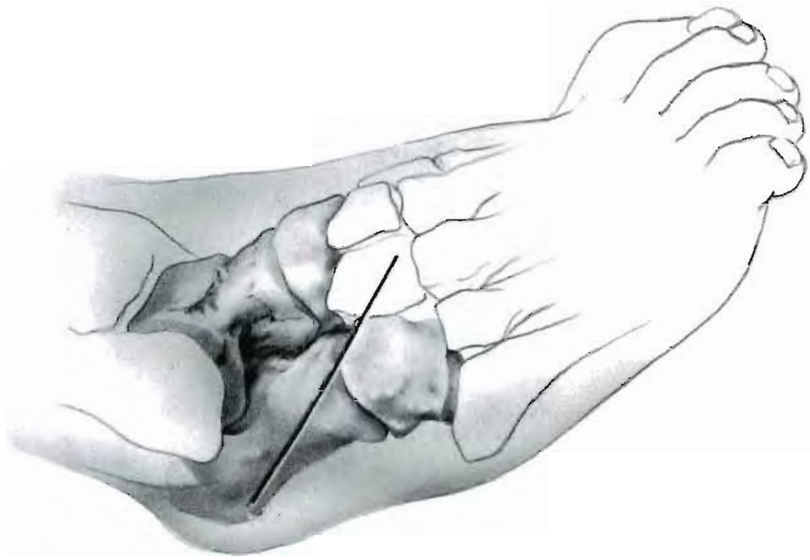
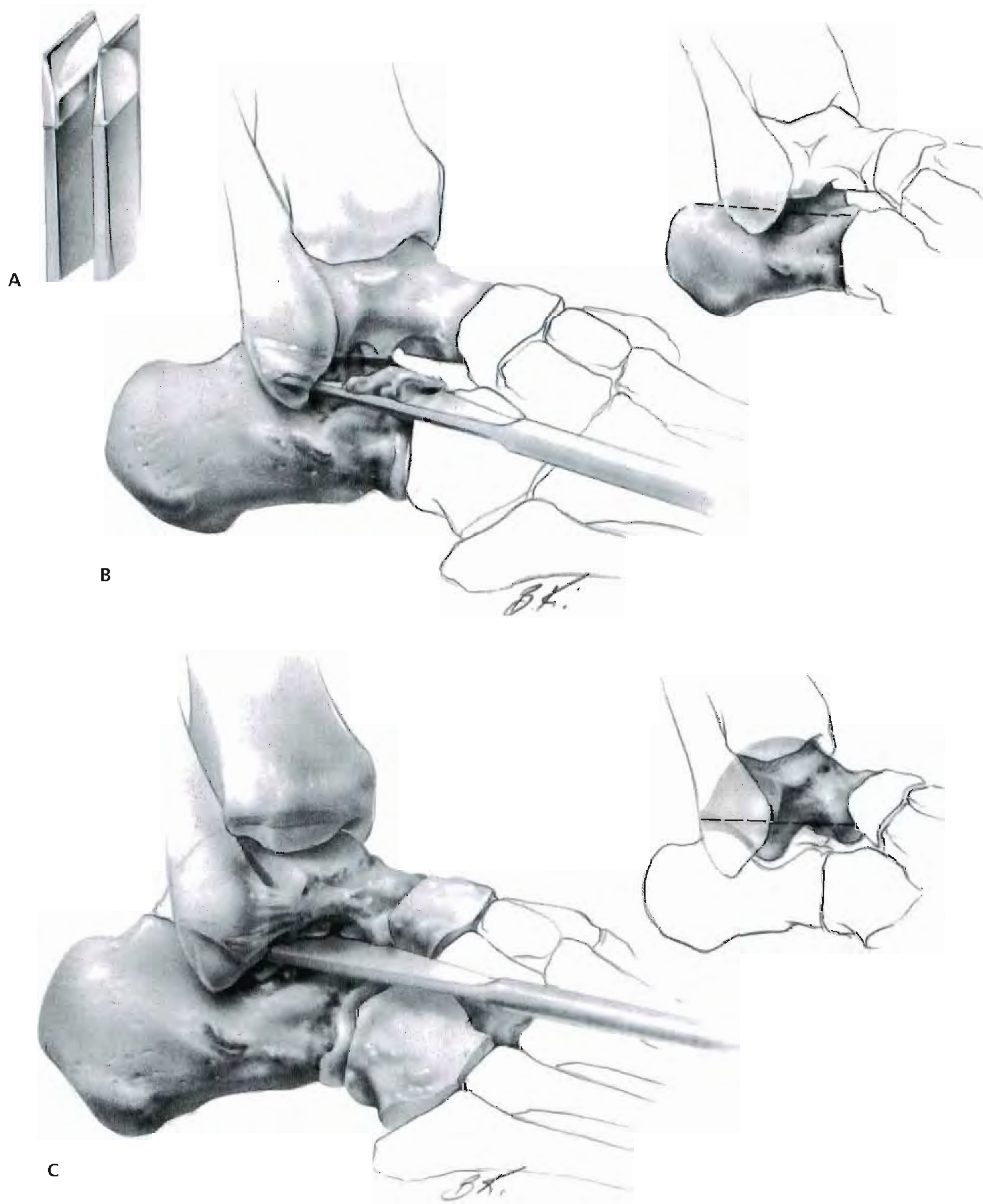


FIGURE 7-65. The operation is illustrated for the most common deformity: varus. The patient is placed on the operating table with a sandbag under the hip on the side to be operated, thus bringing the lateral side of the foot into better position. A small, sterile sandbag or other support is placed under the medial side of the foot. This supports the foot while the joint surfaces are cut. The incision is a straight lateral incision that crosses the lateral side of the talonavicular joint and the distal end of the calcaneus. It should extend from just medial to the most lateral extensor tendons dorsally to just past the peroneal tendons volarly. There should be no undermining of the skin edges. After the fascia over the extensor brevis muscle is incised, the proximal insertion of this muscle is found, and the muscle is elevated to expose the lateral capsules of the calcaneocuboid and talonavicular joints. The fibrofatty tissue is removed from the sinus tarsi, exposing the lateral aspect of the subtalar joint. (This exposure is described in more detail in Procedure 7.10.)

FIGURE 7-66. The talonavicular and calcaneocuboid capsules are widely incised, exposing the joint surfaces. It will assist removal of the bone wedges of the subtalar joint if as much stripping as possible of the capsule of the subtalar joint is accomplished. This can be done by sliding a curved periosteal elevator (e.g., a Crego elevator) around the lateral and then posterior aspect of the subtalar joint. After this, as much of the capsule of the subtalar joint as can be seen is incised, the interosseous ligament is divided, and a large bone skid is used to pry the joint open. This will provide the surgeon an excellent view of the two bony surfaces of the subtalar joint that are to be excised.


A
B
C

◀ **FIGURE 7-67.** The wedges of bone are now excised. The subtalar joint is done first. Most of the bone for the correction should be removed from the calcaneus. It is better to use a chisel than an osteotome for these cuts. The chisel, with its flat surface as opposed to the double-beveled surface of an osteotome, is easier to keep on a straight course **(A)**.

The cut into the dorsal surface of the calcaneus should be parallel to the bottom of the heel **(B)**, whereas the cut in the bottom of the talus should be parallel with the ankle mortise from medial to lateral **(C)**. It is best to make the most proximal and distal aspects of these cuts first and the middle portion in between them last. This is because the middle part will be the most difficult to remove with remaining capsule attached to the prominent sustentaculum tali and the most worrisome to cut through with the neurovascular bundle in close proximity.

If these cuts are made correctly, when the two cut surfaces are opposed, the heel will be in neutral regarding varus and valgus.

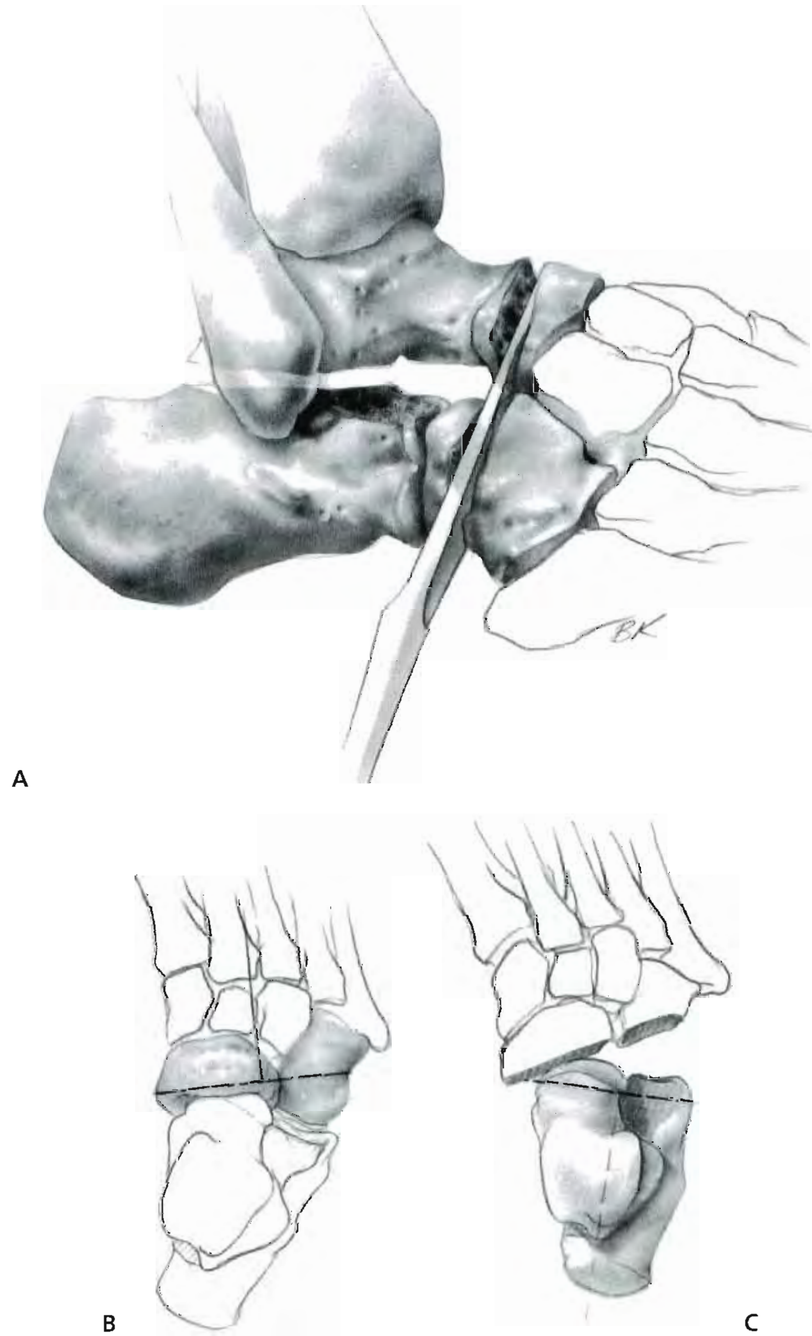


FIGURE 7-68. The same principle is used in aligning the forefoot. The cuts in the navicular and the cuboid should be perpendicular to the longitudinal axis of the forefoot **(A, B)**, whereas the cuts in the distal talus and calcaneus should be perpendicular to the longitudinal axis of the hindfoot or calcaneus **(C)**.

FIGURE 7-69. When the wedges are removed, the foot is placed in the corrected position, and the surfaces are inspected. Good coaption should be present to ensure prompt healing. The external contour of the foot should be inspected to be certain that the desired alignment has been achieved. If all is as desired, each of the joints is held together with a staple. The power staple driver is an ideal tool for this. A drain is placed in the wound and brought out distally, where it can easily be removed. A well-padded short-leg cast is applied. Some surgeons prefer to use Steinmann pins or no fixation other than casting alone.

A B C D

FIGURE 7-70. Anteroposterior **(A)** and lateral **(B)** radiographs of a 16-year-old boy with a rigid cavus foot with the heel fixed in varus resulting from Charcot-Marie-Tooth disease. At 6 weeks, there is still not trabeculation across the lines of joint resection; however, healing is sufficient to permit weight bearing in a short-leg cast **(C)**. At 12 weeks, healing is complete, and no further cast protection is needed **(D)**.

POSTOPERATIVE CARE

The immediate postoperative period is usually characterized by significant discomfort. For this reason, continuous epidural analgesia is a good adjunct to the postoperative management. It can be continued for the first 2 to 3 days while the patient is maintained on bed rest with the foot elevated. The patient is discharged on a three-point, non–weight-bearing crutch gait. At 6 weeks, the cast is removed, and radiographs are obtained to monitor the progress of the healing. At this time, healing is usually sufficient to permit application of a short-leg walking cast for an additional 4 to 6 weeks, after which time healing should be complete as evidenced by obliteration of the osteotomy cuts, and cast immobilization can be discontinued.

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7.10 GRICE EXTRAARTICULAR SUBTALAR ARTHRODESIS

The extraarticular arthrodesis of the subtalar joint that was devised by Grice was initially used in the treatment of children with polio (1). The procedure is most often applied in the treatment of spastic valgus deformity in cerebral palsy, with other paralytic and congenital conditions being less common. Because the arthrodesis is extraarticular, it does not disturb the growth of the bone and necessitate the removal of large amounts of articular cartilage that would be required to expose the cancellous bone in an immature child. The Grice procedure is commonly recognized among experienced orthopaedic surgeons as an operation that is difficult to perform correctly and that has a significant failure rate (2–4). Although good results have been reported in patients with cerebral palsy (5), others have found this procedure to perform the worst in this population (6). The most common complications in long-term follow-up are anterior orientation of the graft leading to slippage and nonunion, unrecognized ankle valgus deformity, overcorrection into varus, and uncorrected calcaneus deformity (7).

The procedure is designed as a bone block to prevent eversion of the calcaneus with consequent valgus deformity. The foot must be correctable to a neutral position before the operation can be considered. In addition, any equinus deformity must be corrected before the Grice procedure. A common error is to perform a subtalar stabilization when there is instability in the ankle joint. This problem is usually encountered in children with spina bifida and can be avoided by assessing the ankle joint with a standing radiograph before surgery. The bone graft is best taken from the iliac crest. If taken from the tibia, as originally described, it can result in fracture, and if taken from the fibula, it can result in fibular shortening and a subsequent valgus deformity at the ankle (Figs. 7-71 to 7-75).

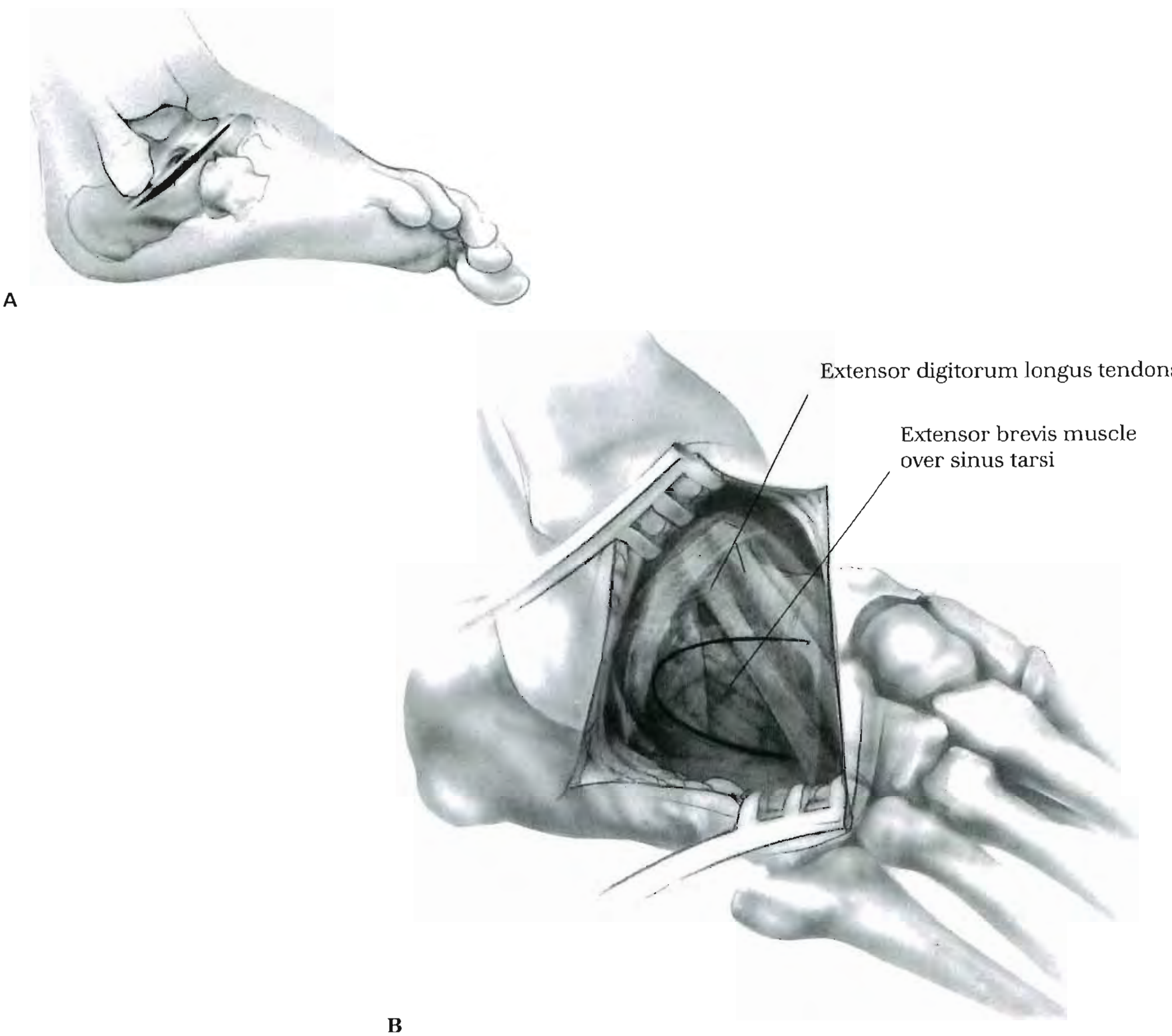
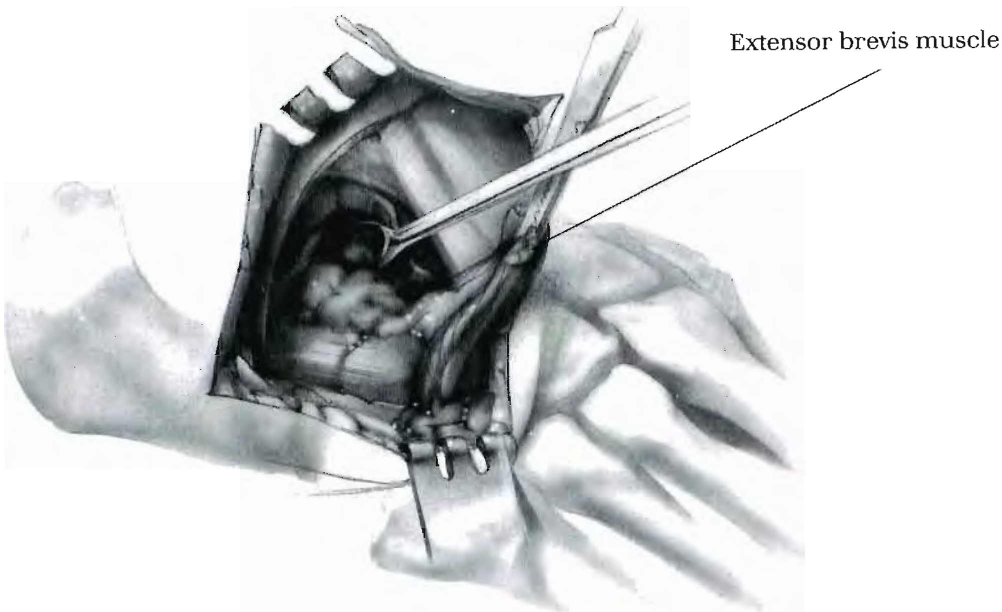
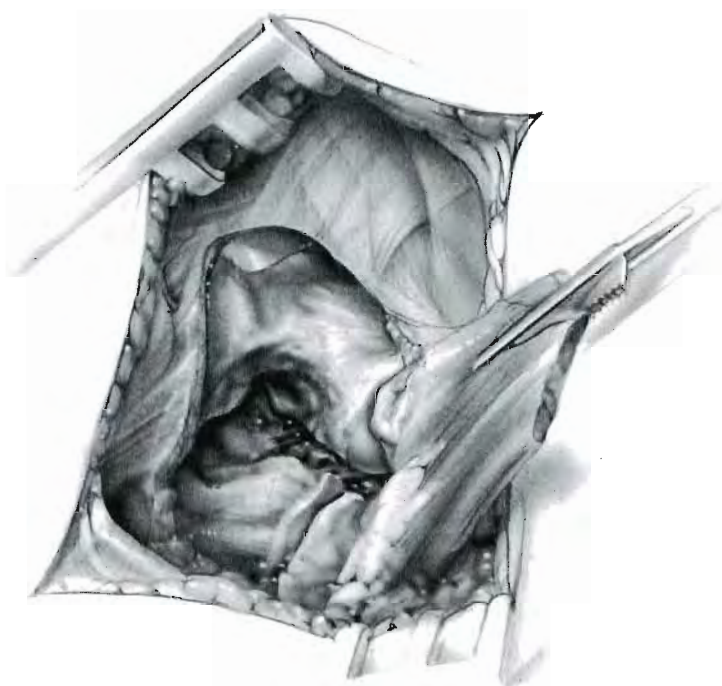


FIGURE 7-71. The incision is a straight, obliquely placed incision over the sinus tarsi that follows the normal skin lines, as described in the excision of the calcaneonavicular coalition **(A)**. The incision is carried directly down to and through the deep fascia layer that overlies the origin of the extensor brevis muscle. This fascia is divided and undermined proximally to expose the origin of the muscle and the fibrofatty tissue filling the sinus tarsi as well as the peroneal tendons that are freed and retracted plantarward. When the wound is closed, approximation of this deep fascia also approximates the thin skin, lessening the tension on it and minimizing wound problems.

At this point, the inexperienced surgeon may be disoriented regarding the bony landmarks and begin by removing the fibrofatty tissue from the sinus tarsi with a knife and rongeur. If the surgeon knows where the bone lies under the soft tissues, however, it is easier to excise the fibrofatty tissue that fills the sinus tarsi and elevate it as well as the muscle as a single, distally based flap. The cut along the underside of the talus and the dorsal surface of the calcaneus is illustrated by the *solid line* **(B)**. With a knife, an incision is made down to the bone, first starting on the dorsal surface of the calcaneus just proximal to the calcaneocuboid joint. This incision is carried proximally and then dorsally along the medial side of the body of the talus onto the inferolateral side of the talar neck, where the incision then turns distally until it reaches the talonavicular joint.



A



B

FIGURE 7-72. This U-shaped incision is deepened to excise all of the material from the sinus tarsi. If this is done, the fibrofatty tissue will remain attached to the muscle and can be retracted by a hemostat. Any remaining soft tissue that obscures the bony anatomy can be excised with a rongeur or a curette **(A)**. During this exposure, the subtalar joint may be opened, but this is of no consequence. The surgeon should be able to see clearly the neck of the talus that forms the roof of the sinus tarsi and the dorsal surface of the calcaneus that forms the floor of the sinus tarsi **(B)**. The exposure shows the calcaneocuboid joint and the talonavicular joint capsules. This is shown for better orientation of the anatomy but should be avoided, if possible, because it is not a necessary part of the exposure.

FIGURE 7-73. An osteotome can be used to determine both the correct size of the graft and its location. With the foot in equinus, the calcaneus is inverted, opening the sinus tarsi. Osteotomes of various sizes can be placed in the sinus tarsi while the foot is dorsiflexed and everted. Inspection of the foot, at this point, will give the surgeon an idea of what the position of the foot will be with various-sized grafts. When the foot is dorsiflexed, the osteotome (and subsequently the graft) should lie in a direct line with the tibia.

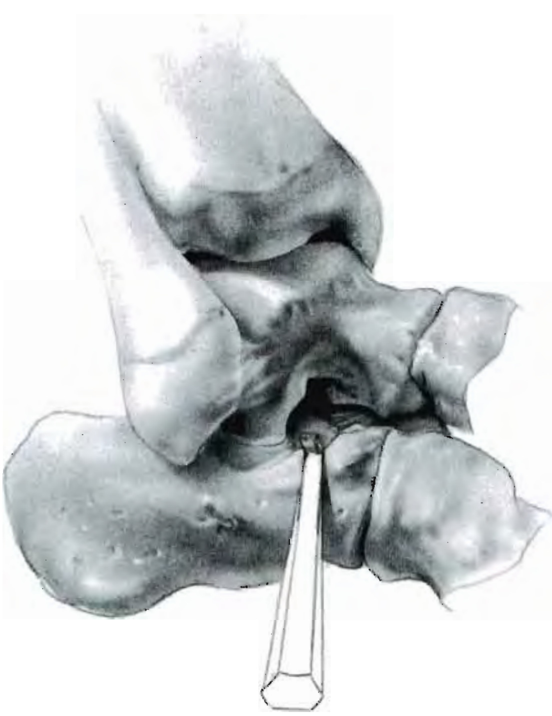
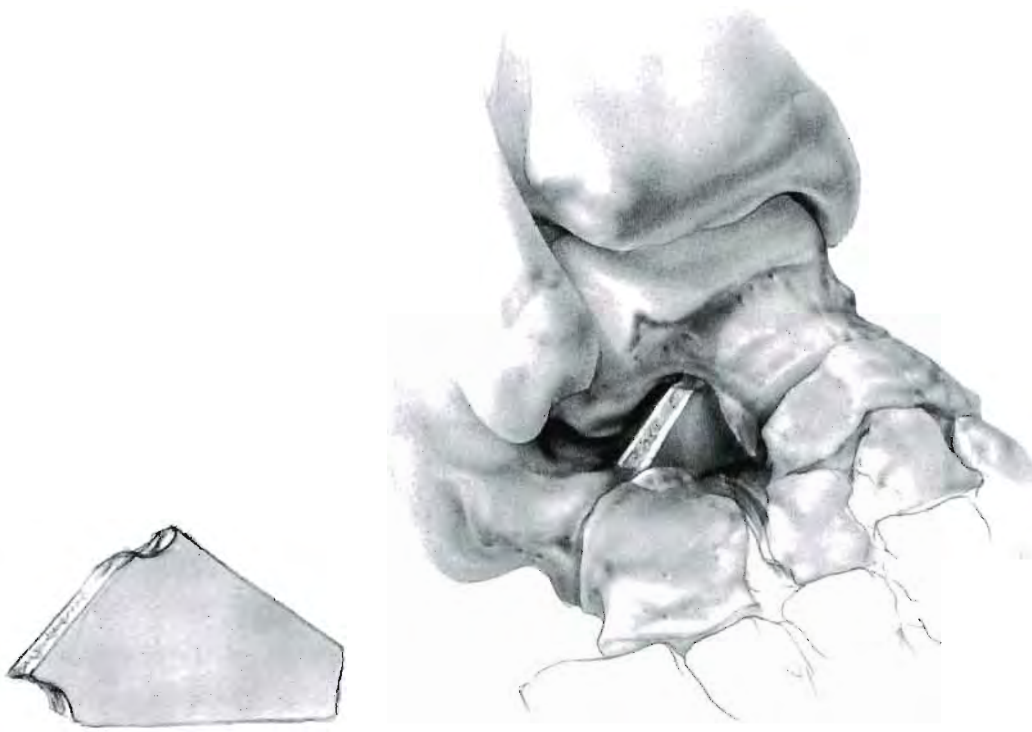


FIGURE 7-74. When the correct location for the graft is determined, a small channel is cut into the neck of the talus and the dorsal surface of the calcaneus with a narrow osteotome. As originally described, this cut should not go completely through the cortex into the cancellous bone because it would collapse into the cancellous bone with resulting loss of correction. This, in part, may account for the problem of nonunion. At least the lateral cortical edges should be left intact. The graft is shaped in such a fashion that its lateral portion will fit over this cortical rim while the remainder of the graft can sink into the cancellous bone.



A B

FIGURE 7-75. The bone graft is taken from the anterior iliac crest just behind the anterosuperior iliac spine. The graft is shaped to fit into the channels. The approximate height of the graft can be judged by the size of the osteotome that produced the desired correction **(A)**. It should be left slightly longer than measured because it can always be trimmed but not increased in size.

The graft is put into place by plantar flexing and inverting the foot, placing the graft, and then dorsiflexing and everting the foot **(B)**. With the graft firmly held in place, the foot is inspected carefully to ensure that the correction is as desired. It is best to leave slight valgus to ensure against the worse complication of producing varus.

The wound is closed by trimming away the excess fibrofatty tissue from the sinus tarsi and bringing the extensor brevis muscle back over the sinus tarsi. The deep fascia layer is closed, followed by skin closure. During this closure, an assistant must hold the foot dorsiflexed and everted to prevent displacement of the graft. It is possible to fix the subtalar joint with a Steinmann pin, if desired. A short-leg cast is applied with the foot still held in the correct position.

POSTOPERATIVE CARE

The cast should be left in place until the graft has solidly united. This may take 10 to 12 weeks. During this time, the patient should not bear weight. After radiographic confirmation of healing of the graft, the patient is started on range-of-motion exercises for the ankle and is progressed from a partial weight-bearing crutch gait to full weight bearing, as tolerated.

References

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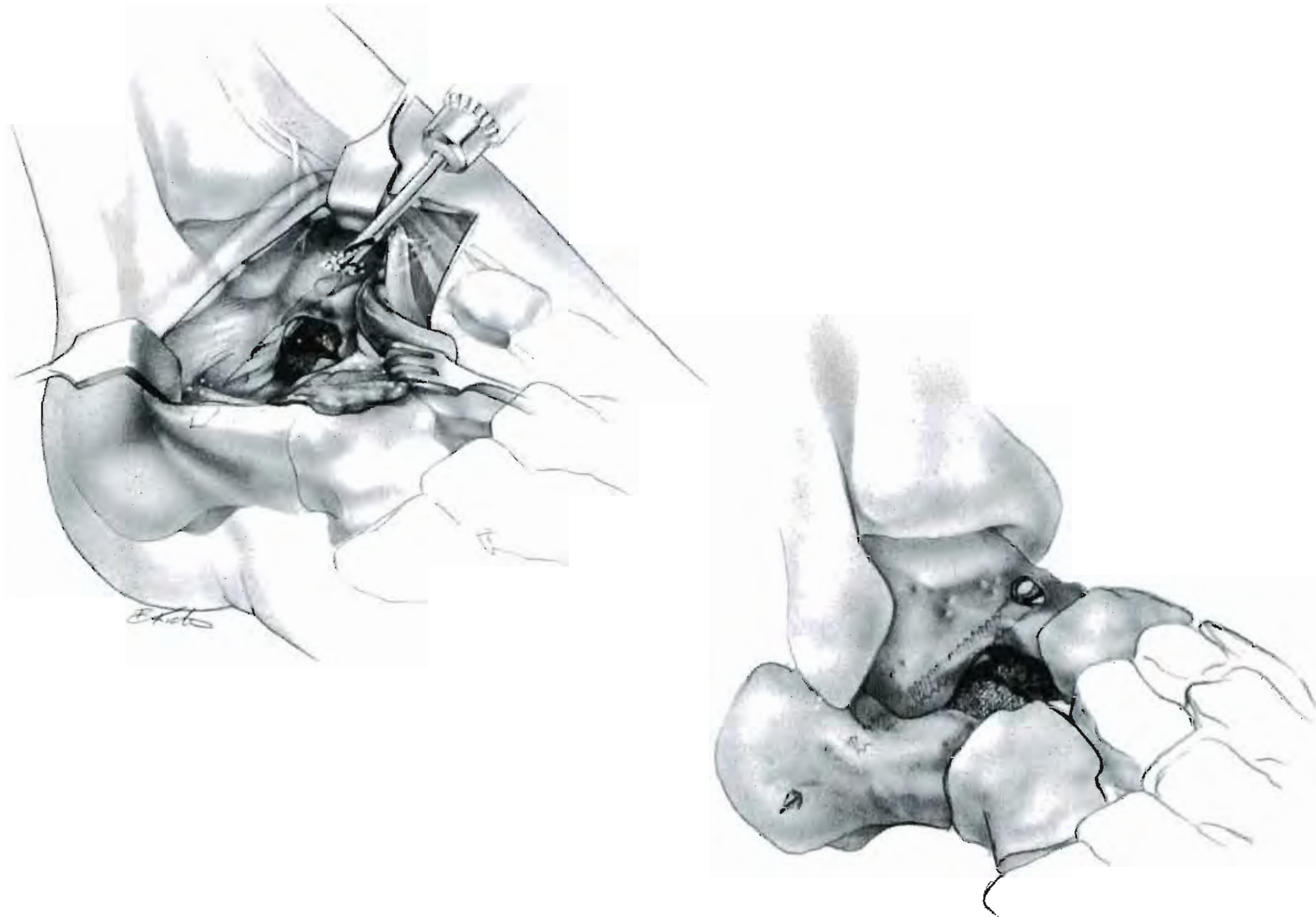
7.11 EXTRAARTICULAR SUBTALAR ARTHRODESIS WITH CANCELLOUS GRAFT AND INTERNAL FIXATION (DENNYSON-FULFORD TECHNIQUE)

Variations of the Grice technique of extraarticular subtalar arthrodesis have been tried to circumvent the problems inherent in the technique. The most popular of these is the technique of Dennyson and Fulford (1), also called the *Princess Margaret Rose technique,* using cancellous bone for more certain and rapid healing and a screw for internal fixation of the subtalar joint. The results and complications of this procedure have been reported (2).

POSTOPERATIVE CARE

Healing is usually complete in 6 to 8 weeks. Although Dennyson and Fulford did not specify when weight bearing was permitted, we usually choose to keep the patient non–weight bearing for the first 3 weeks. After 3 weeks, the cast is changed, and walking is permitted (Figs. 7-76 to 7-79).

FIGURE 7-76. The surgical approach and exposure are the same as for the Grice procedure (see Procedure 7.10). After this is completed, a small osteotome or curette is used to remove cortical bone from the undersurface of the talar neck and the dorsal surface of the calcaneus. This decortication should be confined to the medial aspect of the sinus tarsi because it is important to preserve the cortical bone laterally, where the screw will pass.



A

FIGURE 7-77. Next, it is necessary to expose a small area on the dorsal surface of the neck of the talus because this is where the screw must start. The interval between the extensor digitorum longus and the neurovascular bundle is the correct interval through which to approach the talus. This can be done by extending the lateral incision farther medially and by retracting the skin further, as illustrated here, or by making a second small longitudinal incision directly over the area.

The foot is held in the desired position relative to dorsiflexion and inversion. The appropriate-sized drill for the screw is used to drill through the neck of the talus in a posterolateral direction **(A)**. The screw must not pass directly through the center of the talus and calcaneus because this will be too close to the axis of rotation of the subtalar joint and will result in poor fixation. This is one of the problems of the Batchelor technique of subtalar arthrodesis.

Most often, the best screw is a 4.5-mm cortical AO screw. It should pass through the calcaneus to emerge through the lateral cortex near the plantar surface **(B)**. The drill can be seen passing through the sinus tarsi and should enter the calcaneus posterolateral to the area of decortication. The length of the screw can be measured from the length of the drill bit that is in the bone. The drill is removed and the appropriate-sized screw is inserted and tightened **(A)**. The subtalar joint should now be secured in the correct position.

FIGURE 7-78. After completion of fixation, cancellous bone graft is obtained from the iliac crest in the region of the anterosuperior iliac spine and is packed into the sinus tarsi. Banked cancellous bone may also be used.

The wound is closed, as described in the section on the Grice procedure (see Procedure 7.10), by first closing the fascial layer to aid in holding the bone graft in place.

FIGURE 7-79. A: Standing lateral radiograph of the foot of a 8-year, 5-month-old girl with juvenile rheumatoid arthritis. The foot has been developing an increasing valgus deformity with pain for the past 2 years. The foot can be corrected to neutral. **B, C:** Intraoperative radiographs demonstrate the proper placement of the screw before the bone graft being placed. **D:** Six months later, when the patient is admitted for screw removal, the consolidation of the bone graft producing an extraarticular bone block can be seen. Note the subsequent narrowing of the posterior facet of the subtalar joint.

References

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7.12 MITCHELL BUNIONECTOMY

In adolescents, hallux valgus is more often accompanied by metatarsus primus varus than in adults (1). It is generally accepted that metatarsus primus varus is almost always present in adolescents with hallux valgus, and its correction should be a part of any surgical plan to correct hallux valgus. Correction usually entails the removal of the exostosis, with care taken not to remove the joint itself; correction of the hallux valgus; and realignment of the first metatarsal.

Although the removal of the exostosis and the soft tissue repair to correct the valgus of the great toe are standard, there are many methods described for correction of the metatarsus primus varus. Most surgeons seem to have their favorite method, but other considerations, such as whether the metatarsal is short or long, should also play a role in the choice of the procedure.

The Mitchell procedure displaces the metatarsal head laterally by means of a step cut just behind the metatarsal head (2). Although this procedure has a good record, it is technically demanding if the reported complications of avascular necrosis of the metatarsal head, nonunion, malunion, and excessive shortening, are to be avoided (3). Because some shortening of the first metatarsal is inevitable with this procedure, it is best used in patients with a first metatarsal that is longer than the second metatarsal (Figs. 7-80 to 7-88).

FIGURE 7-80. The incision is placed on the dorsomedial side of the first metatarsal. It should extend from the flare of the proximal phalanx proximally three fourths of the way up the metatarsal. The incision is deepened directly down to the periosteum and capsule, with care taken not to harm the dorsal or plantar branch of the nerve.

FIGURE 7-81. A V incision with the base on the proximal phalanx is now made in the capsule of the metatarsophalangeal joint. The two limbs of the V should be far enough apart and positioned such that when the capsule is repaired it will not pull the toe into dorsiflexion or plantarflexion. This can occur if the base of the V on the phalanx is too far dorsal or plantar. This flap is elevated from proximal to distal by blunt and sharp dissection. In addition, the periosteum is elevated from the distal half of the metatarsal. Care should be taken to leave the lateral attachments of capsule and periosteum because this is the sole remaining blood supply of what will become the distal fragment.

FIGURE 7-82. At the completion of the elevation of the capsular flap, the joint will be open and the exostosis will be exposed. There is usually a clear demarcation between the exostosis and the actual metatarsal joint surface. This demarcation is a groove, often referred to as *Clark's groove.* It is important to resist the temptation to remove too much bone with the exostosis because this may leave the medial side of the metatarsal head deficient.

A $^{1}/_{2}$-inch osteotome is placed at the medial edge of Clark's groove and directed proximally in line with the metatarsal shaft. In adolescents, this exostosis is not usually large, and a large portion of it consists of cartilage and fibrous tissue. This is a potential problem if a proximal opening-wedge osteotomy using the exostosis as graft is planned.

FIGURE 7-83. After the exostosis is removed, the holes through which the suture will be passed to secure the osteotomy are drilled. The positioning of these holes will determine the location of the osteotomy, and they therefore should be placed carefully. The first hole is placed 1 cm behind the joint surface and toward the medial cortex, whereas the second hole is placed 1 cm proximal to the first hole and toward the lateral cortex. The holes are drilled from the dorsal aspect of the metatarsal and should be kept perpendicular to the axis of the shaft.

FIGURE 7-84. The suture that will hold the osteotomy can be passed at this point. A large, strong absorbable suture on a large needle is used. The needle is straightened somewhat and passed through the holes by the end that the suture attaches to rather than the sharp end. This way, it will have less tendency to catch in the cancellous bone in the hole. Because it will be easier to tie the suture on the dorsal aspect of the metatarsal, the suture is passed through the first hole from the dorsal to plantar side and through the second hole from the plantar to dorsal side. The suture is left loose so that it will not be cut while performing the osteotomy. If the surgeon wishes, the suture can be passed after the osteotomy is performed.

Some surgeons prefer to fix this osteotomy with a Kirschner wire or a small headless screw.

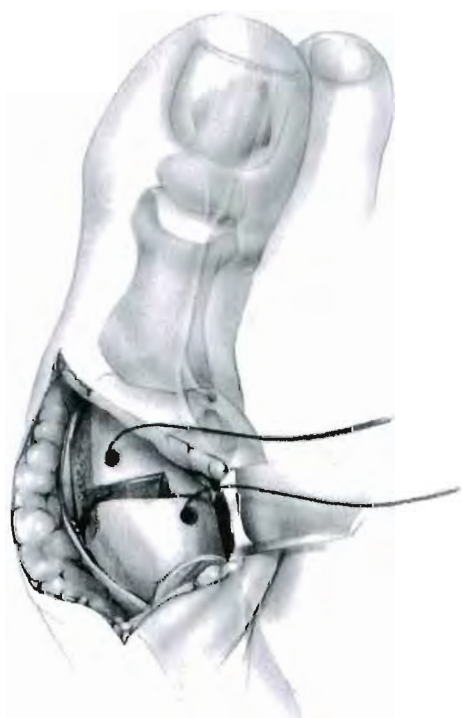

FIGURE 7-85. The osteotomy is created by first removing a small wedge of bone from the medial two thirds of the metatarsal midway between the two holes. If the distal cut is angled distally to produce a trapezoid, more tilt of the metatarsal head will be gained with less shortening (3). This wedge must be kept small enough to avoid excessive shortening, but with enough step-off to produce stability when the metatarsal head is displaced.

In addition, it is crucial that the cuts be perpendicular to the longitudinal axis of the metatarsal. If this is not accomplished correctly, the metatarsal head may be plantarflexed or dorsiflexed, resulting in metatarsalgia of the first or second metatarsal heads, respectively.

After the wedge is created, the more proximal cut is completed through the metatarsal shaft, completing the osteotomy.

FIGURE 7-86. The distal fragment is displaced laterally, locking the step of bone on the proximal fragment over the lateral side of the proximal fragment. When judged to be satisfactory, the suture is tied, securing the osteotomy.

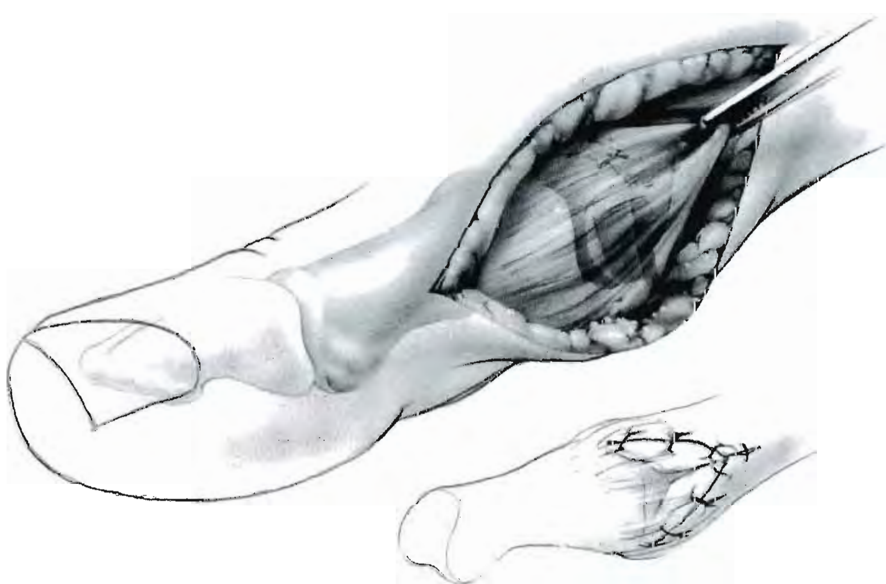

FIGURE 7-87. The capsular flap is pulled proximally, and the correction of the hallux valgus is observed. It should not require excessive tension on this flap to correct the hallux valgus. This flap is in essence a Y-to-V advancement. It is sutured to the capsule and periosteum. A bone anchor with attached suture may also be used. The wound is closed without a drain.

FIGURE 7-88. A: Preoperative radiograph of the right foot of a 10-year-old child with bilateral symptomatic bunions. Note the metatarsus primus varus in addition to the hallux valgus. It is unusual for a child of this age to have symptoms. **B, C:** Correction at 6 weeks.

POSTOPERATIVE CARE

Most surgeons have their favorite postoperative bunion dressing. It is important to note, however, that the average adolescent does not behave like the average adult during the postoperative period. After surgery, a short-leg cast is applied. It should be molded around the forefoot and hold a soft bolster between the first and second toe to take any tension off of the capsular repair. This cast is worn for 6 weeks, at which time the osteotomy is usually healed sufficiently to permit full, unprotected weight bearing. While in the cast, the patient may be permitted crutch-protected weight bearing.

References

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7.13 PROXIMAL METATARSAL OSTEOTOMY AND BUNIONECTOMY

The proximal osteotomy aims to achieve the same goals as the distal osteotomies (e.g., the Mitchell osteotomy). The advantages of the proximal osteotomy are that shortening is little to none, the possibility of avascular necrosis of the metatarsal head is avoided, and the fixation is arguably more secure. Excision of the exostosis and correction of the hallux valgus are performed in the same manner as described in the Mitchell osteotomy (Figs. 7-89 to 7-93).

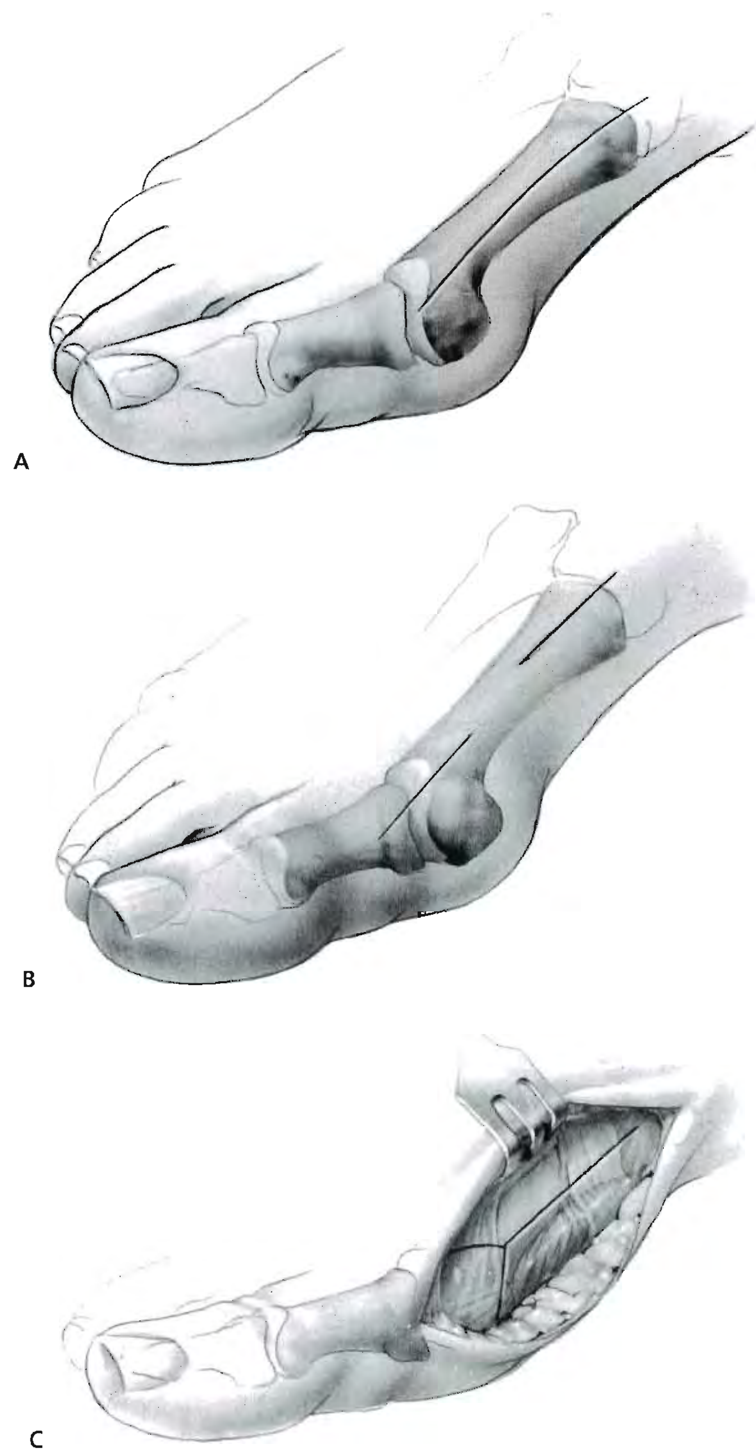


FIGURE 7-89. The operation can be performed through one long incision that is simply a proximal extension to the incision used for the Mitchell procedure **(A)**, or through two separate incisions with the removal of the exostosis and repair of the hallux valgus performed through a distal incision and the osteotomy done through a separate, more dorsally placed proximal incision **(B)**. The incisions in the periosteum through the single-incision approach are illustrated **(C)**.

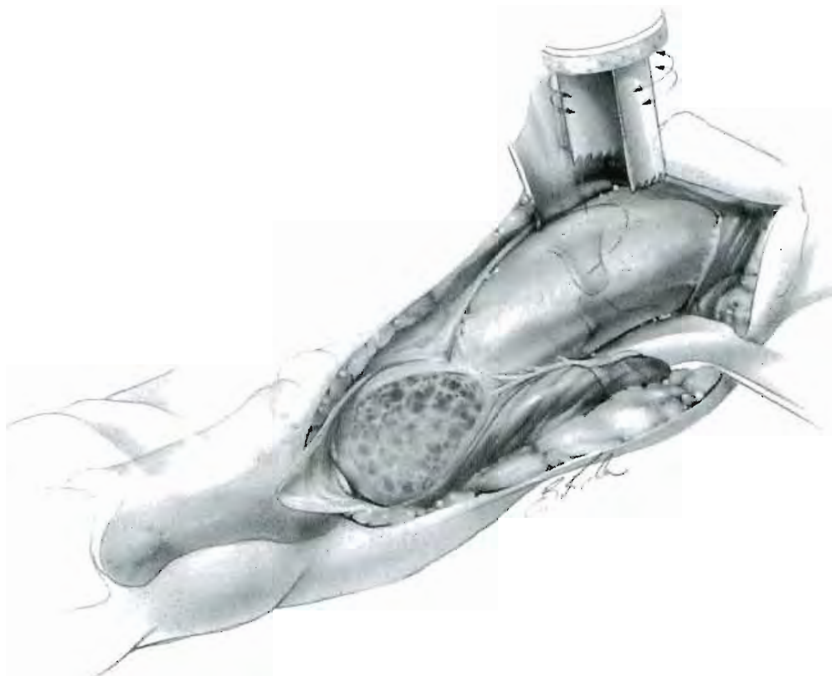


FIGURE 7-90. The periosteum is stripped from the proximal metatarsal to expose the bone 1 cm distal to the metatarsocuneiform joint. Periosteal stripping can be minimized by using two small, sharp, pointed, Hohmann retractors under the periosteum at the osteotomy site.

Although the osteotomy can be performed by connecting multiple drill holes with a small osteotomy, a powered crescentic osteotomy saw can accomplish this much more easily and with less loss of bone. Note that the blade on this saw has a very small excursion; consequently, if the saw is held still, and worse, if it is pressed too hard into the bone, the blade will not move, but the saw will vibrate undetectably in the surgeon's hand. Therefore, when the cut is being made, the saw should be kept moving in an arch, which describes the desired osteotomy, and it should not be pushed too hard into the bone. Copious irrigation should be used to avoid excessive heating of the bone.

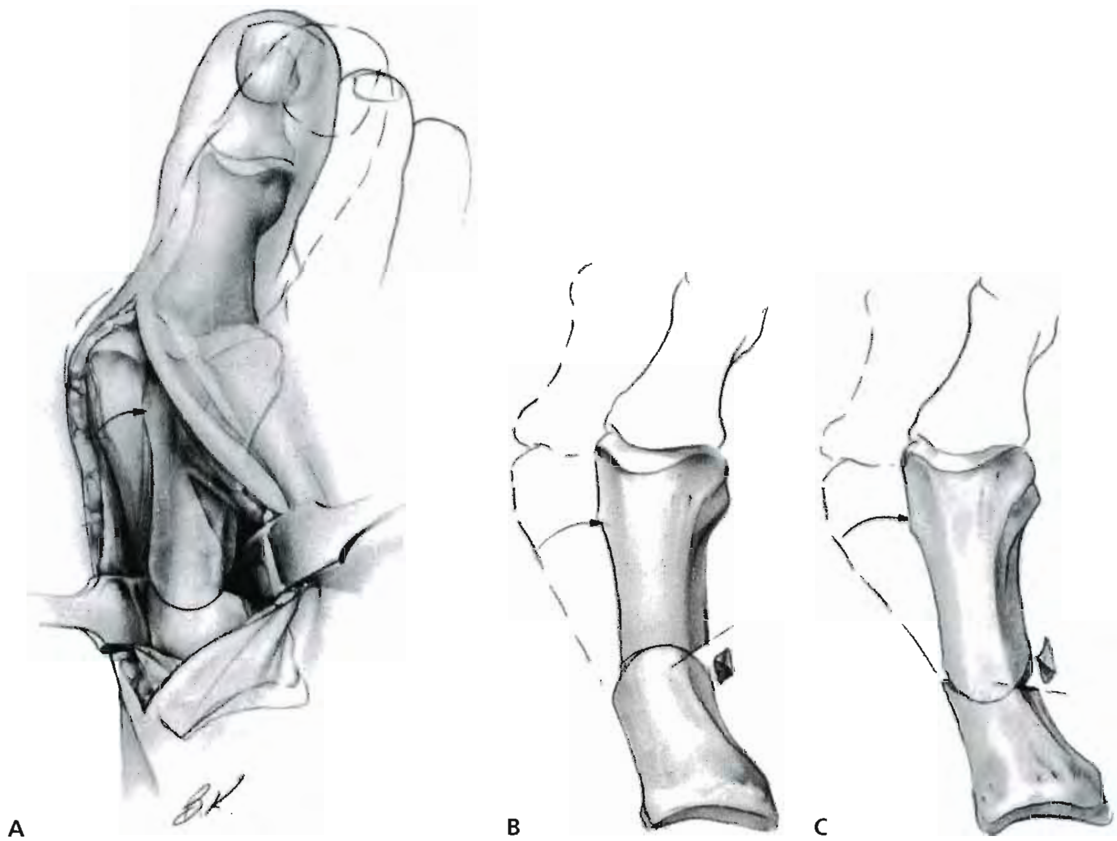


FIGURE 7-91. Whether the osteotomy should be concave on the proximal or distal fragment is a matter of debate. Mann (1) believes that the proximal surface should be concave. This tends to displace the proximal part of the distal fragment medially while the metatarsal head is displaced laterally **(A, B)**. Placing the concave surface on the proximal fragment displaces the entire shaft laterally and tilts the metatarsal head laterally **(C)**. To allow the rotation to occur, the lateral corner of the concave surface should be removed. This is easily accomplished with a small rongeur.

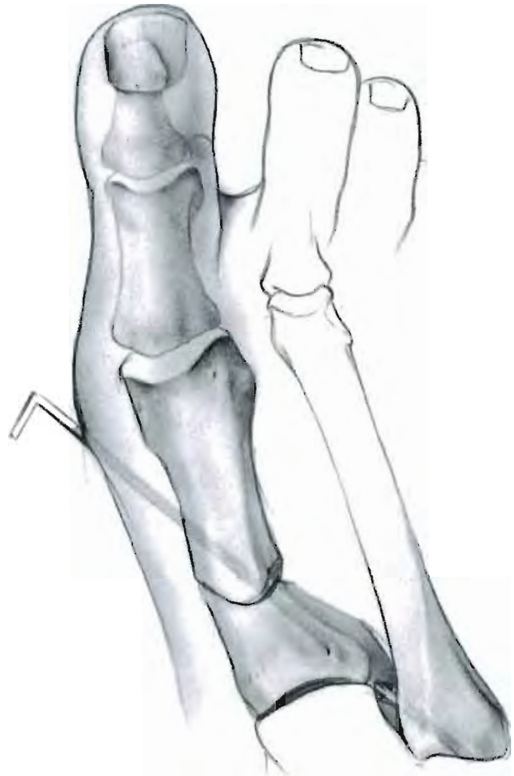


FIGURE 7-92. The osteotomy can be held by several methods of fixation, but none is as simple as a suitably strong Kirschner wire or Steinmann pin. The difficulty of starting this pin at the desired angle through thick cortical bone is avoided by drilling a hole in the lateral aspect of the metatarsal shaft 1 cm distal to the osteotomy. If two incisions are used, this can be done through a small stab wound. This pin usually passes into the base of the more proximally situated second metatarsal. It can be continued into the cuneiform bone. A small length of the pin is left out of the skin so that the pin can be easily removed.

The repair of the capsule to correct the hallux valgus is completed, and the wounds are closed.


A B

FIGURE 7-93. Anteroposterior view of the right foot of a 13-year, 2-month-old girl who had painful bunions secondary to metatarsus primus varus **(A)**. Twenty months later, proximal metatarsal osteotomy and bunionectomy were performed because of the inability to provide relief by modification of the shoe wear that was acceptable to the patient. Six weeks after the surgery **(B)**, the correction of the metatarsus primus varus and removal of the bunion are seen.

POSTOPERATIVE CARE

The postoperative care is the same as for the Mitchell procedure (see Procedure 7.12).

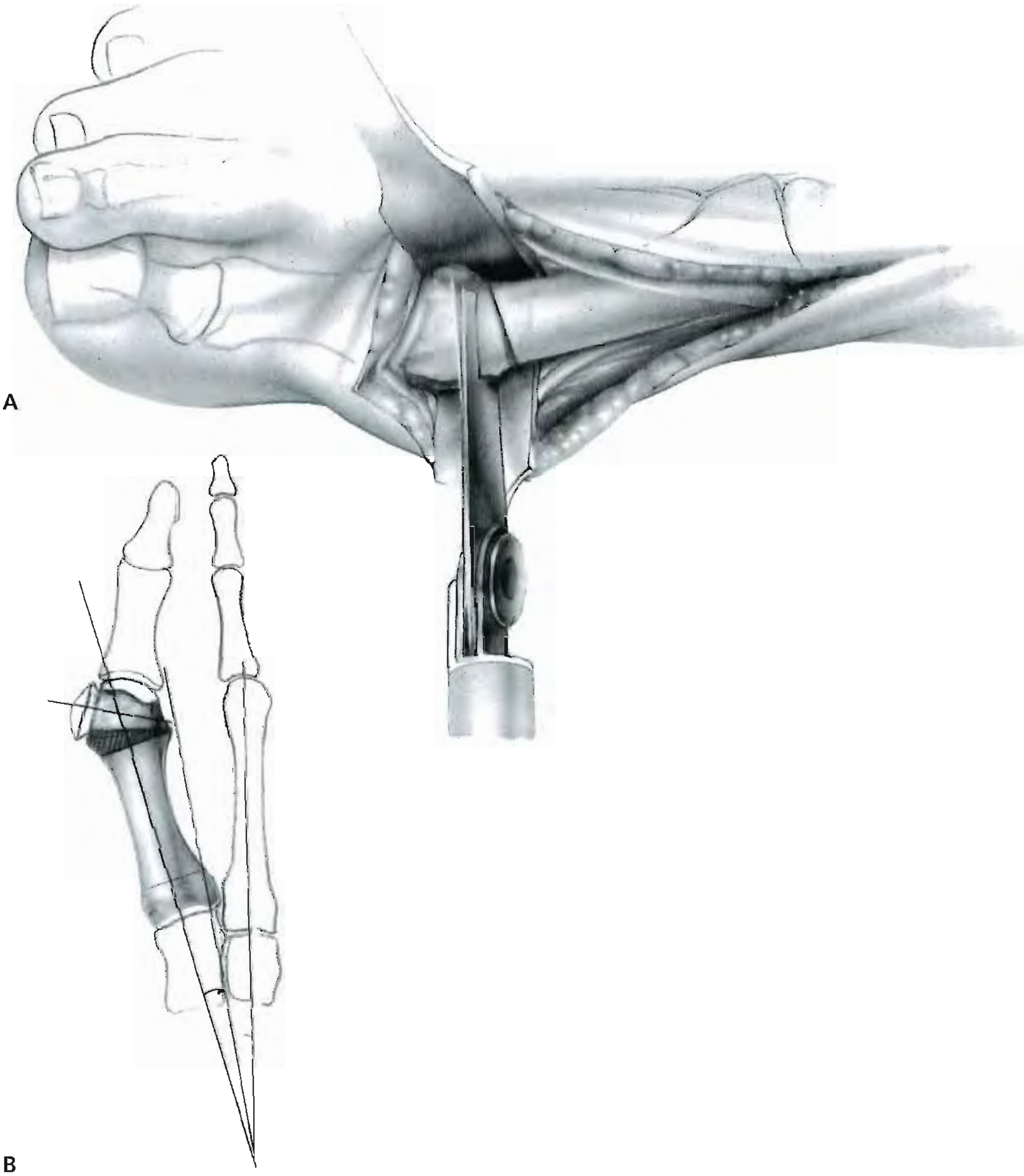
Reference

1. Mann RA. Surgery of the foot, 5th ed. St. Louis: CV Mosby, 1986:95.

7.14 CORRECTION OF HALLUX VALGUS AND METATARSUS PRIMUS VARUS BY DOUBLE METATARSAL OSTEOTOMY

Peterson and Newman (1) modified and reported on a procedure originally described by Logroscino (2). In this procedure, a wedge of bone is removed from the distal part of the first metatarsal just behind the metatarsal head and is inserted into an osteotomy at the proximal part of the same metatarsal. We reserve this procedure for the most severe deformities; the mean metatarsal-phalangeal angle in the patients of Peterson and Newman (1) was 38 degrees. The closing wedge distally corrects the valgus angulation of the metatarsal head and the metatarsophalangeal joint without disrupting the bony and soft tissue relationships of the joint. The opening-wedge osteotomy proximally corrects the increased intermetatarsal angle, realigning the first with the second metatarsal. Both components of the deformity are corrected without the need for displacement or remodeling of the metatarsal. The osteotomies are then transfixed with a smooth pin (1) (Figs. 7-94 to 7-98).

FIGURE 7-94. The first metatarsal is exposed, as described for the proximal metatarsal osteotomy and bunionectomy. This incision, however, is continued more proximally to expose the proximal as well as the distal part of the metatarsal **(A)**. The metatarsal is stripped subperiosteally, with care taken to preserve the most lateral attachments to bone. The capsule is opened with a distally based Y flap. The medial prominence of the metatarsal or bunion is excised with an osteotome, as described for the Mitchell bunionectomy **(B)** (see Procedure 7.12). Small metatarsal retractors are placed to aid the exposure.



A

B

FIGURE 7-95. A small microsagittal saw is used to remove a medially based wedge of bone from the distal aspect of the metatarsal where the head and neck join **(A)**. The size of this wedge depends on the metatarsal-phalangeal angle but usually approximates 20 degrees. The proximal cut is perpendicular to the metatarsal shaft, and the distal limb is parallel to the joint surface **(B)**. The wedge should be removed, preserving the periosteum and a small connection of cortical bone on the lateral side to lend stability. If rotational correction of the toe is necessary, the bone is divided completely to permit rotation.

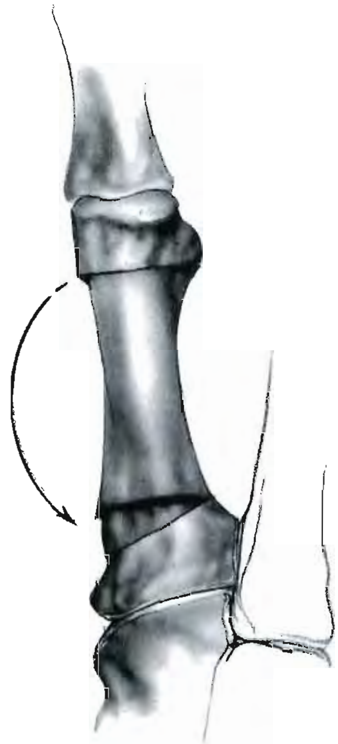


FIGURE 7-96. The saw is used to create a medial opening wedge osteotomy at the proximal end of the metatarsal. This cut in the bone should parallel the joint surface of the proximal tarsal-metatarsal joint. The wedge of bone that was removed distally is inserted into this osteotomy.

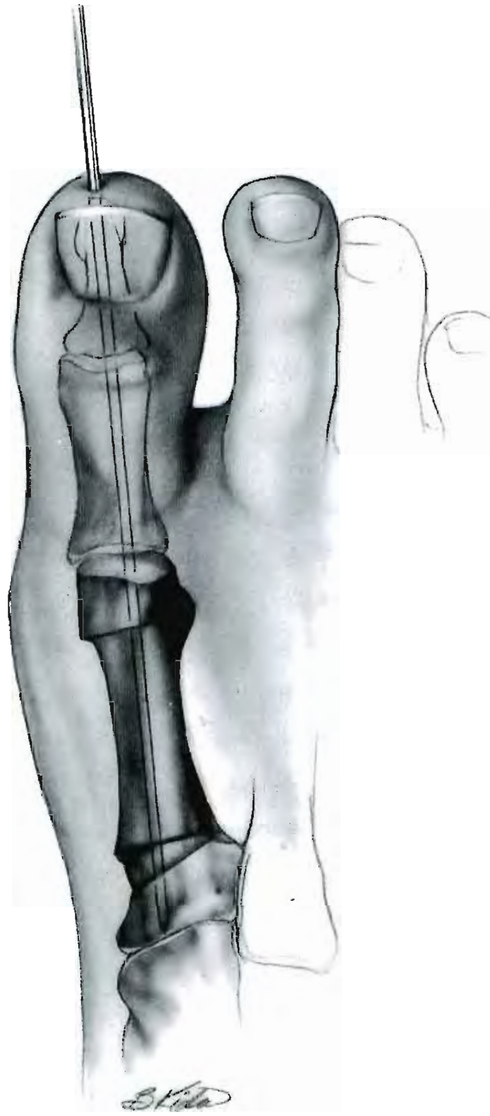


FIGURE 7-97. With the osteotomies held closed, a $^3/_{16}$-inch smooth pin is passed from the distal phalanx proximally to the most proximal portion of the metatarsal, thus fixing both of the osteotomies.

The capsule is closed as in the Mitchell osteotomy. After wound closure, the foot is placed in a well-padded short-leg cast.

FIGURE 7-98. TS is a 15-year-old girl with severe symptomatic hallus valgus and bunions. **A:** Standing anteroposterior radiographs demonstrate the extent of the deformity. **B:** An anteroposterior radiograph taken 6 weeks after surgery when the pin was removed demonstrates the distal closing osteotomy and the proximal opening osteotomy. **C:** Five months after surgery, a standing anteroposterior radiograph shows the correction of the deformity.

POSTOPERATIVE CARE

After 6 weeks, the cast is removed, and the pin is pulled out. This can be performed in the office without anesthesia. Depending on the healing, the patient may (and probably will need to) be placed in a short-leg walking cast until there is radiographic evidence of solid union of both osteotomies.

References

1. Peterson HA, Newman SR. Adolescent bunion deformity treated with double osteotomy and longitudinal pin fixation of the first ray. J Pediatr Orthop 1993;13:80.
2. Logroscino D. Il trattemento chirugico dell'alluce valgo. Chir Organi Mov 1948;32:81.

7.15 PHYSIOLYSIS AND METATARSAL OSTEOTOMY IN THE TREATMENT OF LONGITUDINAL EPIPHYSEAL BRACKET OF THE FIRST METATARSAL

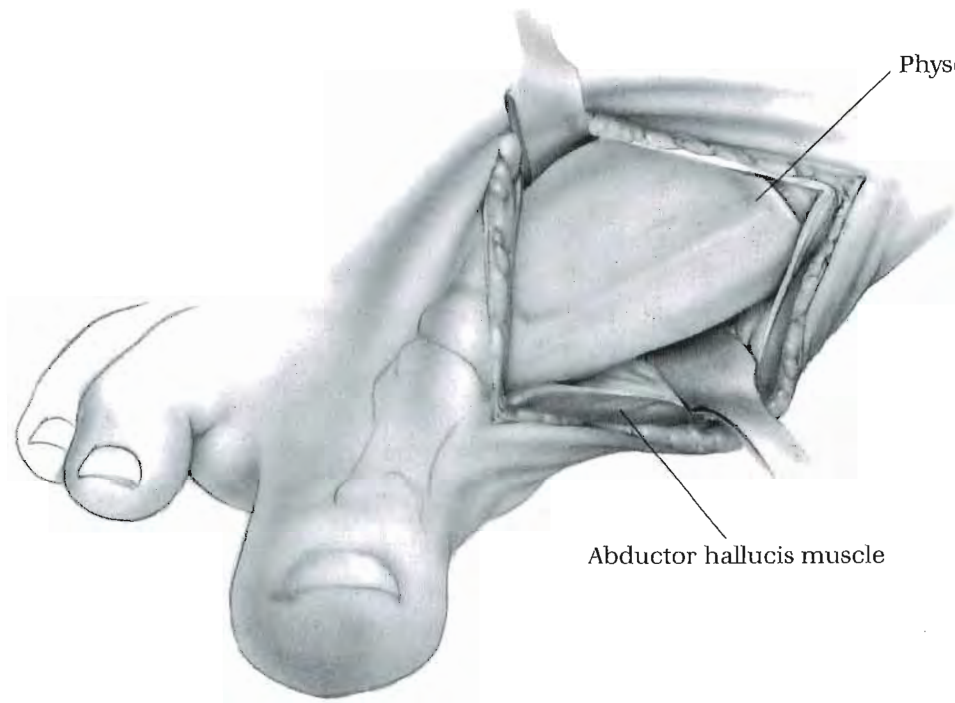
Longitudinal epiphyseal bracket of the metatarsal is analogous to the delta phalanx of the thumb (1). Although this condition has been described in several bones of the hand and foot (2,3), Mubarak and colleagues (4) have highlighted this problem in the first metatarsal.

The condition is characterized by a shortened and angulated first metatarsal. The pathoanatomy has been described by Ogden and colleagues (5). The diaphysis and metaphysis of the bone are bracketed by a continuous epiphysis. There is a variable degree of angulation, deformity, and shortening of the bone. This condition can occur in the phalanx, metatarsal, or metacarpal bones but appears limited to those bones that ordinarily have a proximal physis. It also occurs frequently in association with polydactyly. The surgeon, therefore, should be especially aware of this condition when excising an extra digit adjacent to a shortened metacarpal.

The continuous nature of the physis is not apparent on plain radiographs until the child is older and there has been ossification of the bracket (see Fig. 7-104A). In such cases, it can be documented, if necessary, with magnetic resonance imaging. The bracket almost always lies on the plantar medial side of the metatarsal and is best seen by any imaging study when this is taken into account.

In the treatment of the delta phalanx of the thumb, the principles are to remove the abnormal physis and realign the distal and proximal remaining physis with the longitudinal axis of the bone. In such cases, a variable amount of growth takes place. Soft tissue tightness is one of the obstacles that has been observed to limit the correction with osteotomy of the delta phalanx. Mubarak and colleagues (4) have recommended that polymethyl methacrylate be used as an interposition material to prevent regrowth of the physis. It is yet to be demonstrated that this is necessary. It has not been found necessary in the treatment of delta phalanx of the thumb (Figs. 7-99 to 7-104).

A



B

FIGURE 7-99. The incision is longitudinal and extends the length of the metacarpal **(A)**. The abductor hallucis muscle is released from its distal attachment because it will be tight and limit correction. The periosteum of the metacarpal is incised and subperiosteal exposure is obtained of the dorsal, medial, and plantar aspects of the bone. In older children, the physeal bracket may be obscured by bone, making it difficult to locate **(B)**. If uncertainty exists at this point concerning the location of the distal and proximal physis or the bar, they can be identified by inserting Keith needles into the desired areas with guidance from the image intensifier.

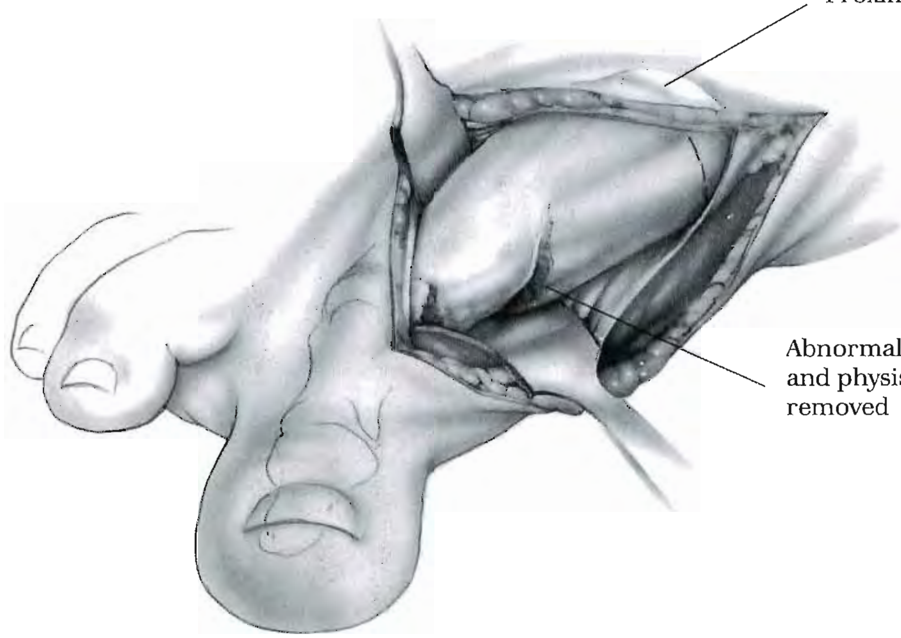


FIGURE 7-100. A rongeur is used to bite away the abnormal bony bridge and physis. This should be done distally and medially until the more normally oriented parts of the physis are reached. This is where the image intensifier verification of the correct area is usually necessary. Beneath this abnormal bone and physis, the cortical bone of the diaphysis will be encountered.

At this point, the surgeon should make a decision. If an osteotomy is to be performed, it seems neither desirable, from the point of healing, nor necessary, from the point of regrowth of the physeal bar, to use cement interposition. If an osteotomy is not necessary to reorient the distal and proximal physes and the phalanges perpendicular to the longitudinal axis of the bone, cement can be used.

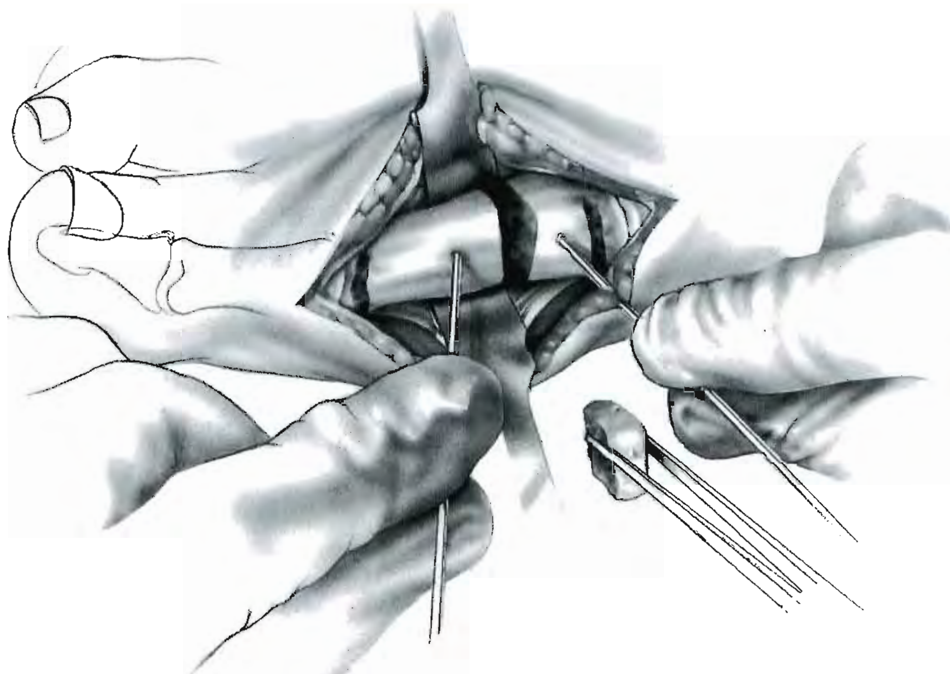


FIGURE 7-101. To perform an osteotomy, the bone is divided at the point of its most acute angle. To manipulate the fragments, it may be necessary to put small Steinmann pins in the proximal and distal fragments. Using these pins to realign the distal fragment, tight soft tissue structures can be identified and released. It may also be desirable to correct any true hallux valgus by release of the medial capsule of the metatarsal phalangeal joint. A small piece of autogenous or allograft bone is inserted into the opening. A longitudinal pin is then passed through the phalanges into the metatarsal, fixing the graft and both of the fragments.

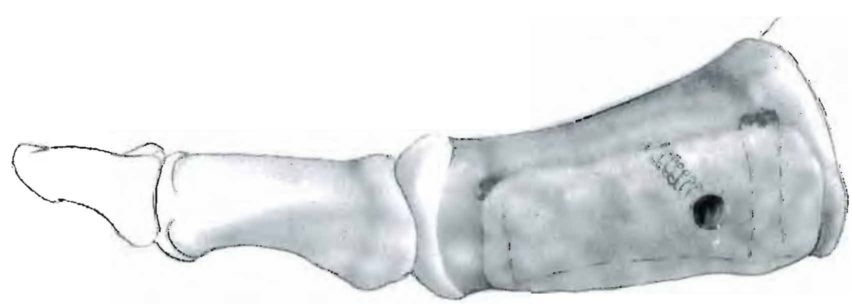
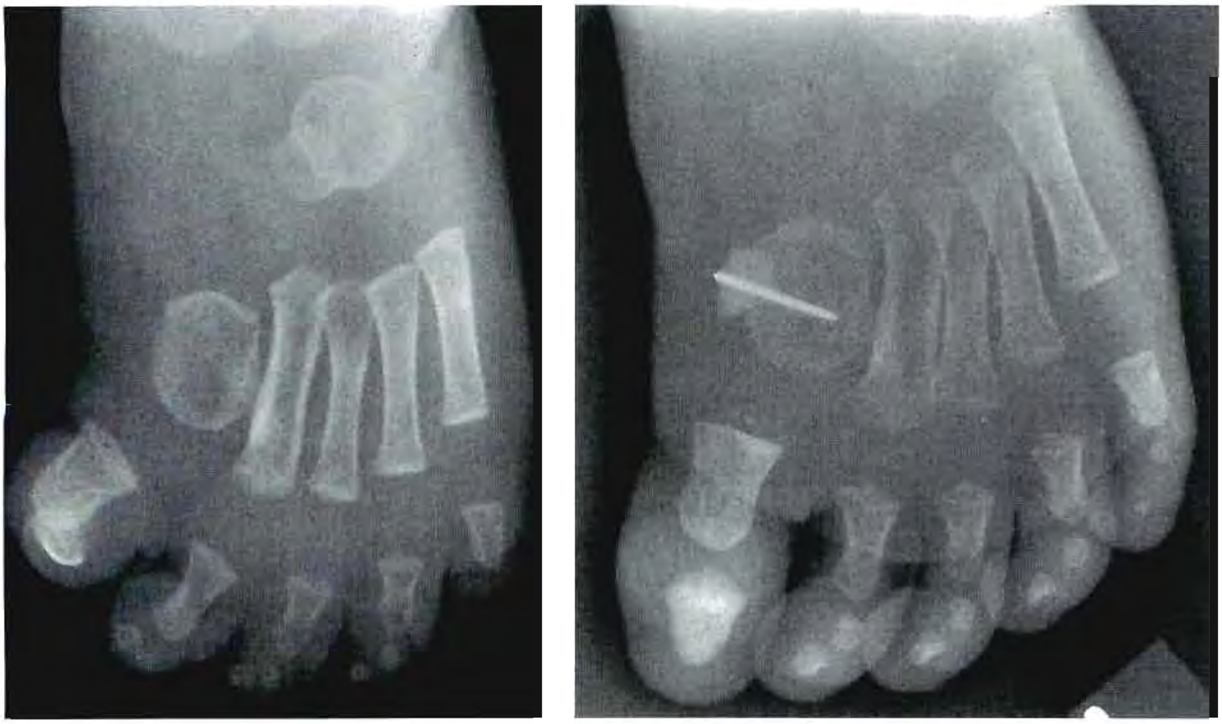


FIGURE 7-102. If an osteotomy is not necessary and the surgeon wishes to use cement, a small, threaded Kirschner wire is drilled into the midportion of the metatarsal, engaging both cortices. A layer of cement is then applied to the side of the metatarsal between the two remaining portions of physis. When this is set, the pin is cut flush with the cement. If a capsular repair is performed, it is done as described previously (see Figs. 7-81 and 7-87).

A B

FIGURE 7-103. A: Anterosuperior view of the foot of a 5-year-old girl who was born with an extra rudimentary first ray that was surgically removed at 6 months of age. Correction of this clubfoot was done at the same time. With growth, the medial side of the foot remained shorter, and the deformity worsened. Radiographs demonstrated the bracket epiphysis of the first ray. The physis and epiphyses at both ends of the first metatarsal were continuous along the inferomedial side of the bone. **B:** The result 5 weeks after resection of the bar without cement interposition and a metatarsal osteotomy at the same time.



A B

FIGURE 7-104. **A:** Anteroposterior radiograph of an 11-month-old boy who presented with a shortened and medially deviated first ray. The bone bar of the bracket is not visible at this time on this view but may be surmised by the deformity. **B:** The immediate appearance after excision of the abnormal bone and physis and interposition with methacrylate. Note that with a different radiographic view showing more of the plantar aspect of the first metatarsal, a small rim of bone is visible.

POSTOPERATIVE CARE

The patient is place in a short-leg cast. If an osteotomy has been performed or a longitudinal Kirschner wire used, weight bearing is not permitted. The cast and the wire are removed after 6 weeks, by which time healing of the osteotomy and capsule should have occurred. Because of the residual deformity that is usually present, the surgeon may be tempted to continue casting or prescribe splinting. The benefit to continued treatment is not proved, but long-term splinting appears to make more sense after 6 weeks.

References

1. Jones BG. Delta phalanx. J Bone Joint Surg [Br] 1964;46:226.
2. Carstam N, Theander G. Surgical treatment of clinodactyly caused by longitudinally bracketed diaphysis. Scand J Plast Reconstr Surg 1975;9:199.
3. Jaeger M, Refior HJ. The congenital triangular deformity of the tubular bones of the hand and foot. Clin Orthop 1971;81:139.
4. Mubarak SJ, O'Brien TJ, Davids JR. Metatarsal epiphyseal bracket: treatment by central physiolysis. J Pediatr Orthop 1993;13:5.
5. Ogden JA, Light TR, Conlogue GJ. Correlative roentgenography and morphology of the longitudinal epiphyseal bracket. Skel Radiol 1981;6:109.

7.16 OPEN LENGTHENING OF ACHILLES TENDON

Lengthening of the Achilles tendon is one of the most common operations in pediatric orthopaedics. Traditionally, the operation is performed by completely exposing the tendon. Once exposed, the tendon can be divided completely in a Z manner and then sutured together at a longer length. This is indicated when it is also necessary to open the posterior aspect of the subtalar or tibiotalar joint.

Because of the unique anatomic arrangement of the fibers in the tendon, it is also possible to perform a lengthening while leaving the fibers in continuity (1). Within the portion of the tendon that is exposed for lengthening, the fibers rotate 90 degrees. Therefore, as described by White (1), if the anterior two thirds of the tendon is divided just above its insertion into the calcaneus, and its medial two thirds is divided at the proximal extent of the tendon, the two bundles of fibers will slide past one another as the foot is dorsiflexed. Although initially described as a percutaneous technique, this is most often performed as an open technique (Figs. 7-105 to 7-110).

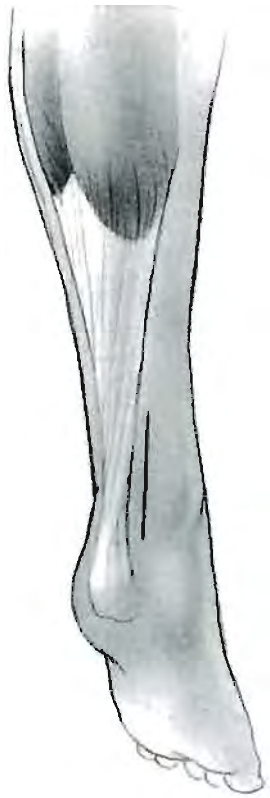


FIGURE 7-105. An open lengthening of the Achilles tendon is most easily performed with the patient prone. With an assistant to hold the leg, however, it is possible to perform the operation with the patient supine if this position is dictated by other procedures that are performed at the same time.

The skin over the Achilles tendon is thin, and this in turn can lead to problems in the healing of the wound. The incision should not be placed over the thin skin directly posterior to the Achilles tendon (it should avoid crossing the most proximal heel crease). Incisions with curves are not necessary and can only lead to further problems. The incision should be placed on the medial side on the ankle just anterior to the Achilles tendon. This skin has a good layer of subcutaneous tissue and will pose no problems for wound closure or healing.

FIGURE 7-106. The incision is carried through the dermis and into the subcutaneous fat. The knife then angles slightly posteriorly, cutting directly into the sheath of the Achilles tendon. The sheath around the tendon is composed of multiple layers of thin, filmy tissue. In one small area of the incision, before all of the subcutaneous fat is divided, care is taken to deepen the cut to penetrate every layer of this filmy tissue.

At this point, a small forceps is used to lift this filmy sheath from the tendon, and one blade of a scissors is passed between it and the tendon. The remainder of the incision is now opened, with the scissors cutting through the subcutaneous fat and tendon sheath together. In so doing, the tendon sheath is left attached to the subcutaneous fat. This will preserve the sheath, and as the subcutaneous tissue is closed, the sheath also closes without the need for sutures.

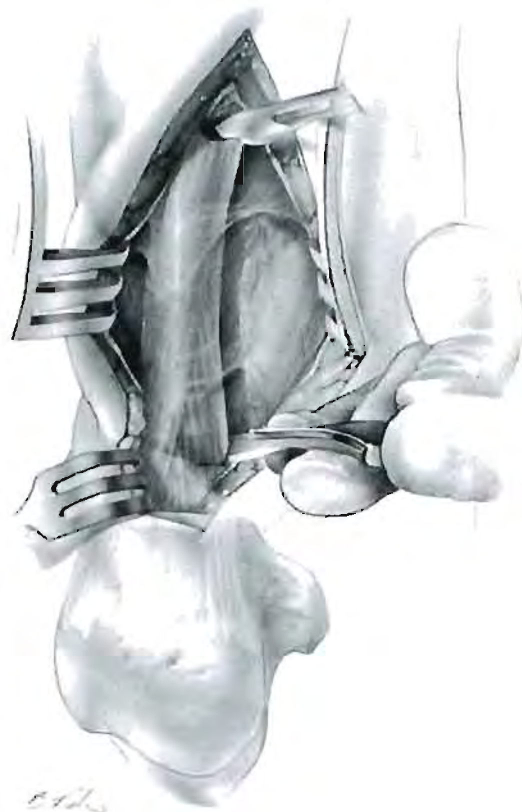


FIGURE 7-107. If a sliding lengthening is performed, the first incision is placed just above the attachment of the tendon into the calcaneus. Starting on the anterior surface or undersurface of the tendon, the anterior two thirds of the fibers are divided almost completely across to the lateral side.

FIGURE 7-108. Next, the medial two thirds of the tendon are divided proximally. This cut should be made as far proximal to the distal cut as is possible while remaining in the purely tendinous portion of the tendon. As this cut is made, the foot is held in dorsiflexion to produce tension on the tendon. Shortly after half of the tendon is divided, the foot should start to go into dorsiflexion as the two halves of the tendon start to slide past one another. It is not usually necessary to suture the tendon because it should remain in continuity and because further undesired lengthening is prevented by the cast.

FIGURE 7-109. If it is desired to perform a Z lengthening, it is easiest to start the incision at the proximal extent of the tendon. A #15 knife blade is inserted completely through the tendon and, with a sawing motion, is drawn distally, producing a division down the middle of the tendon. As the knife reaches the insertion to the calcaneus, it is turned 90 degrees, and the distal-medial half of the tendon is detached from the calcaneus. The knife is then reinserted into the proximal extent of the longitudinal cut that was made previously and turned laterally, dividing the proximal lateral half of the tendon.

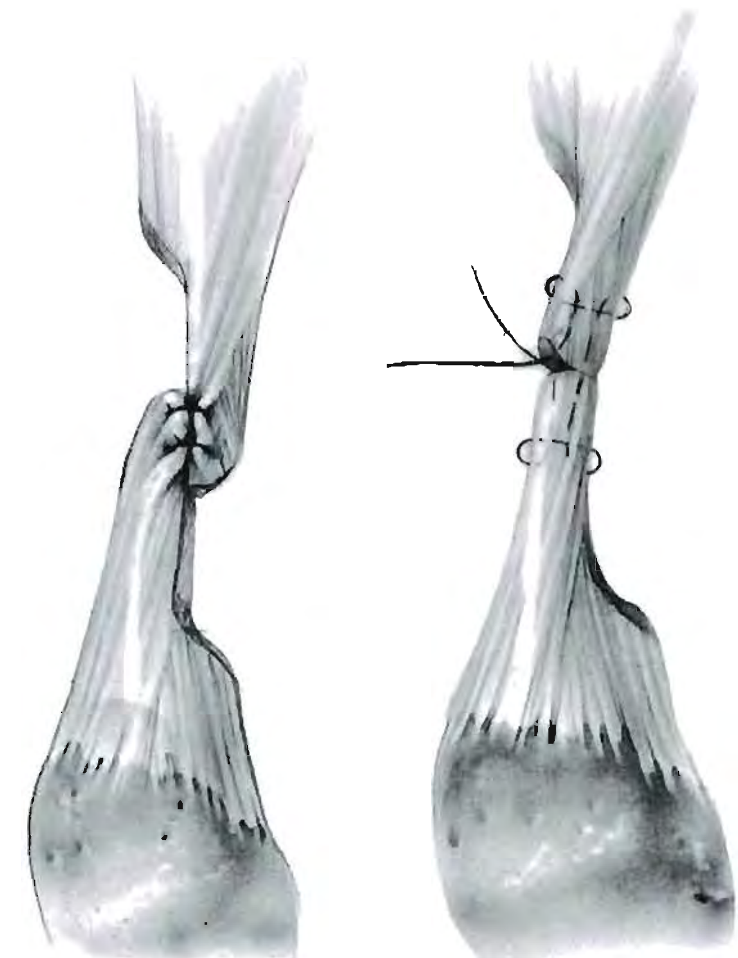


FIGURE 7-110. The foot can be dorsiflexed to the desired position. With an assistant holding the foot in the correct position, the surgeon determines where the tendon should be sutured. This may be done by overlapping the two ends of the tendon and suturing them side to side **(A)**. It is also possible, especially in smaller children, to cut off the excess length from one or both sides and perform an end-to-end repair with a buried suture **(B)**. This technique minimizes the amount of foreign body (suture) and thus should minimize inflammation in the tendon sheath. The surgeon should suture the tendon under moderate tension to avoid significant weakening of plantar flexion and a consequent calcaneus gait.

The wound is closed with a fine, interrupted, absorbable suture in the subcutaneous tissue and subcuticular suture in the skin. Although the fact that the gastrocnemius muscle crosses the knee joint would call for a long-leg cast, this is rarely necessary. A short-leg cast is applied with the foot in the desired position.

POSTOPERATIVE CARE

Usually, the procedure is performed on an outpatient basis. The parents are requested to keep the child's foot elevated for 2 to 3 days, after which the patient may begin ambulation in the cast. The cast can be removed safely after 6 weeks, at which time the tendon should be completely healed.

Reference

1. White WJ. Torsion of the Achilles tendon: its surgical significance. Arch Surg (Am) 1943;46:784.

7.17 PERCUTANEOUS LENGTHENING OF ACHILLES TENDON

Percutaneous lengthening of the Achilles tendon has several advantages over open lengthening and, in our opinion, almost no disadvantages. It can be performed at any age and can be done for a repeat lengthening of the tendon. There is no incision, and the postoperative pain is considerably less.

Percutaneous Achilles lengthening is best done with a tenotomy knife. This is a small, specially shaped knife that is designed for percutaneous tenotomy. It is shaped so that it can be stabbed through the skin. Its blade is not as sharp as the disposable surgical knife, and it is far less likely to cut the skin.

Although the tenotomy can be done with two cuts in the tendon (1), it is most easily done by placing three cuts in the tendon (Figs. 7-111 to 7-113).

FIGURE 7-111. The tendon is divided in three places. The medial half of the tendon is divided at both the proximal and the distal extents of the tendon, and the lateral half is divided midway between the two medial cuts. The location of the entry portals is just above the insertion into the calcaneus, at the most proximal portion of the tendon before it becomes muscular, and midway between these two.

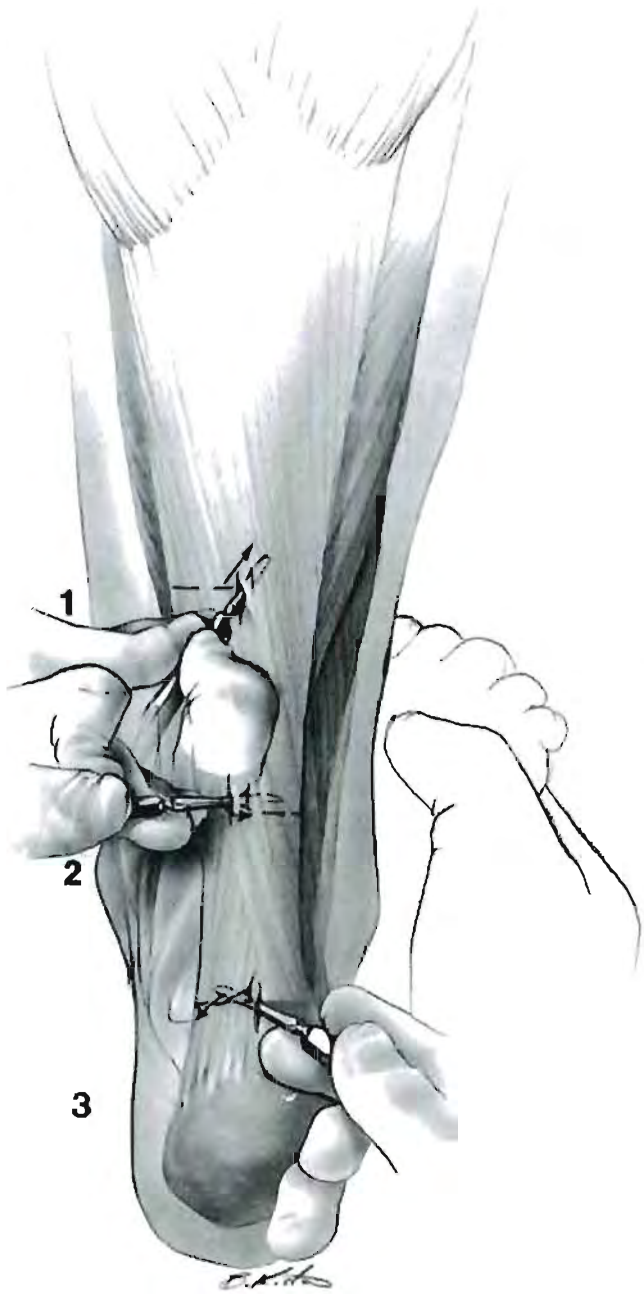


FIGURE 7-112. The three sequential steps in cutting the tendon are illustrated. Step 1: the tenotomy knife is pushed directly through the skin and the tendon, keeping the blade oriented longitudinally with the tendon. (It is easier to make the initial stab wound in the skin with a #15 disposable surgical blade.) Step 2: the blade of the knife is rotated 90 degrees toward the part of the tendon that is to be divided. Step 3: the surgeon drops his or her hand to bring the blade of the knife under the portion of the tendon that is to be cut. Using a sawing motion, a portion of the tendon is cut. The knife will be cutting toward the skin. If the surgeon keeps his or her finger directly over the portion of the tendon being cut, he or she will feel the blade of the knife when the cut is completed. The knife will not be so sharp that it cuts through the skin as a disposable knife blade would.

FIGURE 7-113. The most proximal and distal cuts should be made first and the middle cut last. If the middle cut is made before the proximal and distal cuts, either the proximal or distal segment can lengthen because tension is kept on the tendon. When the middle cut is made, the foot should go into dorsiflexion, and the tendon fibers start to slide. A small dressing is placed over the stab wounds, and a short-leg walking cast is applied.

POSTOPERATIVE CARE

The surgery is performed as an outpatient procedure. The parents are requested to keep the child's foot elevated for 24 to 48 hours, after which time the patient may resume ambulation. Mild narcotic analgesic may be needed for the first night. The cast can be removed in 6 weeks.

Reference

1. White WJ. Torsion of the Achilles tendon: its surgical significance. Arch Surg [Am] 1943;46:784.

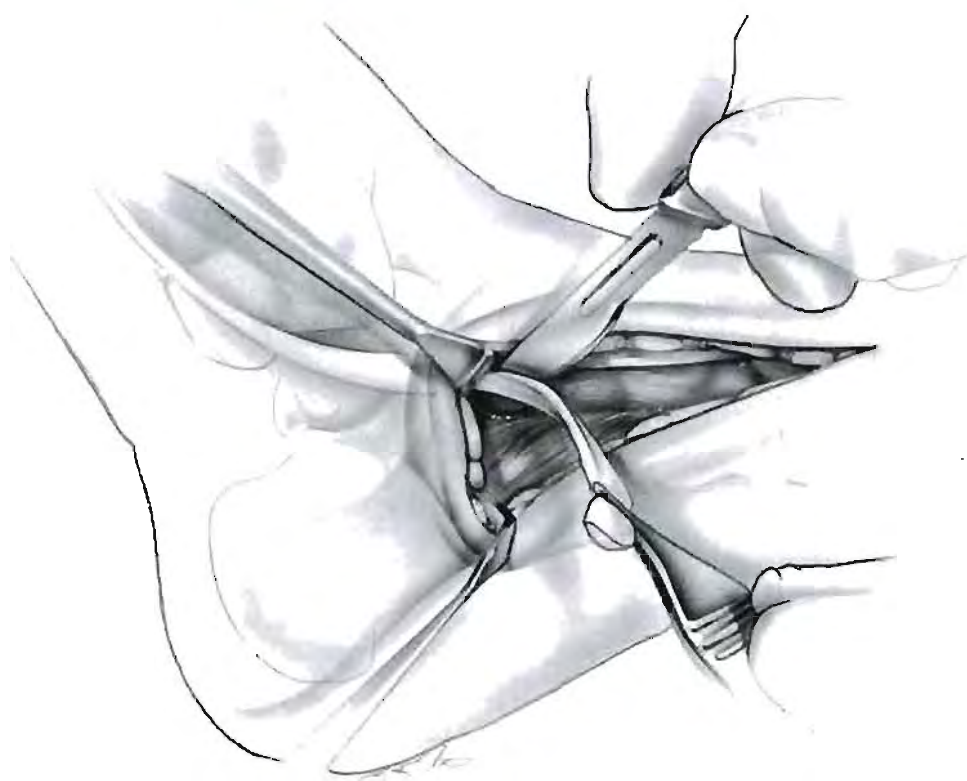
7.18 SPLIT POSTERIOR TIBIAL TENDON TRANSFER

Spasticity of the posterior tibial tendon is recognized as a frequent cause of hindfoot varus in cerebral palsy. Usually, this is associated with equinus deformity, producing the typical equinovarus foot. Many operations have been described for the treatment of varus from this cause, including lengthening, rerouting of the tendon anterior to the medial malleolus, anterior transfer of the tendon through the interosseous membrane, and tenotomy. All of these operations, however, have been associated with a significant incidence of complications, ranging from recurrence to collapse of the foot.

Kaufer (1) described splitting the posterior tibial tendon and transferring half of it to the lateral side of the foot. His goal was to use part of the spastic muscle to balance the foot rather than to transfer the entire spastic muscle or eliminate its function entirely. Green and colleagues (2) and Kling and associates (3) further described the technique and their results. A technique for performing this procedure through a Cincinnati incision has also been described (4).

The surgeon must be certain that it is the posterior tibial tendon and not the anterior tibial tendon that is the deforming force. This can usually be determined by observation of the child in gait. The foot is typically in equinus as well as varus. The foot remains in varus during the entire swing cycle, and the lateral side of the foot strikes the floor first. The posterior tibial tendon rather than the anterior tibial tendon appears taut. There should be no fixed deformity. A percutaneous lengthening of the Achilles tendon can be done at the beginning of the procedure to correct the equinus component, if it exists (Figs. 7-114 to 7-117).

A



B

FIGURE 7-114. The patient is placed supine on the operating table. Placing a large sandbag under the hip on the side to be operated makes operating on the lateral side of the foot easier and does not interfere with the medial part of the procedure. Kling and colleagues (3) described using two large incisions, whereas Green and colleagues (2) described four smaller incisions. The first incision is directly over the insertion of the posterior tibial tendon extending from just distal to the tip of the medial malleolus to the insertion of the tendon on the navicular **(A)**.

Through this incision, the inferior half of the posterior tibial tendon is split and detached **(B)**. It is advisable to detach one of the plantar extensions of the tendon, as described in the medial release of clubfoot. This will be useful in securing the tendon at the conclusion of the operation. The foot is everted to pull as much of the tendon into the wound as possible, and the tendon is split as far proximally as possible. A portion of the tendon sheath should be left intact to hold the remaining tendon in place behind the medial malleolus.

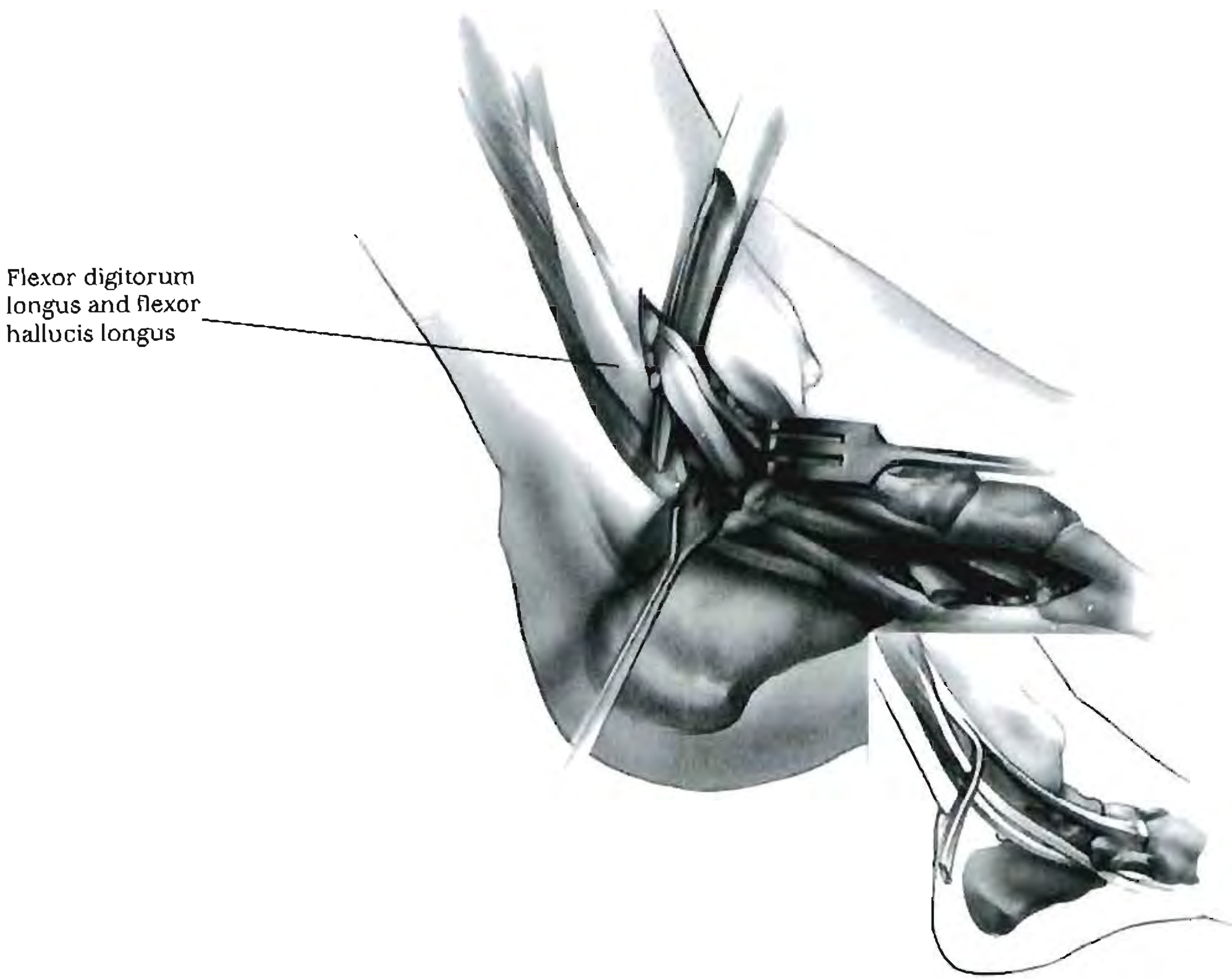


FIGURE 7-115. The second incision is made over the course of the posterior tibial tendon along the posterior border of the tibia beginning 1 cm above the medial malleolus and extending for about 4 cm. The foot is then inverted to permit the distal part of the tendon to be drawn into this wound. It is usually possible to identify the most proximal division of the tendon that was accomplished through the first wound. When the split in the tendon is identified, the incision into the tendon is continued, to divide it as far proximally as possible. Caution must be used because, in many children, this is not a large tendon, and it can be difficult to divide it into two equal halves. When the division is complete, the split portion of the tendon is drawn into this wound.

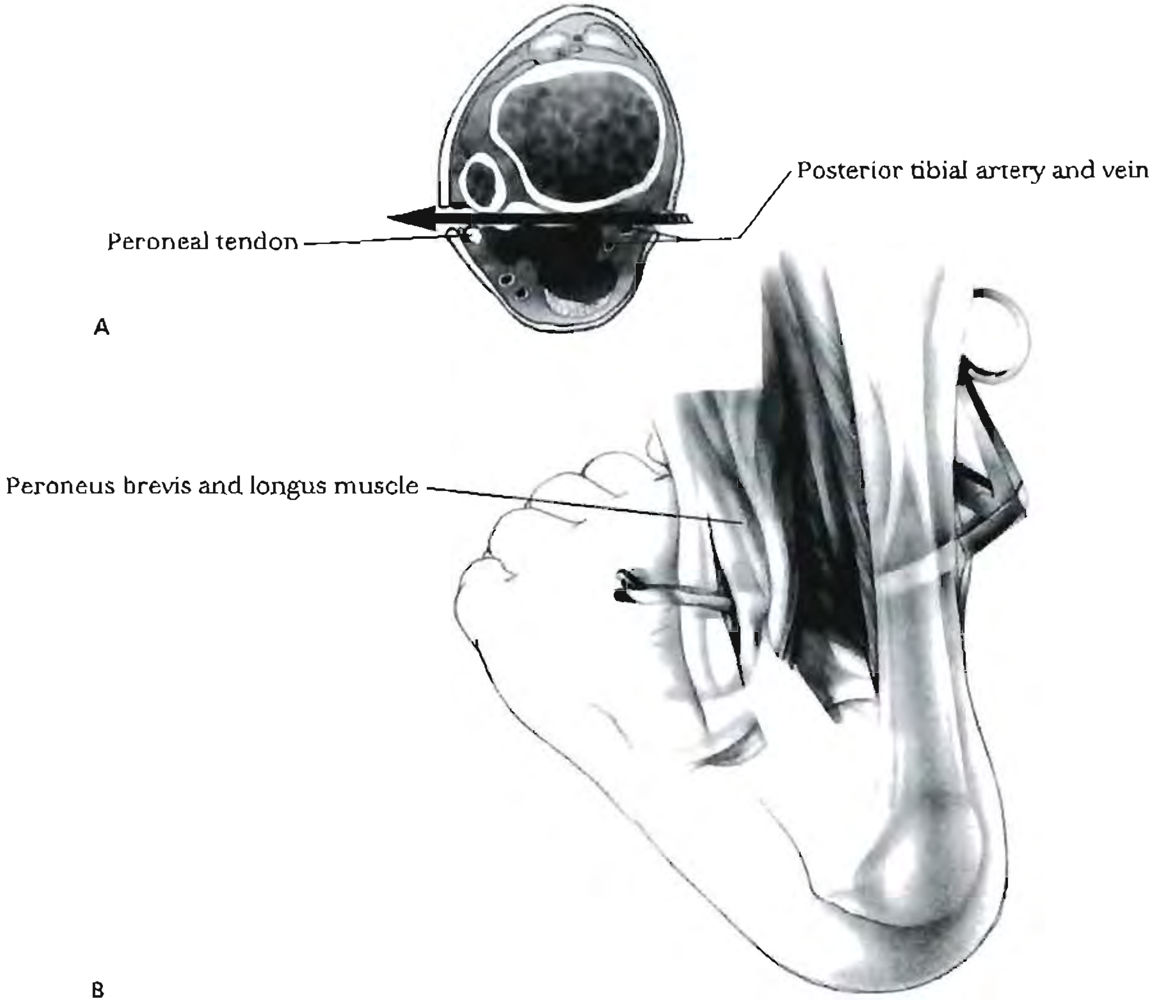


FIGURE 7-116. The third incision is made behind the lateral malleolus. It should extend from near the distal portion of the malleolus proximally for about 4 cm. The peroneal tendons are exposed and the peroneus brevis tendon identified. The peroneus brevis muscle is the smaller and most superficial and movable of the two peroneal tendons. Confirmation can be made after the next incision is made.

The next task is to pass the split portion of the posterior tibial tendon from the medial side of the leg to the lateral side. In doing so, the tendon must remain in contact with the posterior surface of the tibia and anterior to the neurovascular structures **(A)**. It is easier to start the tendon passer on the medial side, where it is certain that it is in contact with the posterior surface of the tibia **(B)**. After pulling the tendon through, its direction should be checked to be certain that it takes a relatively straight course. An error is not splitting the tendon far enough proximally so that it takes off from the muscle belly at an acute angle.

At this point, the two medial wounds should be closed.

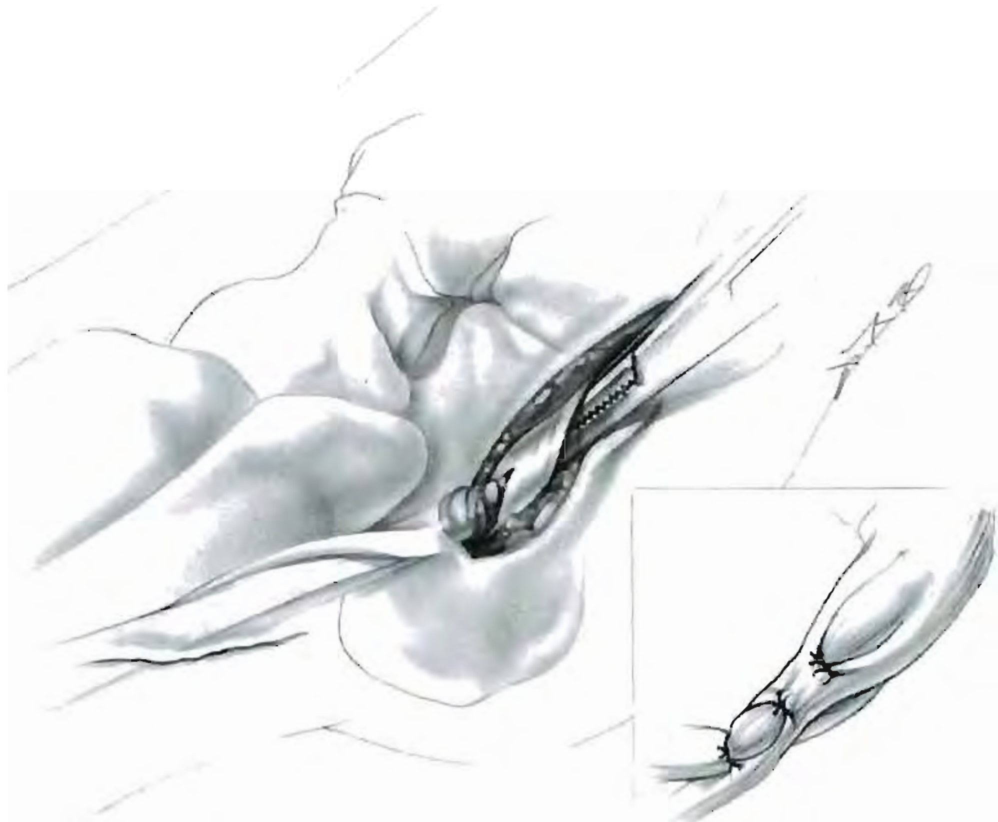


FIGURE 7-117. The final incision is made along the course of the peroneus brevis tendon from just distal to the tip of the lateral malleolus to a point just proximal to the base of the fifth metatarsal. The peroneus brevis muscle is exposed.

The split portion of the posterior tibial tendon is passed behind the lateral malleolus, under the retinaculum holding the peroneal tendons in place, and into the sheath of the peroneus brevis tendon.

At this point, the proximal wound is closed, leaving only the distal wound to close after the tendon is secured.

The split portion of the posterior tibial tendon is now woven through two or three small splits in the peroneus brevis tendon. Care should be taken to adjust the tension in the transfer. With the foot held in a neutral position of varus-valgus, the portion of the posterior tibial tendon is pulled firmly and sutured to the peroneus brevis tendon, where it passes through it. The final suture should secure the end of the posterior tibial tendon to the strong tissue of the insertion of the peroneus brevis tendon. It is at this point that the surgeon appreciates the few extra minutes to get all of the possible length on the posterior tibial tendon. This wound is then closed.

POSTOPERATIVE CARE

We do not use a long-leg cast for this procedure or for an Achilles tendon lengthening in an ambulatory child. This does not affect the result or cause greater discomfort, and it allows the child to ambulate sooner and more easily. The cast is maintained for 6 weeks. After the cast is removed, the child is placed in a brace, if indicated, or allowed unrestricted ambulation if the brace is not indicated. Our requirement for not using the brace is that the child be able to dorsiflex the foot actively to neutral. It is rare for a child with equinovarus deformity resulting from cerebral palsy to be able to do this, and bracing is usually required in these patients for at least 1 year.

Reference

1. Kaufer H. Split tendon transfers. Orthop Trans 1977;1:191.
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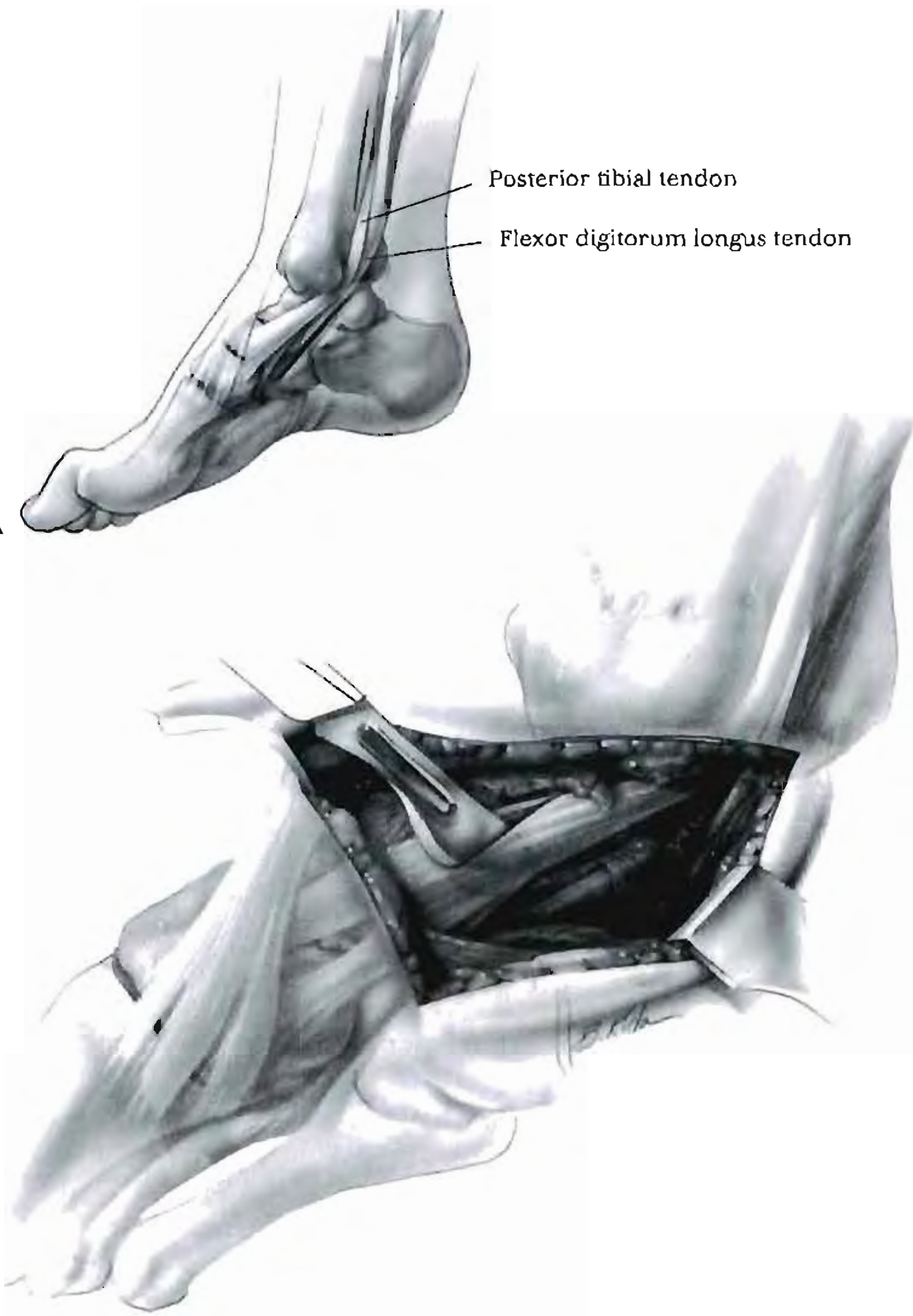
7.19 TRANSFER OF THE POSTERIOR TIBIAL TENDON TO THE DORSUM OF THE FOOT

Transfer of the posterior tibial tendon to the dorsum of the foot has been recommended in the treatment of many conditions, including cavovarus deformity, as seen in Charcot-Marie-Tooth disease or Duchenne's muscular dystrophy; recurrence of forefoot deformity in clubfoot; and conditions that weaken dorsiflexion of the foot, such as polio, traumatic injuries, and cerebral palsy (1,2). This transfer accomplishes two goals: it removes the posterior tibial tendon as a deforming force, and it augments dorsiflexion of the foot. It is important to realize that the posterior tibial muscle cannot substitute for the anterior tibial muscle. The reasons for this are numerous: the muscle is required to act out of phase after the transfer, it will be difficult to establish proper tension in the transferred muscle, and although the posterior tibial muscle is stronger than the anterior tibial muscle, its excursion is less (3). With these facts in mind, the decision is often between transfer and tenotomy of the posterior tibial tendon. In Charcot-Marie-Tooth disease, in which the posterior tibial tendon often remains strong for a considerable time, transfer to augment dorsiflexion makes sense; whereas in Duchenne's muscular dystrophy, in which progression of muscle weakness in all muscles is much more rapid and bracing is required regardless of the surgery, tenotomy makes more sense.

Two techniques have been described for transfer of the posterior tibial tendon to the dorsum of the foot. One technique routes the tendon around the medial side of the tibia and through the anterior compartment of the leg to the dorsum of the foot. This technique does not appear to be widely used. The second technique is to transfer the tendon through the interosseous membrane into the anterior compartment and then onto the dorsum of the foot. This is the technique described here (Figs. 7-118 to 7-124).



A

B

FIGURE 7-118. The first incision extends along the course of the posterior tibial tendon distal to the tip of the medial malleolus **(A)**. The tendon can be identified as a distinct structure in its sheath in the proximal part of the wound at the tip of the medial malleolus. From there, it fans out into its broad insertion. It is important to recognize that deep to and blending with the insertion of the posterior tibial tendon is the anterior tibiotalar and tibionavicular ligaments, which are portions of the deltoid ligament. In detaching the posterior tibial tendon, these ligaments should be left undisturbed by avoiding the tendency to take as much of the tendon as can be dissected off of the bone **(B)**. Extra length, not thickness, is needed. This can be obtained by dissecting and detaching the plantar insertion of the tendon that inserts on the plantar surface of the first and second metatarsals. This continuation of the posterior tibial tendon is not apparent at first and must be exposed by removing the fascial tissue that covers it. This extension of the tendon, one of its many insertions, will be considerably smaller than the proximal portion of the tendon.

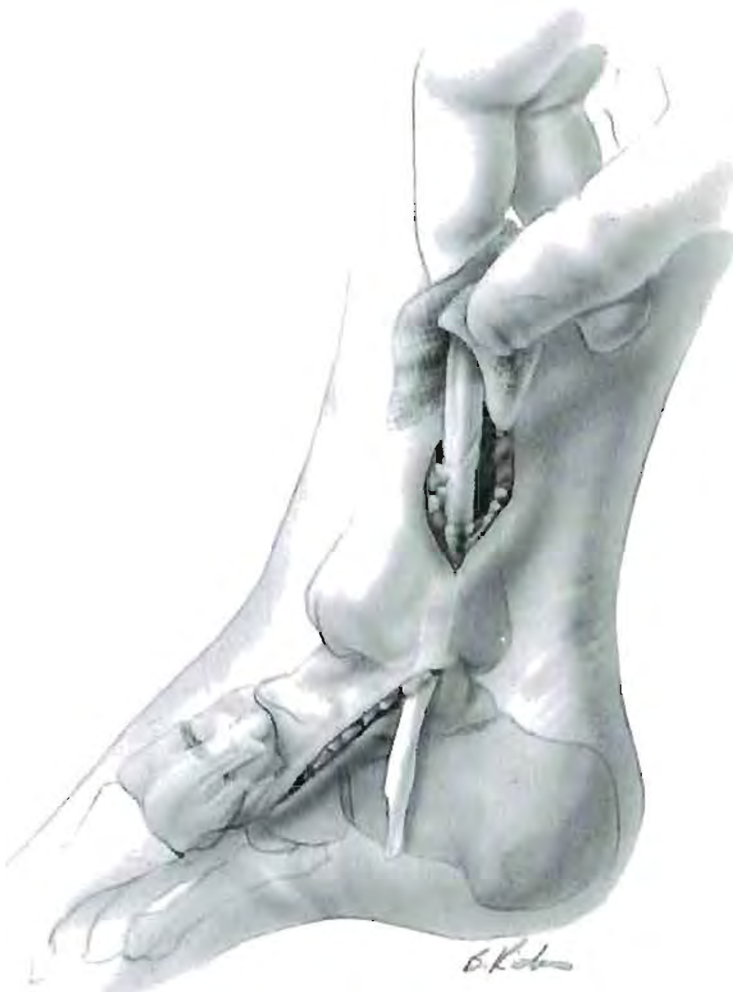


FIGURE 7-119. The next incision is made behind the posterior border of the tibia (see Fig. 7-118**A**). This incision should begin at about the midportion of the leg and extend as far distal as is necessary to free the tendon. The posterior tibial muscle and tendon should lie just beneath the deep fascia just behind the posterior border of the tibia. They can be identified by pulling on the distal end of the tendon where it has been freed at the ankle. Once exposed, a moist sponge is used to grasp the muscle and pull it into the proximal wound. (Placing a hemostat under the tendon and pulling upward can stretch and damage the muscle tissue if there is much resistance to pulling the tendon into the wound.) Pulling the tendon into the more proximal wound will be resisted by the attachments of the paratenon that can be divided blindly. Blunt dissection can be used to free the muscle belly for a distance proximally, but not so far as to disrupt the blood and nerve supply.

Coleman (4) eliminates this incision. He removes a large window from the interosseous membrane anteriorly (to be described next) and pulls the muscle belly and tendon through this window from the posterior compartment. We have both found this easy to accomplish, and it eliminates one incision.

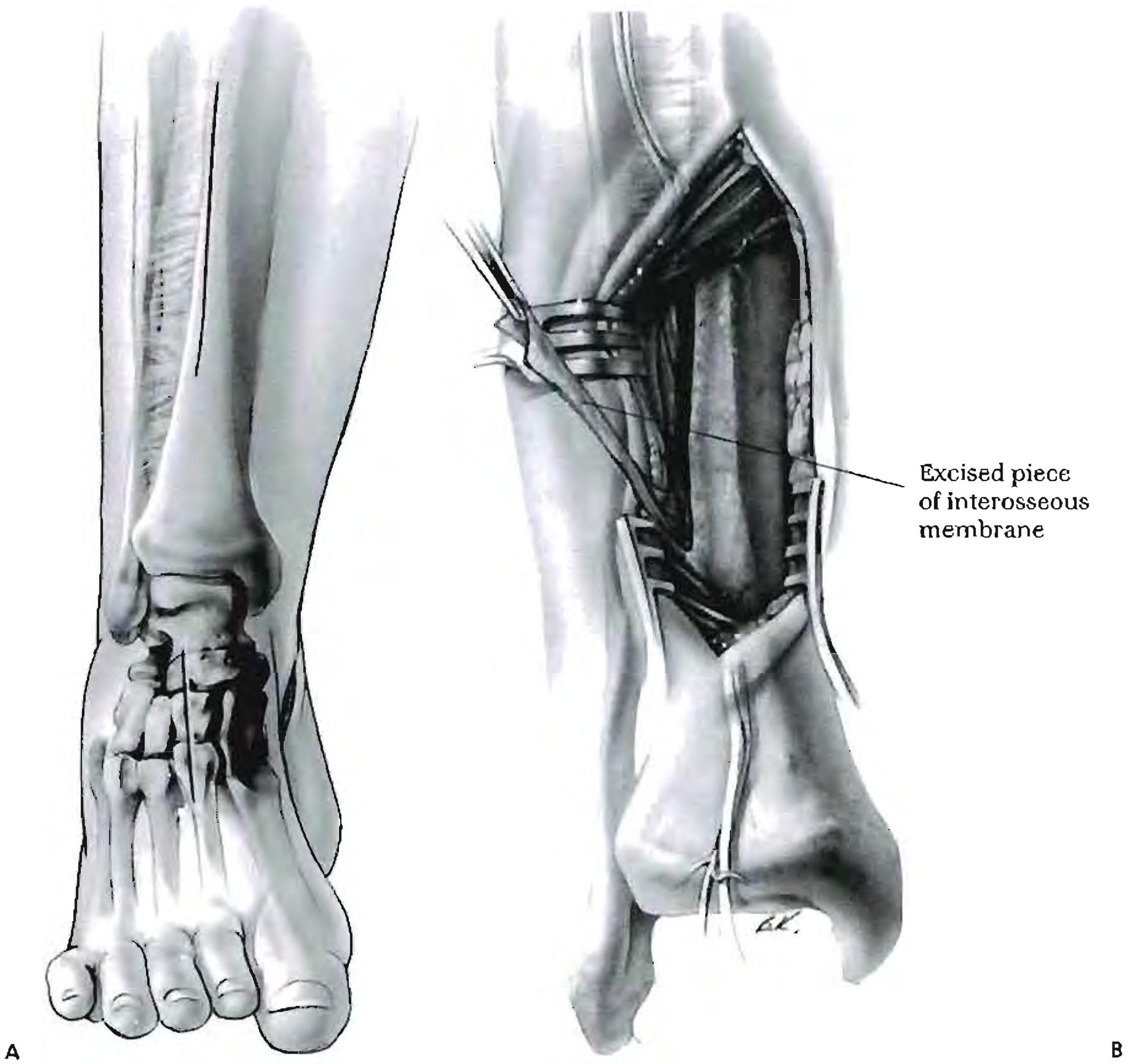
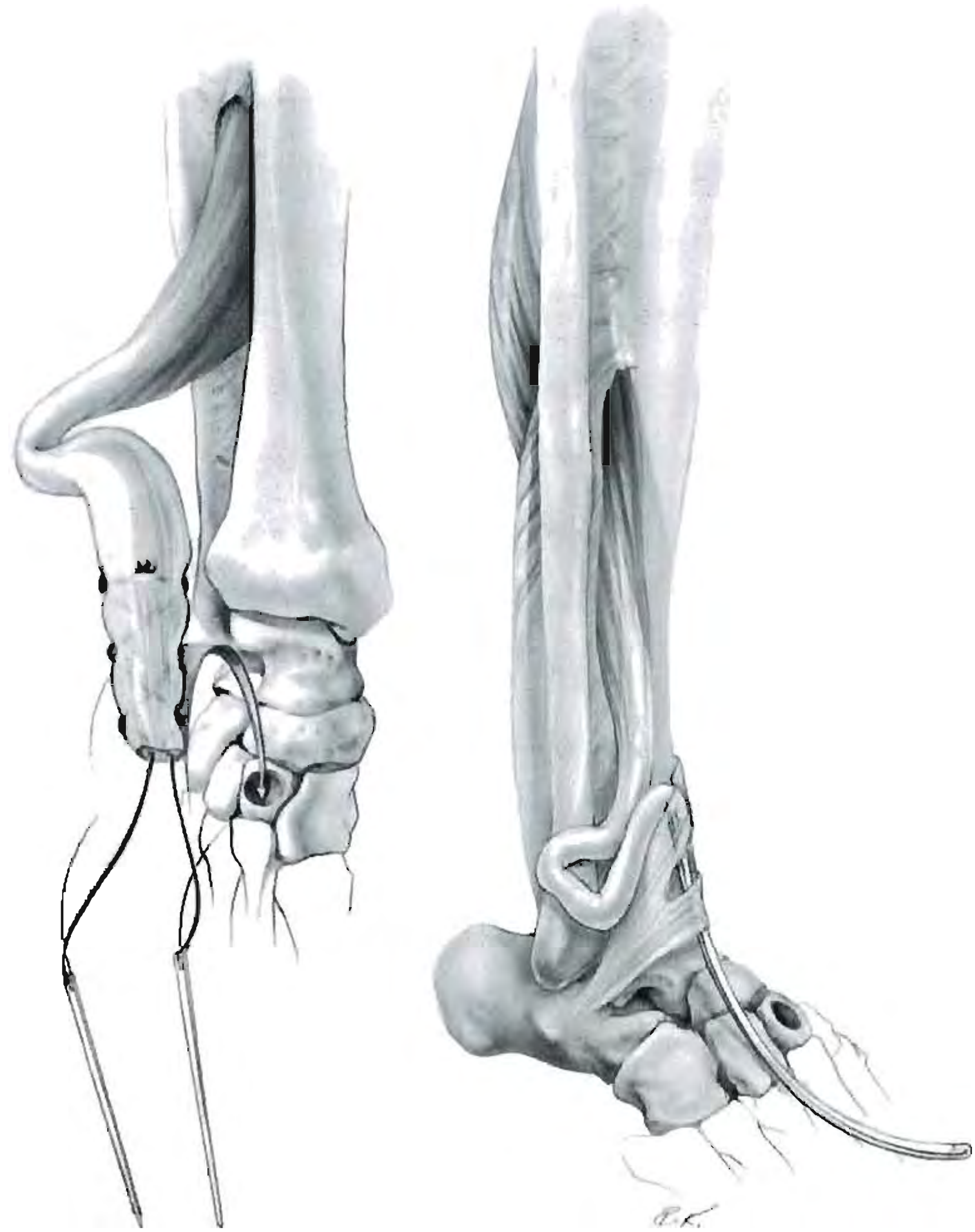


FIGURE 7-120. A proximal incision is made over the anterior muscle compartment of the leg, lateral to the tibial crest, and extends from the midportion of the leg distally **(A)**. To permit adequate exposure, it will need to be about 6 to 7 cm in length. The deep fascia over the anterior tibial muscle is opened. A periosteal elevator is used to elevate the anterior tibial and extensor hallucis muscles, as well as the neurovascular bundle, off the lateral surface of the tibia and the interosseous membrane. This is done extraperiosteally. With these structures safely retracted out of the way, as large a segment as possible of the interosseous membrane is removed **(B)**. The posterior tibial muscle lies on the opposite side of this membrane.

FIGURE 7-121. The final incision is placed over the second or third cuneiform bone and the proximal portion of the corresponding metatarsal, depending on where the surgeon wishes to place the tendon. After the bone is exposed and identified, the periosteum is elevated, and a drill is used to make a hole completely through the bone. Because of the length of the tendon and the size of the hole necessary for the tendon, it is best to use the cuneiform bone rather than a metatarsal bone.

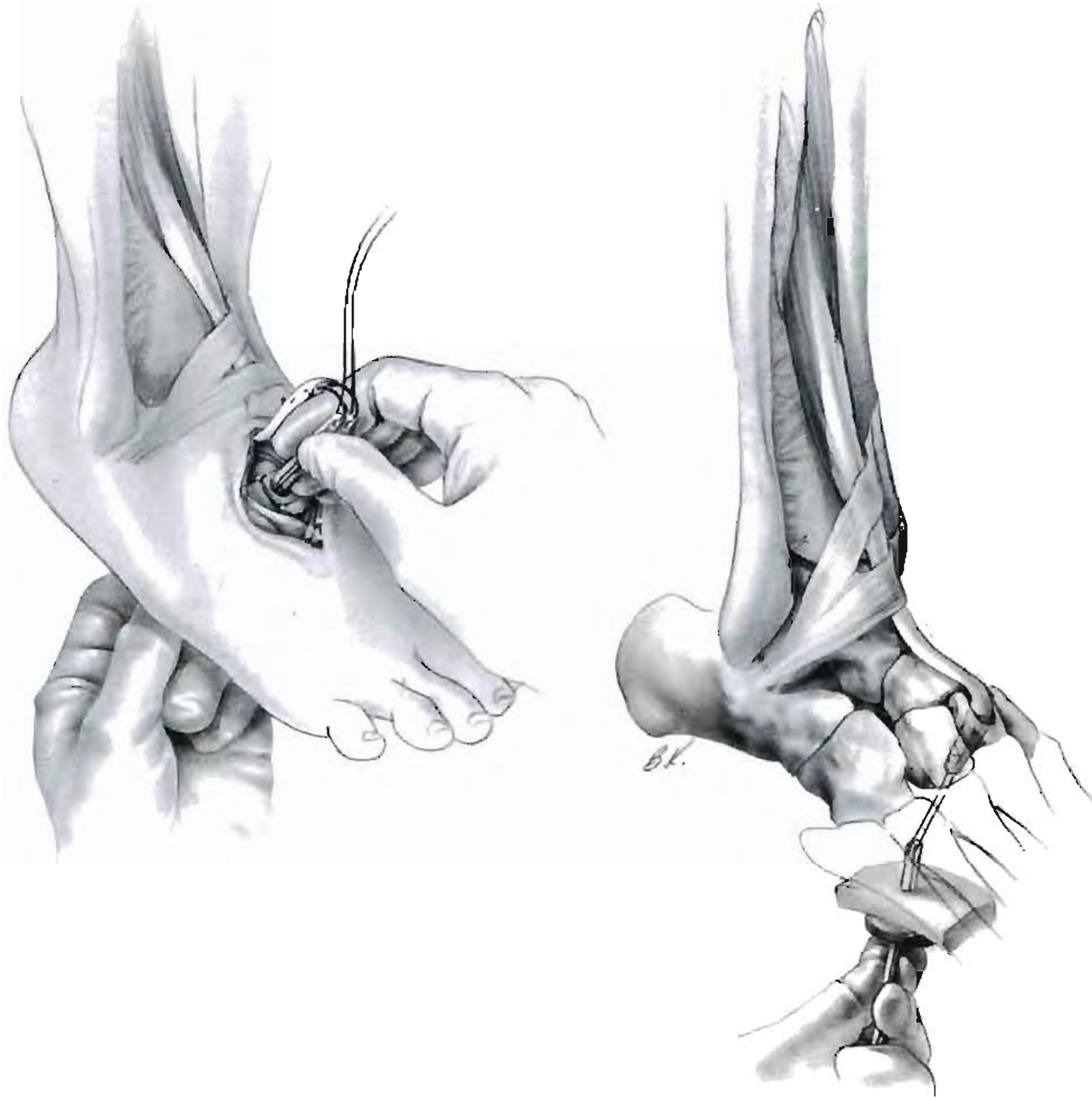
FIGURE 7-122. The tendon can be passed from the posterior compartment to the anterior compartment. To accomplish this, a tendon forceps is passed from the anterior compartment into the posterior compartment and out of the proximal wound along the medial border of the tibia. The forceps should be kept close to the posterior surface of the tibia. The distal end of the tendon is grasped and pulled into the anterior compartment. At this point, care should be taken to ensure that the window in the interosseous membrane is large enough and is placed such that the posterior tibial muscle and tendon have a straight line of pull.



A B

FIGURE 7-123. A heavy absorbable suture is woven through the end of the tendon. This can be done in such a way as to narrow the end of the tendon to make its passage through the hole in the bone easier **(A)**. A flat, malleable tendon passer is passed beneath the extensor retinaculum of the ankle **(B)**. Both ends of the suture that is attached to the tendon are passed through the hole in the tendon passer, and the tendon is then drawn into the distal wound. Pulling on the distal end of the tendon should demonstrate an absence of bow-stringing of the tendon at the ankle and indicate that it has been passed beneath the retinaculum.

The first three incisions are now closed.



A

FIGURE 7-124. Each end of the suture in the tendon is threaded on a large, straight Keith needle. Both of these needles, held together, are passed through the hole in the bone and out through the sole of the foot **(A)**. As the needles emerge from the sole of the foot, they are passed through a piece of sterile felt or sponge rubber and then through the holes of a button **(B)**.

With the foot held in the corrected position, the sutures are pulled while the tendon is guided into the hole. A common and significant problem at this point is that the tendon will not pass smoothly through the hole in the bone. If this occurs, the surgeon may believe that he or she has pulled the tendon tight, when in reality, it remains too loose to provide any effective force. To correct the problem, be sure the hole is large enough and that no extraneous portions of the tendon remain. When satisfied that the tension is correct, tie the sutures over the button. This should not be done with excessive force, or else pressure necrosis of the underlying skin may result. The periosteum on the dorsum of the cuneiform bone is sutured over the tendon.

While an assistant holds the foot in the corrected position, the wound is closed. A short-leg cast is applied. No drains are necessary.

POSTOPERATIVE CARE

The patient remains in a short-leg cast for 6 weeks. A long-leg cast is not necessary because the muscle does not cross the knee joint. The patient may be ambulatory in the cast.

The care after the cast is removed depends on factors relating to the disease itself (e.g., is bracing necessary?) and the beliefs of the surgeon (e.g., does intensive therapy to retrain the muscle improve the result?).

References

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7.20 THE BUTLER PROCEDURE FOR OVERLAPPING FIFTH TOE

Overlapping of the fifth toe on the fourth toe is a common condition seen in children, often with a familial tendency. Although some patients present with symptoms from shoe wear, many come because of parental concern or cosmetic concerns during adolescence. Many patients have no symptoms, and it is likely that many will remain symptom free. This makes it difficult to decide who needs surgery for this condition, especially because it is easier and results are probably better when it is performed before adulthood.

The deformity consists of dorsiflexion and adduction at the metatarsophalangeal joint with external rotation of the toe. The operation releases the extensor tendon and the capsule and secures the correction by a dermodesis (1). In our experience, it has been extremely effective (Figs. 7-125 to 7-128).

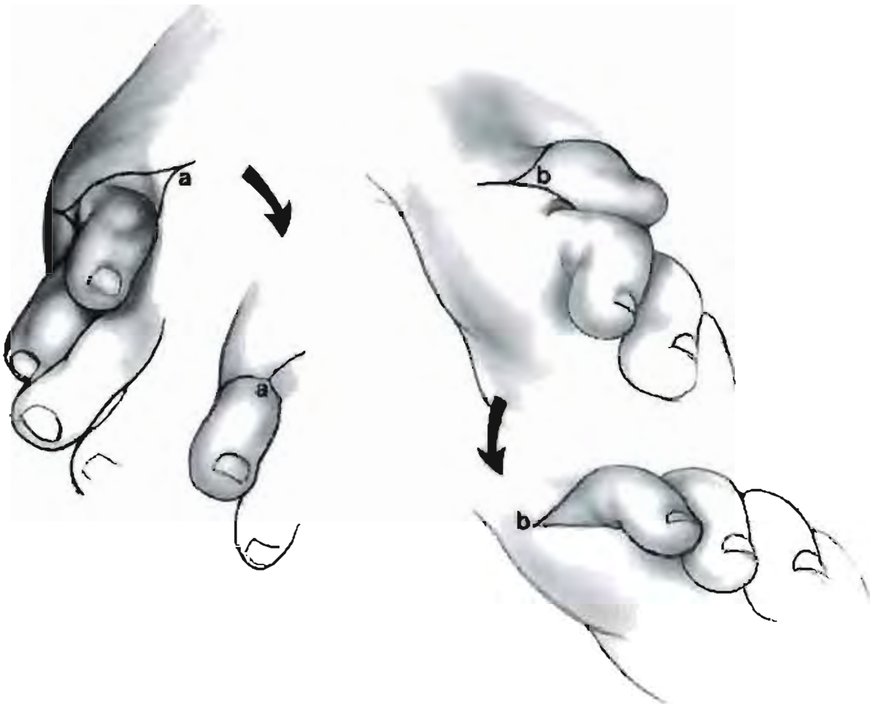

FIGURE 7-125. The incision is a racket incision with an extra handle on the plantar aspect. The plantar handle should be longer than the dorsal and should be directed more laterally The reason for this is apparent when it is understood that the dermodesis is accomplished by a V-to-Y advancement of the dorsal incision and a Y-to-V advancement of the plantar incision.

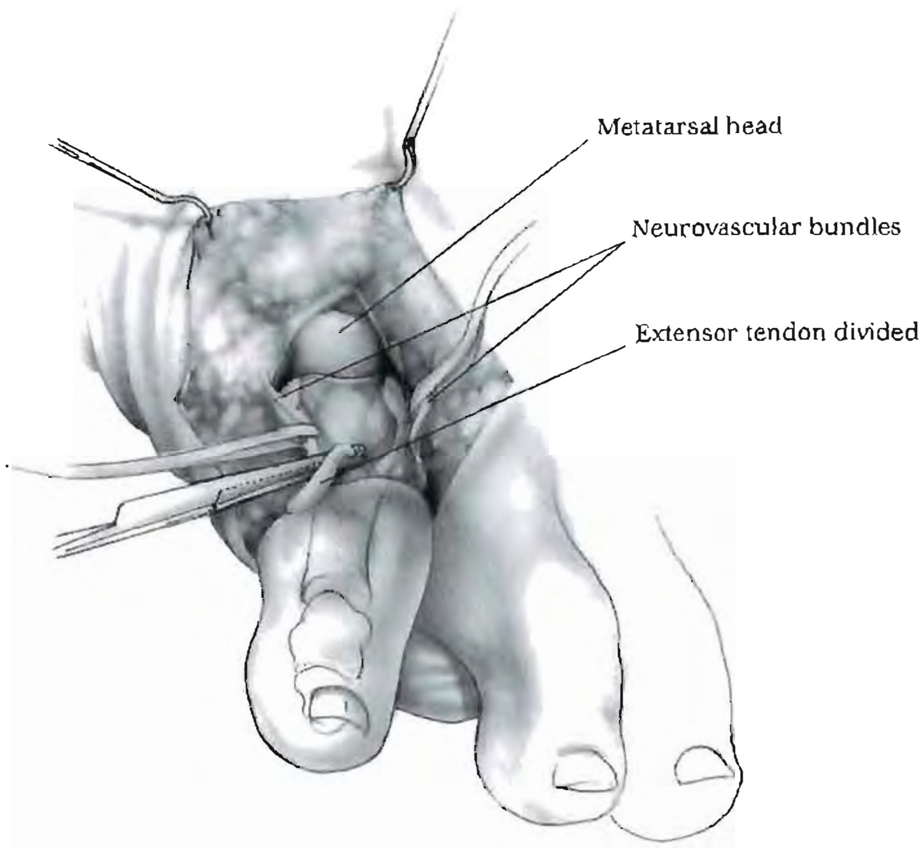

FIGURE 7-126. After the skin incisions are made, they are carefully deepened through the subcutaneous tissue by sharp and blunt dissection to mobilize the skin. Care should always be taken to avoid injury to the neurovascular bundles. Starting dorsal by the extensor tendon (which can be tensed by flexing the toe), a small hemostat is used to separate the tissue off of the capsule both medially and laterally. Here, the neurovascular bundles are illustrated as having been isolated for clarity; however, this is not necessary if care is taken to stay close to the capsule and bone.

The extensor tendon is divided along with the dorsal aspect of the capsule. With the capsule now exposed on both sides, it is a simple matter to divide it safely medially and laterally down to the plantar aspect.

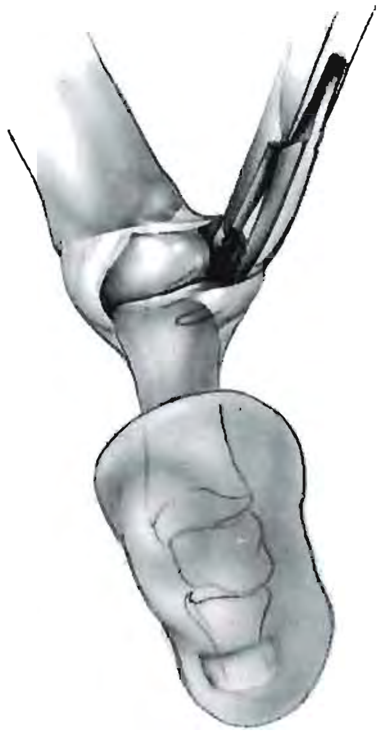

FIGURE 7-127. If the toe does not lie in a normal position after this release, it is most likely because of adherence of the capsule to the plantar aspect of the metatarsal head. This can be freed by inserting a small, curved hemostat around the head and spreading.

FIGURE 7-128. The skin is closed, advancing the plantar flap into the racket incision that was extended somewhat laterally. This is the Y-to-V advancement. The dorsal skin flap now will not fit as it did before, leaving a longer linear incision. This is the V-to-Y advancement. The remainder of the incision is closed. Fine absorbable sutures are used in the skin to obviate the difficult problem of removal.

POSTOPERATIVE CARE

A soft dressing is applied. The patient may walk with the aid of crutches or simply on the heels, if they are reliable. After 3 weeks, healing should be sufficient to permit full weight bearing.

Reference

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7.21 FLEXOR TENOTOMY FOR CURLY TOE DEFORMITY

Curly toe deformity, sometimes referred to as *underlapping toes,* is a common deformity in children. The deformity is characterized by varying degrees of flexion at the proximal interphalangeal joint, varus deviation, and external rotation. The deformity appears to be a result of a congenital shortening of the long flexor tendon. If the metatarsophalangeal joint is flexed, the interphalangeal joint can be corrected.

Rarely do these deformities cause a problem in childhood, and it is debatable how often these deformities become a problem in later life (1–3). Although most children are seen because of parental concern, an athletic adolescent occasionally presents with symptoms related to the tip of the toe.

Although several operations have been proposed for this condition, evidence appears to favor simple release of the short and long flexor tendons over tendon transfers (Girdlestone procedure) (4,5). Authorities agree that whatever incision is used, it must not cross a flexion crease and that strapping and other conservative measures are without value (Figs. 7-129 and 7-130).

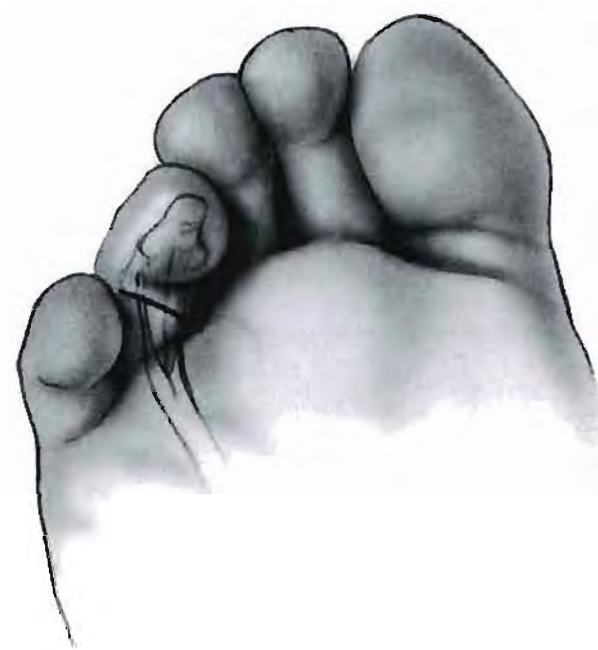

FIGURE 7-129. The patient can remain supine with the table elevated and in the Trendelenburg position with the surgeon seated. An oblique incision is made over the proximal phalanx, with care taken not to cross either flexion crease.

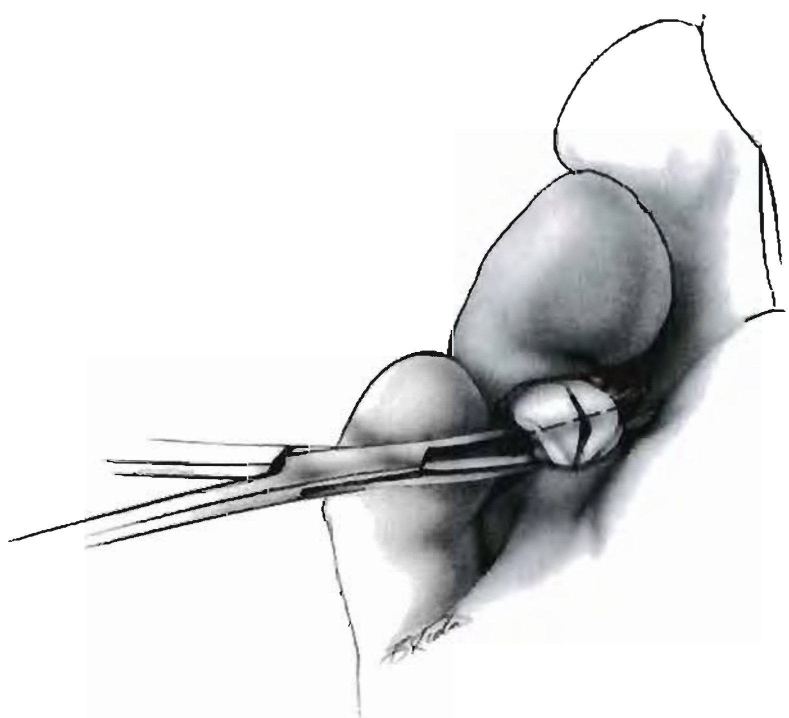

FIGURE 7-130. After dividing the subcutaneous tissue, the flexor sheath is opened. A small, curved hemostat is used to deliver all three slips of tendon, long and short, into the wound, where they are divided. The interphalangeal joint should be correctable with extension at the metatarsophalangeal joint. One or two simple skin sutures of a fine absorbable material are all that is necessary for closure.

POSTOPERATIVE CARE

A soft dressing is applied, and the patient is allowed to ambulate, as tolerated.

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7.22 SYME AMPUTATION

Harris (1) has written an excellent historical review and rationale for the Syme amputation. Although the Syme amputation or disarticulation at the ankle is most often performed in childhood for congenital deficiency of the lower extremity, Syme first reported this operation for sepsis 22 years before his son-in-law, Joseph Lister, began his experiments in antiseptic surgery and 3 years before Morton first administered ether for anesthesia at the Massachusetts General Hospital (1).

There are two important differences regarding the Syme amputation in congenital deficiencies in children compared with adults. First, in children with severe congenital deficiency of the lower extremity, the foot is often in severe equinus, with the heel pad proximal to the end of the tibia. This may result in difficulty in bringing the heel pad down over the end of the tibia, even after sectioning of the Achilles tendon. Second, no bony alteration of the distal tibia is necessary. The malleoli are not a problem with prosthetic fitting because they do not attain the usual medial and lateral dimensions of the adult (2). In fact, a slight prominence is necessary for suspension of the prosthesis.

The most often cited benefit of this amputation is the end-bearing ability of the stump, which permits walking without a prosthesis and better prosthetic use. This end-bearing quality is dependent on preservation of the unique structural anatomy of the heel pad by careful subperiosteal dissection of the calcaneus. One of the most obvious benefits of a Syme amputation (or any disarticulation) in childhood is the elimination of bony overgrowth with the necessity for revision that accompanies through-bone amputation in the growing child.

Although there are many reports of the long-term results in patients undergoing the Syme amputation, most of these have been performed for other indications (3,4) (Figs. 7-131 to 7-136).

FIGURE 7-131. The dorsal part of the incision begins at the tip of the lateral malleolus, crosses over the dorsum of the foot near the dorsiflexion crease of the ankle, and ends about 1 cm below the tip of the medial malleolus. In children with complete absence of the fibula, this landmark can be estimated by palpation of the anatomy as well as visually. The volar part of the incision connects the ends of the dorsal incision crossing the plantar aspect of the foot at the distal end of the heel pad. In young children who have not been walking, the heel pad is often difficult to identify, and care should be taken to bring the incision far enough distally to retain sufficient tissue.

FIGURE 7-132. The next step is to complete the plantar incision. Because nothing distal to this point will be saved, this incision can be carried directly down to the bone, identifying and cauterizing the bleeding vessels later when the tourniquet is released. The tendons and nerves can be pulled distally and sectioned so that they retract proximally and the vessel can be ligated or cauterized. Completing this part of the incision simplifies the most difficult and important part of the operation, which is to divide the medial and lateral ligament structures without injuring the posterior tibial vessel and its branches that supply the heel pad.

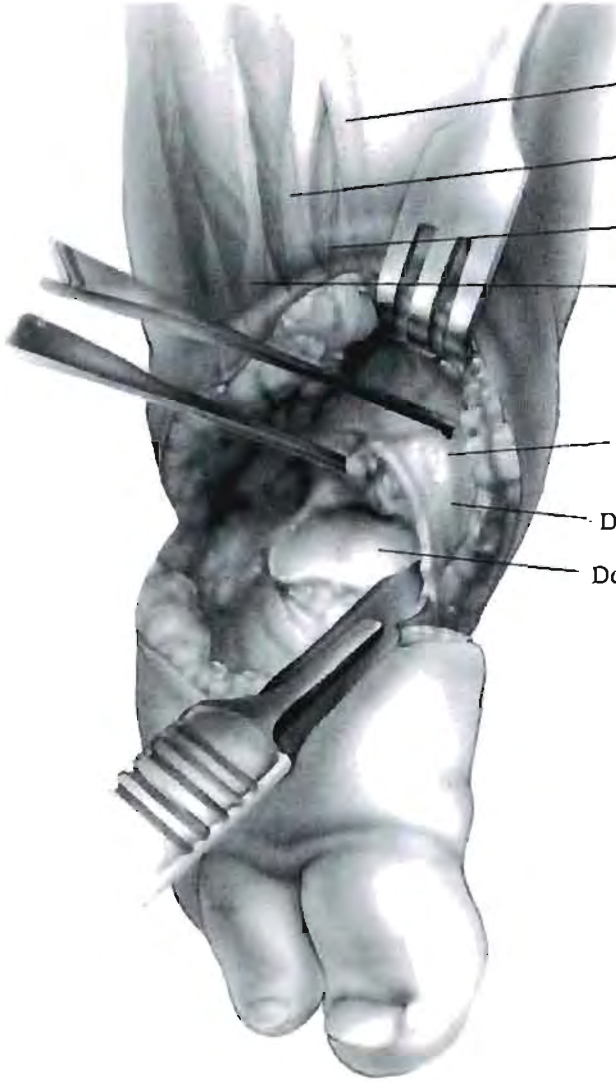

FIGURE 7-133. Next, the dorsal incision is deepened through the subcutaneous tissue. The dorsalis pedis vessels are identified and cauterized, and all of the tendons and nerves are pulled distally, sectioned, and allowed to retract proximally. This exposes the anterior ankle joint, which is now cut open completely. Working carefully between the talus and the medial malleolus, the deltoid ligament is cut, freeing the medial aspect of the ankle joint. Care is necessary here to avoid damage to the posterior tibial artery and vein. Working on the lateral side of the ankle, the surgeon cuts the tibiofibular ligaments. The only remaining portion of the ankle capsule remaining is posterior.

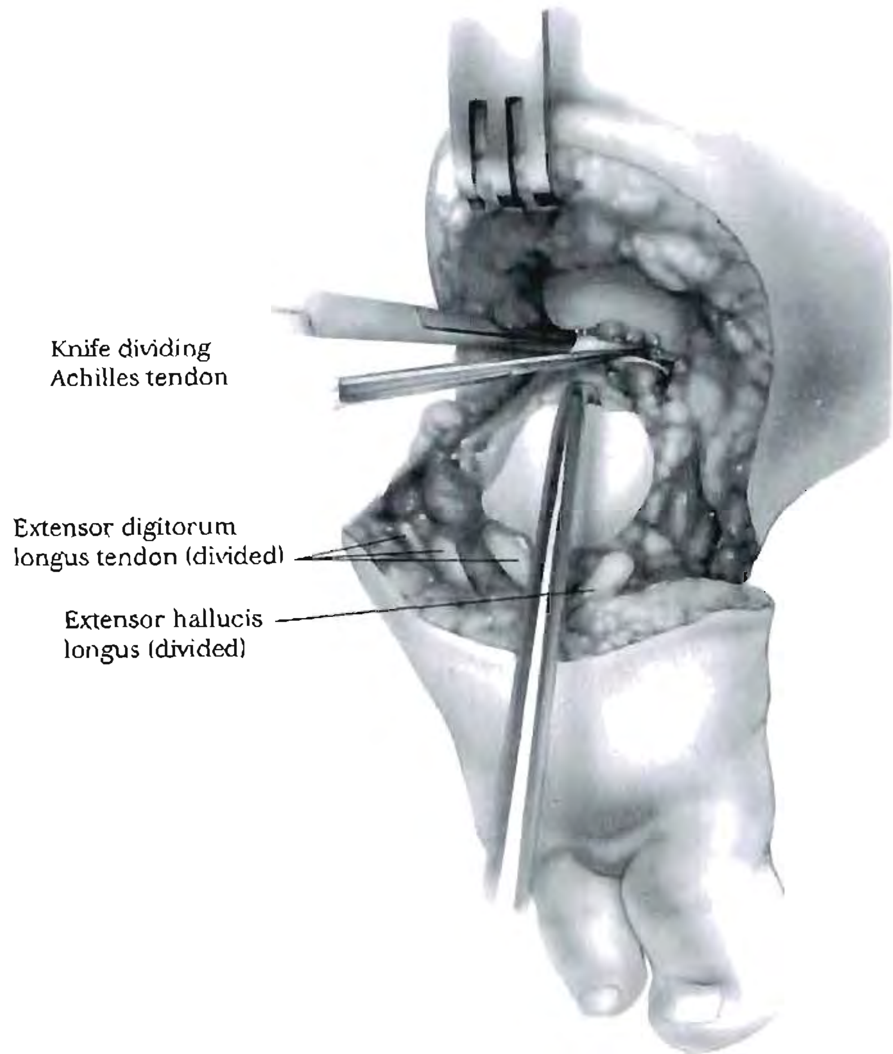

FIGURE 7-134. With the foot severely plantarflexed and a small bone hook placed in the posterior aspect of the talus, the dissection of the posterior ankle capsule is completed, freeing the talus. In the severe congenital foot deformity, this is not easy, and care must be taken to avoid cutting through the cartilaginous portion of the posterior talus. When this part of the release is completed, the talus should come forward, exposing the calcaneus.

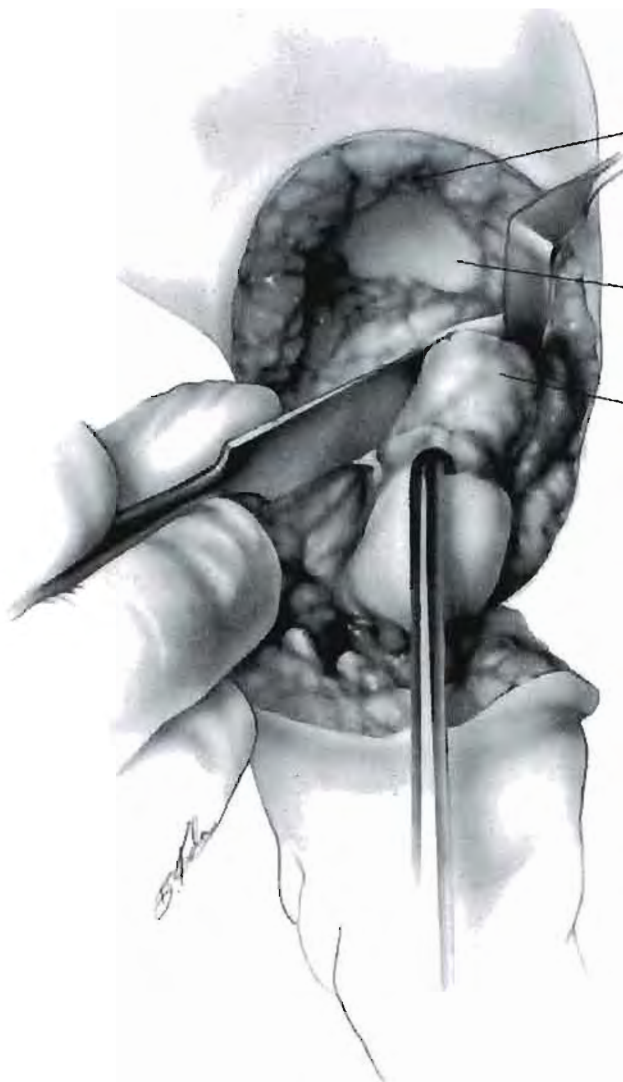

FIGURE 7-135. The dissection is completed with subperiosteal removal of the calcaneus. Using both a scalpel and periosteal elevator, the dissection is started posterior from within the ankle joint. Here again, the surgeon must be careful not to separate the calcaneal apophysis from the calcaneus. As soon as the Achilles tendon is identified, it should be exposed and a portion of it removed. This eliminates the tendency of the gastrocnemius muscle to pull the heel pad off of the tibia, a common complication. After dividing the Achilles tendon, the dissection of the calcaneus proceeds around to the plantar surface. In some congenital anomalies, however, in which the heel is behind the tibia, it will be much easier to start dissecting the calcaneus from the distal to proximal side.

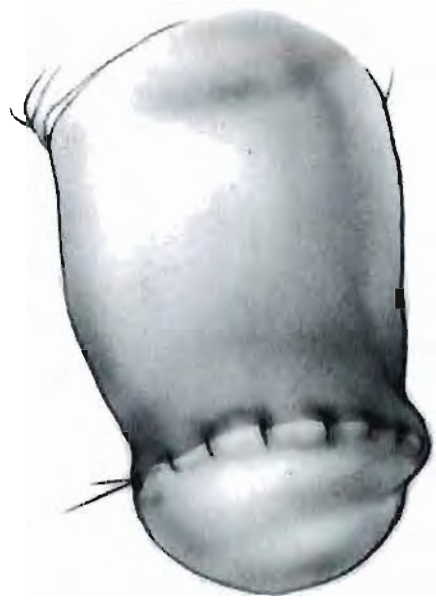

FIGURE 7-136. It is not necessary to remove the cartilage from the distal tibia or to cut any bone from the distal tibia. Closure is accomplished by suturing the deep layer of the heel pad to the deep fascia and periosteal tissue of the proximal part of the dorsal incision. This will anchor the heel pad. Fixation pins are not necessary and are largely ineffective because posterior migration of the heel pad occurs late as a result of imbalance of forces created by failure to section completely all tendons pulling on it. It is wise to deflate the tourniquet before closure to check the circulation to the flaps and control the bleeding. Drains do not appear to be necessary.

POSTOPERATIVE CARE

After closure, a dressing is applied. A rigid dressing may be used, but our experience has not shown any benefit over wrapping with an elastic bandage. A rigid dressing in small children usually loosens within 1 week and comes off shortly thereafter because of kicking and other movements. As soon as the swelling has decreased sufficiently, the prosthetist can take the mold for the socket. This is usually 3 to 4 weeks after the surgery.

References

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7.23 BOYD AMPUTATION WITH OSTEOTOMY OF THE TIBIA FOR FIBULAR DEFICIENCY

This amputation, first described by Boyd in 1939 (1), is best indicated in the limb-deficient child. The amputation is similar to the Syme amputation except that it preserves the calcaneus with the attached heel flap and fuses it to the distal tibia. In the congenitally deformed foot found in congenital lower extremity deficiencies, the fixation and the growth of the often small heel pad may be affected favorably by the arthrodesis, leaving the heel pad intact on the calcaneus. Its disadvantage is that in these same patients, the calcaneus and the distal tibia are largely cartilage, making arthrodesis difficult to achieve. If arthrodesis is not achieved, the calcaneus will migrate from beneath the fibula, requiring revision or conversion to a Syme amputation, which is not required when the heel pad alone migrates. The procedure, although most commonly used in the treatment of fibular deficiencies, has also been used in the treatment of tibial deficiencies by fusing the calcaneus to the fibula (2,3) (Figs. 7-137 to 7-139).

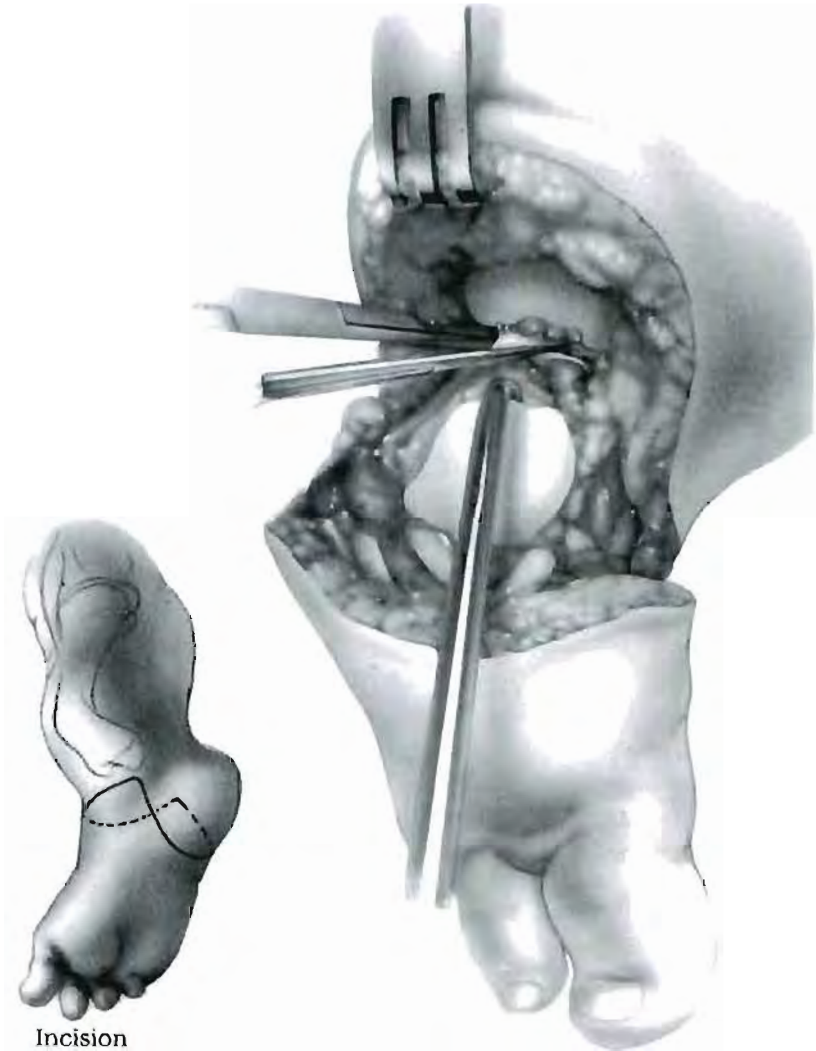


FIGURE 7-137. The incision and the initial exposure for the Boyd amputation is the same as for the Syme amputation through the release of the posterior ankle capsule. At this point, the foot is amputated through the midtarsal joints (calcaneocuboid and talonavicular). Because the forefoot provides a good handle by which to control the hindfoot, it is easiest to dissect most of the talus free and section the Achilles tendon, if possible, before removing the forefoot.

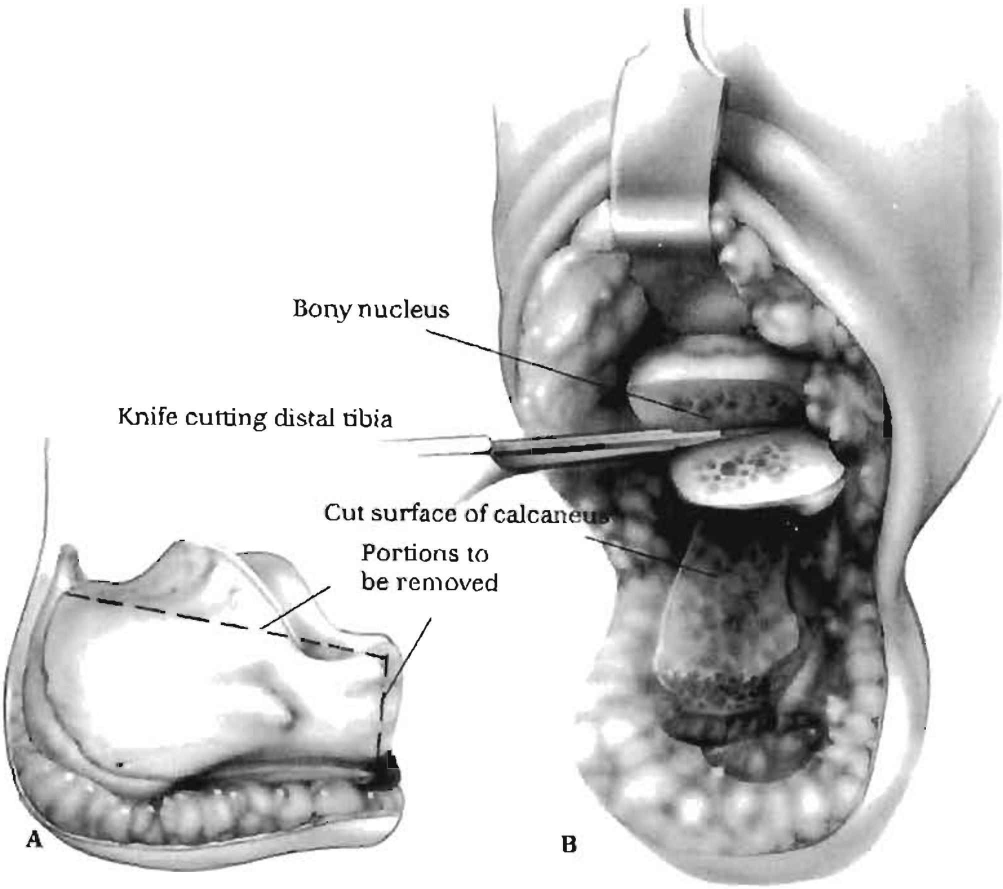
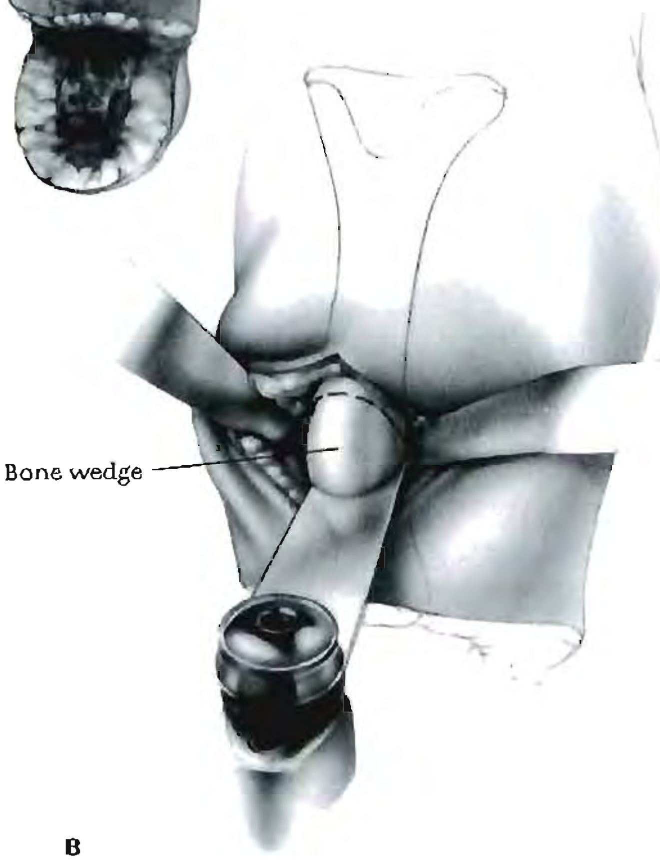


FIGURE 7-138. The talus is completely removed by cutting through the talocalcaneal ligaments. A saw (or often only a knife) is used to fashion a portion of the calcaneus to fit under the articular surface of the tibia. First, remove a portion of the anterior calcaneus. Next, remove the articular surface of the calcaneus to expose cancellous bone **(A)**. Finally, resect enough of the distal tibia to expose the bony nucleus of the distal epiphysis **(B)**

Use a rongeur to shape the calcaneus so that good bony contact is achieved between the calcaneus and the distal tibia. This is stabilized by a smooth Steinmann pin that passes through the heel pad and the calcaneus and into the tibia. The calcaneus must be pulled forward before fixing it to the tibia to avoid a posterior prominence that would interfere with prosthetic fitting and wearing.

A



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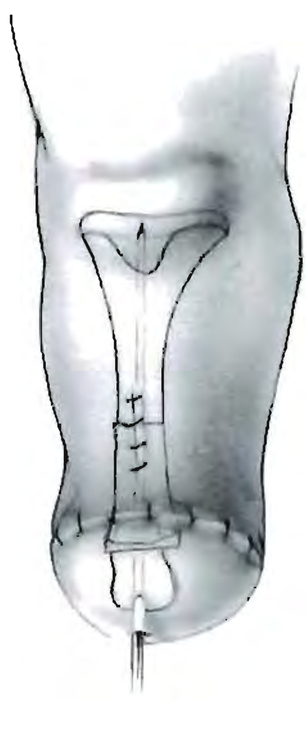

C

FIGURE 7-139. In many cases of fibular deficiency, the tibia is bowed anteriorly. Although this does not cause a problem with prosthetic fitting during the child's younger years, it may worsen with growth, making both prosthetic fitting and alignment of the foot difficult later. If it appears that this deformity will be significant, it is best to correct it at the same time as the amputation (Syme or Boyd) because it does not delay fitting significantly and at this age is preferable to a tibial osteotomy in later childhood.

A straight incision is made directly over the subcutaneous border of the tibia at the apex of the bow and carried directly down through the periosteum **(A)**. A small area of the tibia is exposed subperiosteally, leaving the posterior periosteum intact. A saw or rongeur is used to remove a small wedge of bone in the appropriate plane to correct the deformity. Usually, this is not a straight anterior bow **(B)**. A Steinmann pin is passed through the heel pad, through the calcaneus, into the distal fragment of the tibia, and then into the proximal fragment of the tibia. The wounds are then closed **(C)**.

POSTOPERATIVE CARE

The surgeon may choose either a rigid or soft dressing. Because of the uses of a Steinmann pin and its tendency to come out, particularly if a tibial osteotomy has been performed, we prefer to use a rigid dressing with the knee flexed 90 degrees. Fitting of a prosthesis is usually delayed for 4 to 6 weeks to allow for initial healing of the bony surfaces and for swelling to subside.

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SUBJECT INDEX

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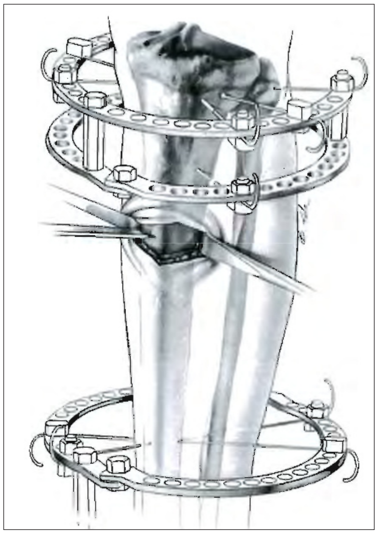

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