into the proximal lateral tibia. Distal screw breakage has been noted in some patients (118). We have found it possible to minimize this problem by using a larger screw distally or using an I-plate (Orthopediatrics, Warsaw, IN).

Osteotomy. Most patients with moderate-to-severe adolescent Blount disease will require an osteotomy of the proximal tibia, and sometimes the distal femur as well, to achieve restoration of a normal mechanical axis and joint orientation. In skeletally mature or nearly mature patients, osteotomy is indicated if the mechanical axis of the lower extremity is deviated medially to the center third of the knee joint. The extent of deformity in both the proximal tibia, represented by the MPTA, and the distal femur, as the lateral distal femoral angle (LDFA), is determined (66, 110–112). In addition, the sagittal plane alignment is assessed and procurvatum deformity noted. Regardless of the method chosen, the proximal tibial deformity should be completely corrected by the redirectional osteotomy including varus, procurvatum, and internal rotation.

Similarly, restoration of the distal femoral alignment with a concomitant femoral varus-correcting osteotomy is indicated if the LDFA measures more than 5 degrees varus (normal LDFA is 87 degrees) (66). If there is sufficient growth remaining, the distal femoral deformity may be amenable to hemiepiphyseal stapling. Alternatively, correction may be obtained with an osteotomy. The osteotomy should be performed in the distal metaphysis proximal to the physeal scar in skeletally mature patients or proximal to the physis in the skeletally immature patient. This allows correction close to the anatomic site of the deformity. A blade plate is used for fixation.

Compensatory valgus may be present in the distal tibia and is assessed on the AP ankle radiograph. Hemiepiphyseal stapling is used if there are 5 degrees or more of distal tibial valgus and the physis is open. If the physis is closed and more than 8 degrees of valgus is present, an osteotomy is performed.

Limited Internal Fixation. Osteotomy with limited internal fixation, the mainstay of treatment of infantile Blount disease, is generally not recommended in adolescent Blount disease. A supplemental long-leg cast often adds minimal additional protection for these extraordinarily large patients. The need for a period of non–weight bearing on the affected extremity, when limited internal fixation is used, makes ambulation difficult for these patients. Outcome of treatment with this approach has been unsatisfactory.

Stable Internal Fixation. Osteotomy, with acute correction and more stable internal fixation, can be effectively utilized in patients with mild-to-moderate varus and procurvatum deformity (119–121) (Figs. 27-50). Because the deformity occurs at the level of the physis, a transverse osteotomy of the tibia in the metaphysis distal to the tubercle must be translated laterally, sometimes as much as the entire diameter of the tibia in order to prevent creation of an offsetting deformity. To circumvent this deformity, Millis (119) has utilized an oblique, laterally based, closing-wedge osteotomy in skeletally mature patients which hinges at the intact cortex just distal to the proximal tibial physeal scar. Fixation is achieved using a laterally placed compression plate that serves as a tension band and permits weight bearing without external immobilization. As the hinge point is near the physeal scar, the correction is achieved at the level of the deformity and a translational deformity is not created. Similarly, an opening medially based wedge can be used. The plate is applied to the medial cortex and bone graft inserted into the gap.

Monolateral External Fixation. External fixation of the tibia can be used for correction of severe deformities. The dynamic axial monolateral fixator has the advantages of ease of achieving an acute correction, adjustability after the initial surgical correction, and relative patient acceptance (112, 114, 122, 123). Price et al. obtained satisfactory stability of the osteotomy fragments even in heavier patients (86). In applying a monolateral fixator of any type, pin placement parallel to the knee and ankle joint aids in obtaining a satisfactory acute correction of deformity. Similarly, Gaudinez and Adar (122) and Stanitski et al. (123) have effectively incorporated the Garche clamp when utilizing a monolateral fixation in the treatment of Blount disease in adolescents. The Garche external fixator optimizes fixation and allows for postoperative frontal plain adjustment and lengthening. It is, however, not conducive to postoperative adjustments in the sagittal plane or in rotation.

Circular External Fixation. Circular external fixation is the preferred approach for gradual correction of the proximal tibia; it allows for the maximal adjustability of the alignment in all planes and is ideally applicable in the most severe deformities and more obese patients (111, 112, 114, 124). Advantages include stable fixation with improved patient mobility, the ability to evaluate alignment in a functional, standing position, and the ability to correct accurately all of the tibial deformities including proximal tibial varus and procurvatum, internal tibial torsion, and distal tibial valgus. A hybrid circular fixator such as an Ilizarov or Taylor spatial frame can be used. The latter device is our preferred method of fixation (Fig. 27-47F,G).

Ideally, all of the deformities are addressed in a single surgical procedure. If distal femoral varus present, it is corrected first. The distal femoral deformity may be addressed by supracondylar osteotomy using a blade plate for stable fixation. This may be performed through a medial or lateral approach, with an opening or closing-wedge osteotomy technique. A lateral approach is preferred for completion of an opening-wedge osteotomy of the distal femur. The fragments are fixed with an adult 95-degree condylar blade plate.

Next, a fibular osteotomy is performed through a posterolateral incision over the midshaft of the fibula at least 10 cm distal to the fibular head. Great care should be taken in obtaining subperiosteal exposure of the fibula to avoid injury to the branches of the deep peroneal nerve, the extensor hallucis longus, or the peroneal vessels, which lie just medial to the fibula. A 1-cm section of the fibula is removed and used as bone graft for the distal femoral osteotomy if needed. In situations where there is significant laxity of the lateral collateral ligament of the knee,

(*Text continued on page 1305*)

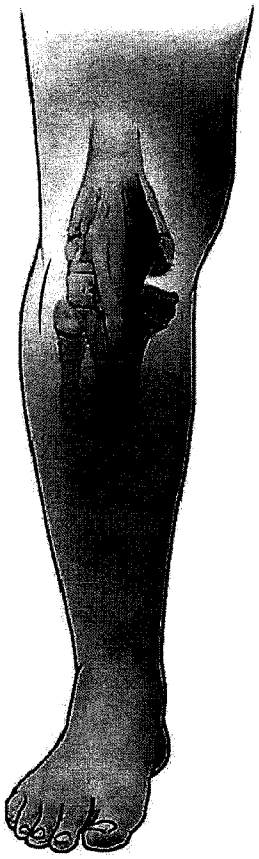

FIGURE 27-51. Growth Modulation Using Eight-Plate. The patient is positioned supine on a radiolucent table. The physis is identified using image intensification. A 3cm incision is centered over the physis to allow insertion of the plate in the midline. For correction of proximal tibial varus, the plate is positioned just anterior to the fibula.

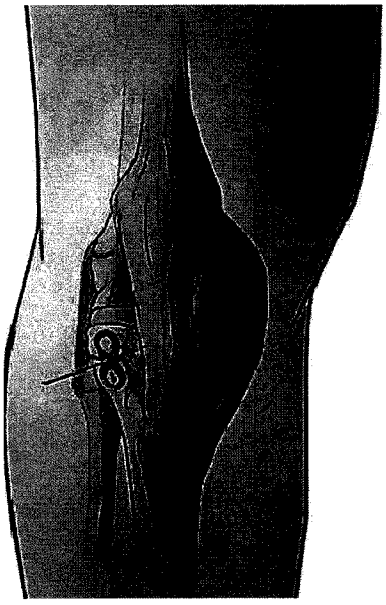

FIGURE 27-52. The bone is exposed extra-periosteally to avoid inadvertent injury to the peripheral physis.The plate is centered over the physis, using a Keith needle through the center positioning hole. Image intensification is used to confirm satisfactory position in the coronal and sagittal planes.

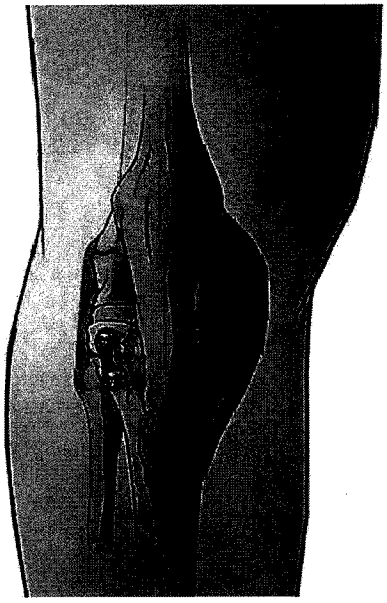

FIGURE 27-53. Screws are inserted into the epiphysis and metaphysis, parallel to the physis. They are of sufficient length to engage the bone without extending beyond the mid-axis of the bone. Position is confirmed using image intensification in both planes. Plates are removed when the mechanical axis is corrected. When used in younger patients where there is a risk of recurrent deformity, the metaphyseal screw is removed, leaving the plate and epiphyseal screw in place should repeat growth modulation be necessary.

Growth Modulation Using Hemiepiphyseal Staples (Figs. 27-54 to 27-56)

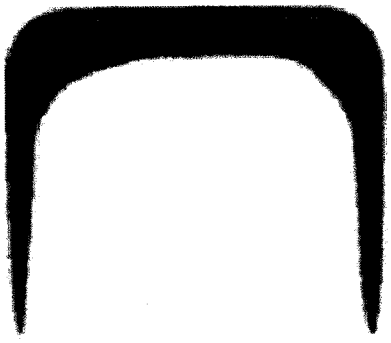

FIGURE 27-54. Growth Modulation Using Hemiepiphyseal Staples. Staples used for growth modulation have reinforced corners (Zimmer, Inc., Warsaw, IN). This feature is necessary to resist deformation by the growing physis. Three sizes are available (3/8, 5/8, 7/8 inch). Staples must be wide enough to span the physis, yet not penetrate the joint. The largest staples may be used when the physis is abnormally wide as may be seen in hypophosphatemic rickets. They are place extra-periosteally to avoid injury to the periphery of the physis.

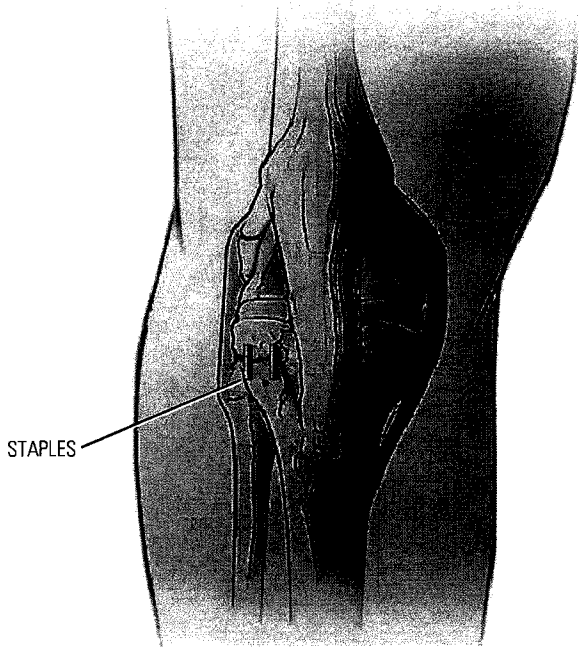

FIGURE 27-55. The technique is similar to that using an eight-plate. For varus in the proximal tibia, typically two 3/8 inch staples are placed parallel to the physis, the first staple placed just anterior to the fibula, the second placed 5-mm anterior to the first. Optimal positioning puts the physis equidistant from the prongs of the staple.

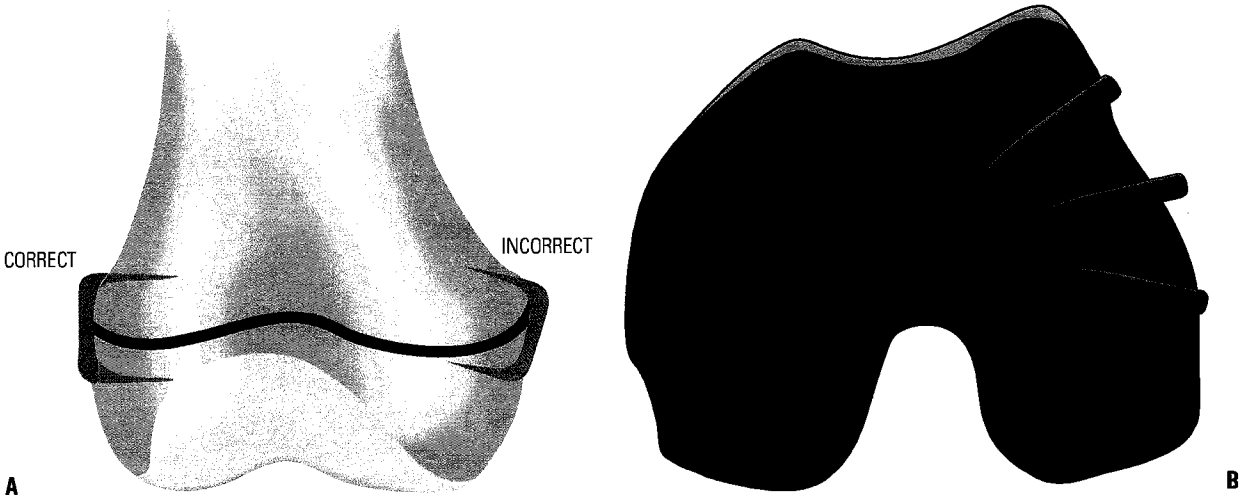

FIGURE 27-56. For correction of angular deformity in the distal femur, two or three 5/8 inch staples are used and are centered about the longitudinal axis of the femur.

the fibula can be left intact and the tibia lengthened, pulling the fibula distally and which tightens the lateral collateral ligament.

The preconstructed circular fixator is placed over the leg and applied with a combination of transfixing wires and half-pins. Ring strategy and placement of transfixing wires vary depending on the presence of open growth plates, the need for fibular transport to correct ligamentous laxity, and the need for distal tibial valgus-correcting osteotomy (112, 124). The proximal tibial osteotomy is performed through a limited incision, using drill bits and osteotomes. If indicated, a distal tibial osteotomy is created in an identical fashion.

Gradual correction is begun on postoperative day 2 or 3, and serial radiographs are obtained to monitor the correction and bone formation (Fig. 27-47H). The patient is encouraged to undertake full weight bearing as early as possible, and physical therapy is instituted to maintain mobility and joint range of motion. Adjustments in the circular frame are made as necessary to correct all planes of the deformity. The fixator is left in place and progressively dynamized until consolidation and cortication of the osteotomy site is complete. Bilateral deformities are corrected one side at a time. Correction of the second extremity is usually planned within 6 months of completion of the first side. This comprehensive approach has provided very satisfactory results in this most difficult group of patients and has been a marked improvement over traditional methods of treatment (Fig. 27-47I–K). There have been very few surgical complications in these patients despite their extremely large size (112, 114, 121). All osteotomies, including those that included lengthening, have healed without delay. The knee and ankle joints have been realigned and the normal mechanical axis of the leg restored. Knee pain has resolved. Patients are satisfied with their more normal lower extremity alignment.

KNOCK-KNEES AND GENU VALGUM

Definition. Parental concerns regarding knock-knees are far less common than those regarding bowed legs (5, 125, 126). Physiologic knock-knee generally becomes a concern when the child is between 3 and 5 years of age, and the normal femoral–tibial angle is at its maximum valgus angle (5, 125, 126) (Fig. 27-57). Parents often notice the flat appearance of the foot before the valgus knee position is noted. There may be occasional complaints of medial foot or medial knee pain.

Typically, valgus knee position becomes apparent after 2 years of age, reaching a maximum femoral–tibial angle of 8 to 10 degrees at approximately 3 to 4 years of age, a time when it is most noticeable (2, 5, 46). As demonstrated by Salenius and Vankka, and more recently by Subharawal et al, valgus gradually decreases to a stable "adult" level of 5 degrees to 7 degrees of femoral–tibial valgus angulation by 6 to 7 years of age (Fig. 27-16). There is, however, wide variation among normal children, that is, those who fall within two standard deviations of the mean. This range includes measurements of ± 8 to 10 degrees, which means that normal femoral–tibial angles may range from 2 degrees of varus to 20 degrees of valgus at 3 to 4 years of age and neutral to 12 degrees of valgus after 7 years of age (46, 125, 126).

Physiologic knock-knees are typically symmetric (5, 125). The severity of the deformity can easily be assessed and documented by standing photographs. Radiographic evaluation is indicated in those children with clinically excessive femoral–tibial angles, those who present outside of typical age range for physiologic valgus, those with asymmetric deformity, or those who fall below the 10th percentile of height.

Genu valgum is a pathologic condition that may result from persistent knock-knee in a young child, but more often develops during early adolescence (Fig. 27-58). Typically, the deformity arises from asymmetric growth in the distal femur and does not spontaneously resolve. In some cases, there is also valgus deformity of the proximal tibia.

Differential Diagnosis. Most children younger than 6 years of age who present with a concern of knock-knees are normal (46). The differential diagnosis includes metabolic bone disease such as rickets, posttraumatic valgus, or skeletal dysplasia (127–130) (Table 27.2). If the onset of rickets (osteomalacia) occurs when physiologic valgus is present, a knock-knee deformity is more likely to develop. Valgus may result from overgrowth of the proximal medial tibia following a proximal tibia fracture (Cozen fracture) or from an injury to the distal lateral femoral physis (130–132). Skeletal dysplasias most typically associated with genu valgum are chondroectodermal dysplasia (Ellis–van Creveld), mucopolysaccharidosis type IV, and spondyloepiphyseal dysplasia tarda (131). Benign neoplastic processes such as multiple hereditary exostoses and focal fibrocartilaginous dysplasia may also produce a valgus deformity (133).

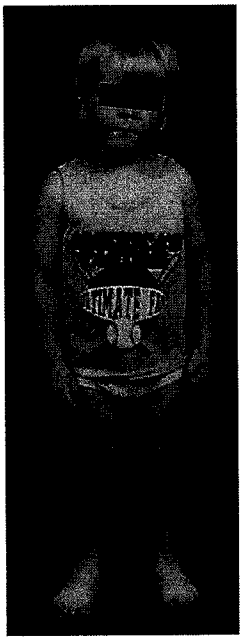

FIGURE 27-57. Physiologic knock-knee peaks between 3 and 4 years of age. It may be associated with asymptomatic flat feet. It is typically symmetric and shows gradual resolution by 8 years of age.

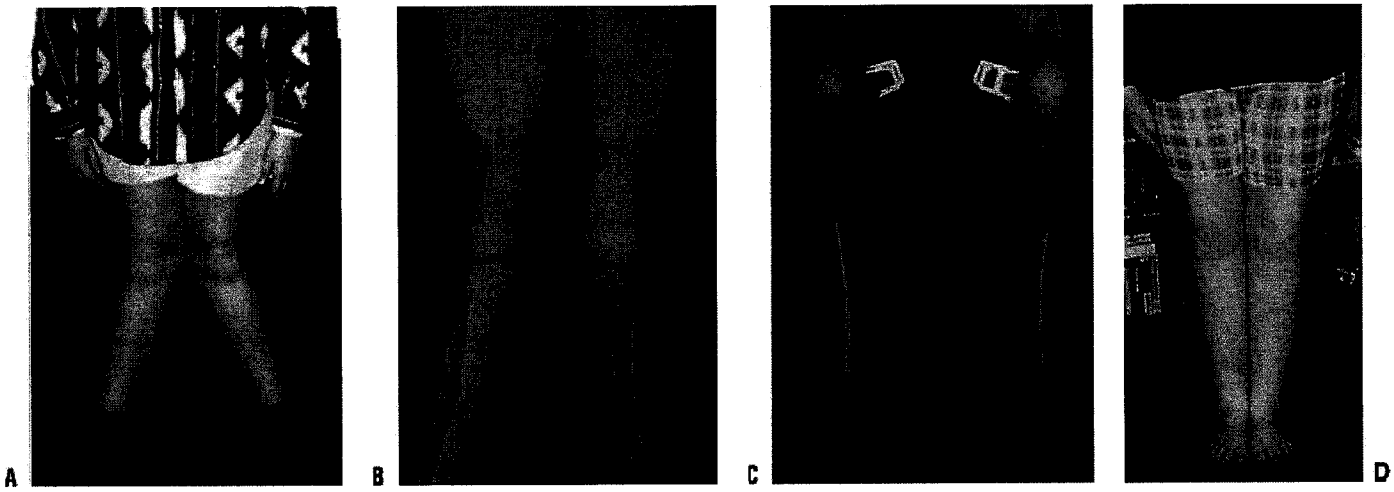

FIGURE 27-58. **A:** Lower limb valgus that persists past 8 years of age is not physiologic. It may cause an awkward gait, in addition to concerns about appearance. **B:** These long cassette films of a 12-year-old girl confirm the presence of valgus. She is not skeletally mature, making hemiepiphyseal stapling a treatment option. **C:** Stapling of the medial physis of both distal femurs in a growing adolescent results in rapid correction. Correction of the mechanical axis is achieved in this patient within a year. **D:** There is marked clinical improvement in alignment. Correction is generally well maintained.

Natural History. Physiologic knock-knee predictably remodels to normal alignment (slight valgus) by 7 years of age (2, 5, 46, 125, 126). No treatment is necessary for this type of knock-knees. Minimal, if any, change in femoral–tibial angle should occur through adolescent growth.

In contrast, genu valgum occurs in older childhood or early adolescence. Knee pain may be present. The clinical deformity is often more striking than the radiographic appearance. It may be associated with an out-toed gait. Lateral patellar subluxation may develop, but is uncommon. Many of these children are above the 90th percentile in height and weight. Walking may become awkward because of the knees rubbing or hitting together as the child tries to narrow the base of support. This degree of deformity is not physiologic and typically does not resolve on its own. Valgus of the knee which increases after 7 years of age is not physiologic. This genu valgum is a pathologic state and often requires surgical treatment (134, 135).

TABLE 27.2 Differential Diagnosis of Knock-Knees

Developmental
Physiologic
Genu valgum
Skeletal dysplasia
Ellis–van Creveld
Pseudoachondroplasia
Morquio MPS IV
Acquired
Metabolic
Posttraumatic
Neoplastic
Multiple hereditary exostoses
Focal fibrocartilaginous dysplasia

MPS, mucopolysaccharidosis.

Assessment. An AP, standing, radiograph of both lower extremities, which includes the hips, knees, and ankles on one image, is best for assessing the mechanical axis and any deviation in joint alignment. The lower extremities should be placed so that the patellae are facing directly forward. This must be done without regard to foot position. This technique produces the truest AP image of the knees and allows for reliable serial comparisons if needed. The mechanical axis of the lower extremity is drawn from the center of the hip through the center of the ankle (Fig. 27-59). A normal mechanical axis passes through the central third of the knee, roughly defined by the tibial spines, or through zones +1 to −1 where positive values represent valgus and negative values varus (41, 89, 135, 136).

Lateral deviation of the mechanical axis, beyond the midportion of the lateral tibial plateau (zone +2 or +3), can result in relative overload of the lateral compartment (41, 136) (Fig. 27-60). The severity of deformity sufficient to produce premature degenerative change in the lateral compartment of the knee is not known. Genu valgum that results in mechanical axis deviation beyond the lateral margin of the tibia is pathologic and warrants correction. In addition to improving the appearance of lower limb alignment, correction can restore a normal mechanical axis (132, 135, 136). Gait analysis has demonstrated abnormal moments about the hip and knee in proportion to the deviation from normal (134).

Treatment of Physiologic Knock-Knees. Treatment of knock-knees consists of education of the parents regarding

FIGURE 27-59. The mechanical axis is assessed on a standing, AP, long cassette radiograph that includes the hips and ankles. A line is constructed from the center of the femoral head to the center of the ankle. For consistent serial measurements, the knees are positioned with the patellae facing forward.

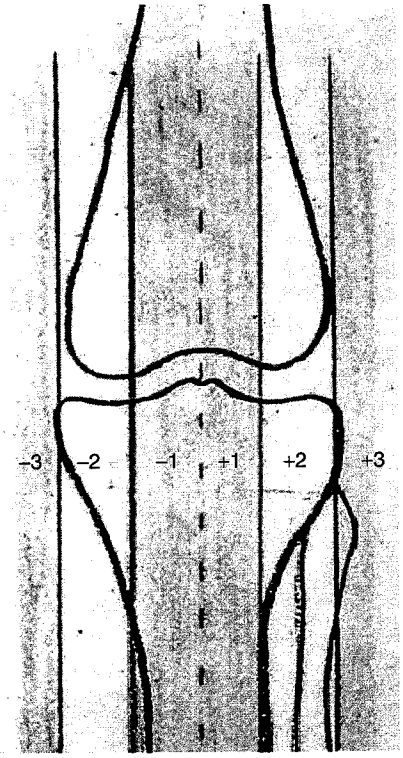

FIGURE 27-60. To determine the mechanical axis of the tibia, the proximal tibia is longitudinally divided into four parts. Positive values are lateral to the midline or valgus. Negative values are medial to the midline or varus. Zone 1 is centered over the tibial spines, zone 2 is within the tibial condyle, and zone 3 is beyond the cortex. A normal mechanical axis falls within zone 1.

the natural history of this physiologic condition, which is anticipation of spontaneous correction by 7 years of age (126). Lower extremity bracing is not indicated (126). The inherited metabolic bone disease XLH requires medical management of the osteomalacia. Genu valgum associated with bone diseases such as XLH and skeletal dysplasias may worsen with time, necessitating surgical treatment. Postfracture valgus deformity also may require treatment, as spontaneous correction does not always occur.

Treatment of Genu Valgum. Surgical treatment of genu valgum is indicated if the mechanical axis passes through zone 3, that is, at or beyond the lateral cortex of the tibial plateau, or if it passes through zone 2 and knee pain is present. In most cases, surgery can be deferred until the child is 10 to 11 years of age.

Hemiepiphysiodesis. Correction in the skeletally immature child with 1 to 2 years of growth remaining can be accomplished with growth modulation or hemiepiphysiodesis (88, 89, 134, 136, 137–140) (Fig. 27-58C,D). Whether this is performed in the distal femur, proximal tibia, or both will depend on the location of the deformity and the amount of growth remaining (131, 137, 140). Most often, genu valgum deformity occurs secondary to asymmetrical growth of the distal femur and occasionally also of the proximal tibia. The mechanical axis of the femur and tibia and the relative abnormality in either the LDFA and/or PMTA should be assessed (Fig. 27-48) to determine the appropriate site(s) for hemiepiphysiodesis (41, 110, 134). The technique of placing an eight-plate or staple(s) implant although simple requires attention to a few important details to maximize its effectiveness and minimize the potential for growth-plate injury (88, 89, 131, 135). The implant is carefully placed extraperiosteally. Use of C-arm image intensification is critical in assuring optimal placement. On the AP or frontal view, the screws of the eight-plate or the staple prongs should both span and be parallel to the physis. This may require a slightly oblique orientation to the cortex. On the lateral view, the implant should be placed centrally (equidistant from the anterior and posterior edges of the physis) to avoid inadvertent creation of a sagittal plane deformity. One eight-plate or two staples per location are generally sufficient.

Timely follow-up is essential for all patients selected for growth modulation, particularly those with more than 2 years of growth remaining. Undesirable overcorrection to a varus position can occur. Radiographs of the lower extremities should be obtained at 3-month intervals. As noted above,

these need to include hips to ankles with the patellae facing forward. Some improvement in the lower extremity mechanical axis should be apparent 3 to 6 months after the insertion of the implant. Once the mechanical axis passes through the central third of the knee joint, the implant should be removed to avoid overcorrection into varus unless the lateral physis is closing (Fig. 27-58D). Following implant removal, rebound medial overgrowth can occur resulting in some loss of correction. This is more common in children who are younger than 10 years when growth modulation is performed (88, 135). It is unclear how long either an extraperiosteal eight-plate or staples can safely span a growth plate without affecting future growth. It has been our practice to remove the implant within 18 to 24 months if resumption of growth is desired. Stevens has reported resumption of growth following removal of an implant that was across the physis for more than 2 years in patients with a variety of deformities.

If rebound overgrowth is a concern and the possibility of another surgical procedure is not acceptable, a complete epiphysiodesis can be performed; however, this will result in limb shortening in proportion to the amount of growth remaining. As the procedure is usually bilateral and performed close to skeletal maturity, the absolute amount of shortening is usually not significant. Alternatively, permanent hemiepiphysiodesis can effectively be used to correct valgus angulatory deformities of the older child and/or young adolescent (137). Correlation of the severity of angulatory deformity and bone age is essential in achieving a satisfactory correction of deformity at maturity. We have not had any experience with this technique.

Osteotomy. Osteotomy is indicated when immediate correction of the deformity is desired (138, 139) (Figs. 27-61 to 27-68). It may be preferred in very young children with severe deformity such as valgus associated with a skeletal dysplasia or in those who are skeletally mature. The site of deformity correction is dependent on the anatomic deviations present in the tibia and/or femur, just as in the determination for hemiepiphyseal stapling or plating. The femur is more often the primary site of valgus deformity. In young children, valgus is corrected using a transverse osteotomy in the distal femur. Appropriately sized K-wires or a small-fragment plate can be used for fixation and supplemented with a long-leg cast. Immediate correction of femoral valgus using internal fixation with a 95-degree condylar blade plate is preferred for older children and adolescents (140). A lateral approach to the distal femur is preferred. It also allows exploration and release of the peroneal nerve, which is sometimes necessary in severe deformities. External fixation can also be used for correcting valgus deformity (138, 139).

Gradual correction using external fixation may also be considered for children with severe deformity, in whom it reduces the risk of peroneal nerve neurapraxia, and for those with limb-length inequality when lengthening is also needed (38, 117, 141). Circular external fixation may facilitate angulatory correction in combination with lengthening (141). A monolateral frame may be considered when external fixation is used with immediate correction.

Similar techniques can be used for valgus correction in the tibia. In young children, correction can be accomplished by simple, closing-wedge technique in the proximal tibia, using two or three crossed stainless steel wires as described regarding rotational variation earlier in this chapter (142). In adolescents and young adults, tibial valgus deformity can be corrected by a proximal tibial osteotomy that uses a medially based oblique wedge osteotomy and hinges proximally and laterally near the physeal scar. The wedge is carefully removed and the distal medial cortex is compressed together utilizing a short compression plate to produce a controlled fracture of the lateral cortex.

Complications. When placing an eight-plate or staples around the growth plate, there is potential for injury to the involved growth plate. Errors in technique can lead to failure in obtaining the desired growth modulation. Either inaccurate placement or poor fixation can compromise results (88, 89). Timing of placement, follow-up, and removal are other sources of error. If growth modulation is performed too late, there will not be adequate growth remaining to correct the deformity. Lack of appropriate and timely postoperative evaluation, resulting in overcorrection, is the most common serious complication of hemiepiphyseal growth modulation. The resultant varus alignment produces greater mechanical loads across the medial compartment of the knee than the same degree of valgus would produce over the lateral compartment (48).

Overcorrection can also occur because of unrecognized premature physeal closure beneath the eight-plate or the staples. The length of time the extraperiosteal implant can be left across a growth plate without permanently affecting growth is unclear. We have used 18 to 24 months as the upper limit if resumption of growth is desired. The actual limit may be dependent on the patient's age at the time of implant placement and the number of eight plates or staples and their design. In recent reports by Stevens (143), none of his patients had premature growth arrest or rebound when treated with temporary physeal stapling for genu valgum.

Complications related to osteotomy include failures of union or fixation, infection, blood loss, knee stiffness, and scar formation. None of these is unique to distal femoral or proximal tibial osteotomy for valgus correction. Peroneal nerve injury is a serious concern in the process of valgus correction. Mobility of the peroneal nerve is limited above the knee as it passes around the distal femur and across the lateral edge of the biceps femoris tendon and below the knee as it curves around the proximal fibula and through the crural fascia (38). More severe deformities may require release of one or more of these sites to reduce the risk of permanent injury. Closing-wedge technique for immediate correction is less likely to stretch the peroneal nerve than opening wedge. Gradual correction of severe deformities as can be achieved with a circular external fixator may allow the nerve to accommodate to these changes more safely than does acute correction. However, when placing the fixator pins, nerve injury must be avoided.

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Distal Femoral Angular Osteotomy (Figs. 27-61 to 27-68)

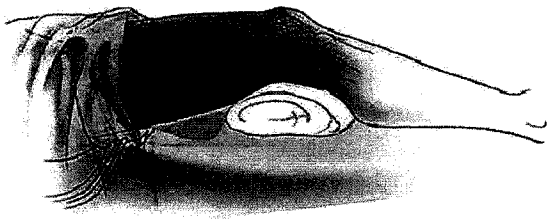


FIGURE 27-61. Distal Femoral Angular Osteotomy. The patient is placed supine on a radiolucent table. A lateral incision is made along the midline of the distal femur from the joint line, extending proximally to accommodate the length of plate to be used. In skeletally immature patients, the osteotomy and fixation are proximal to the physis and a contoured plate is used. The technique described here is for skeletally mature patients and uses a blade plate for fixation.

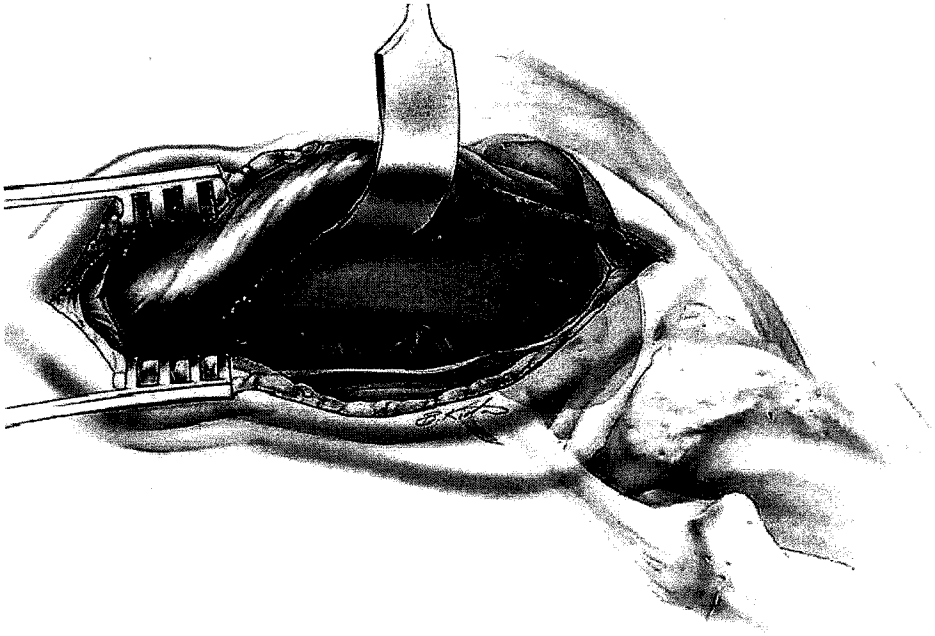


FIGURE 27-62. The iliotibial band is incised in line with the midline of the femur and the vastus lateralis is identified distally and elevated from the fascia using a periosteal elevator. Perforating vessels are identified and cauterized as they are encountered. The periosteum is incised in line with the femoral shaft. The exposure of the femur can be extended by adding transverse cuts in the periosteum, proximally and distally.

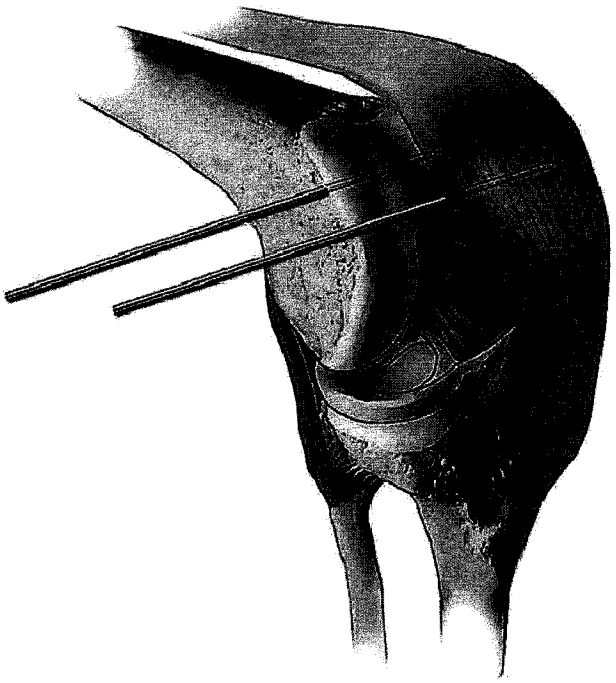


FIGURE 27-63. A smooth Kirschner wire is placed across the femoral condyles to guide placement of the chisel in the distal femur. A second wire is placed 1.5 cm proximal to the joint line, in line with the mid-shaft of the femur, the orientation is confirmed using image intensification.

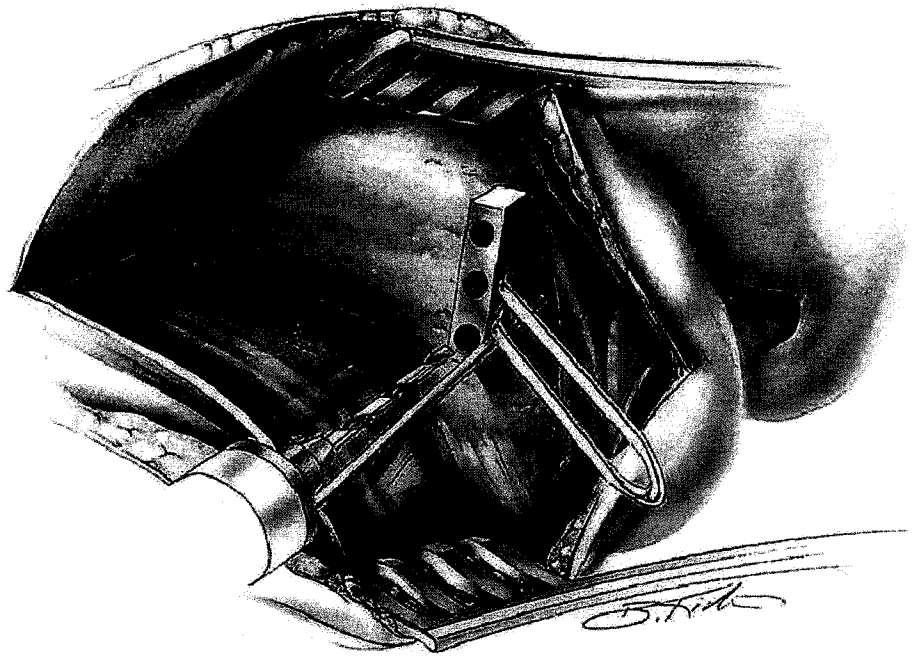


FIGURE 27-64. The drill jig can be used to place 3 drill holes used to establish a small trough in the lateral cortex where the chisel will be inserted.

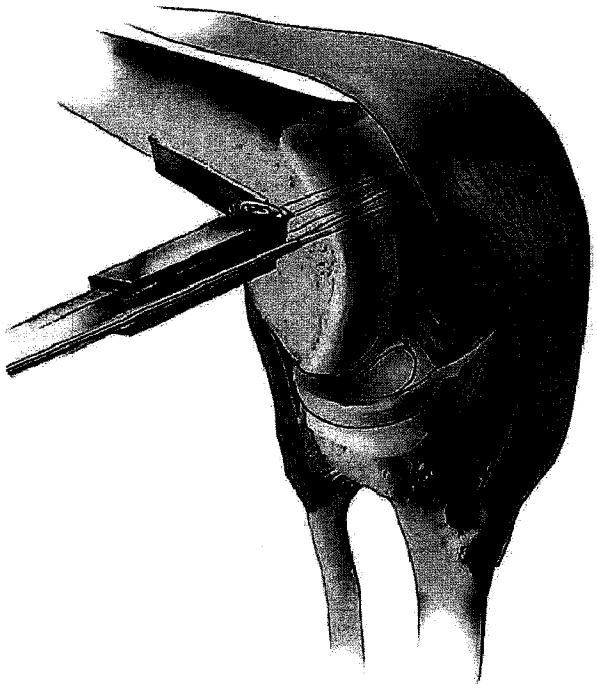


FIGURE 27-65. The seating chisel is inserted taking care to adjust the angle and rotation to allow proper contact of the blade plate with the shaft of the femur.

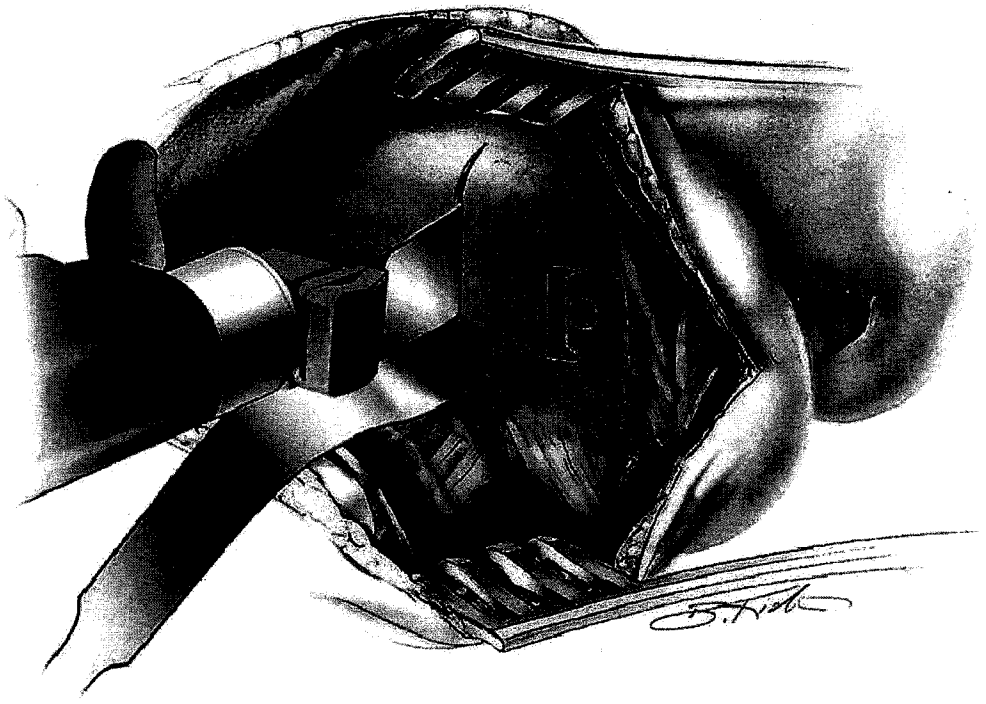


FIGURE 27-66. The chisel is removed and a transverse osteotomy is completed. For correction of a valgus deformity, reduction of the plate along the shaft of the femur, creating an opening wedge, corrects the deformity. Alternatively, a wedge is removed for correction of a varus based on a template of the pre-operative radiograph.

FIGURE 27-67. The blade plate is inserted and reduced along the shaft of the femur. Screws of appropriate length are inserted.

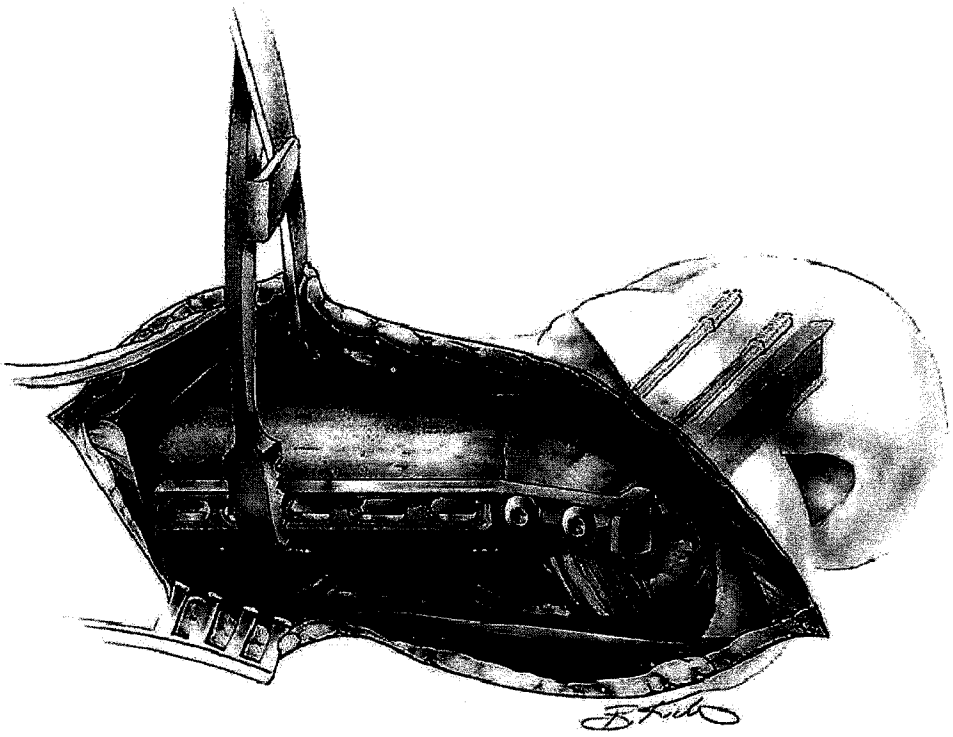
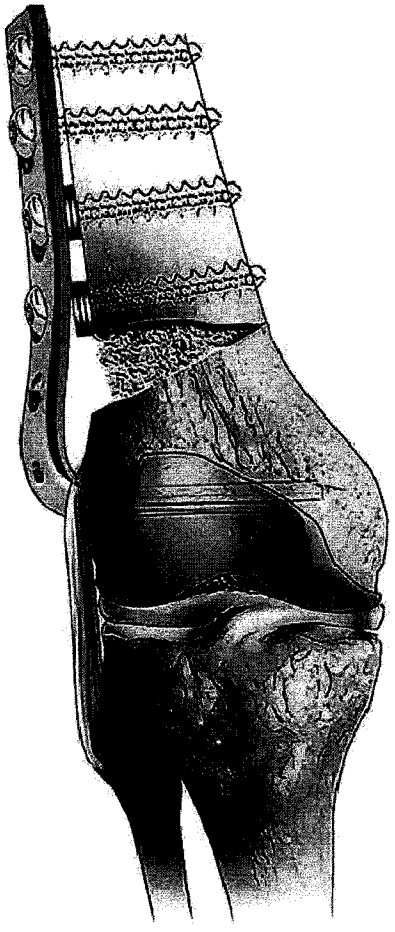


FIGURE 27-68. If optimum correction of the femoral deformity does not allow the blade plate to fully contact the lateral femur, washers can be placed between the plate and bone to provide contact. The washers can be tied together using absorbable suture and positioned between the plate and bone while screws are inserted. The patient is toe-touch weightbearing for six weeks, with weight-bearing advanced based on healing of the osteotomy. In skeletally immature patients, the osteotomy and fixation are completed proximal to the physis. A contoured plate is used. The size of an opening or closing wedge osteotomy is determined using a template of the preoperative radiograph.



BOWING OF THE TIBIA

Congenital Pseudarthrosis of the Tibia

Definition. Bowing of the tibia that presents at birth typically is either anterior, anterolateral, or posterior medial. Anterior tibial bowing that occurs in association with a deficient or absent fibula is diagnostic of fibular hemimelia. Posterior medial bowing occurs in association with calcaneovalgus foot deformity and has a good prognosis. In contrast, anterolateral bowing, which usually presents soon after birth, is typically a progressive deformity which often results in a pseudarthrosis. Anterolateral bowing associated with congenital pseudarthrosis of the tibia (CPT) is rare (1:140,000), yet it is the most common type of congenital pseudarthrosis (144, 145). Neurofibromatosis occurs in more than 50% of patients with anterolateral bowing, with or without pseudarthrosis of the tibia (144–148). This bowing may be the first clinical manifestation of neurofibromatosis (146, 147).

Natural History. Spontaneous resolution is uncommon (142). Rather, the tibia with an anterolateral bow appears dysplastic, with failure of tubulation, cystic prefracture, or frank pseudarthrosis, or a combination of these features, with narrowing of the fragments (144, 146). Fracture with resultant pseudarthrosis typically occurs in the first 4 to 5 years of life (149) (Fig. 27-69). Once established, the natural history of a pseudarthrosis is that of persistent instability and progressive deformity. Numerous classification systems have been proposed in an attempt to predict the natural history and outcome of treatment. In reality, there has been very little correlation with initial radiograph classification and eventual outcome of treatment (146, 149–151). The radiographic appearance of CPT has been classified by Boyd and by Crawford (144, 146). Both noted the variable natural history and prognosis of each of the types they described (Table 27.3). Consolidation of the pseudarthrosis was most difficult to obtain in the Boyd type II or Crawford dysplastic type II-C (Fig. 27-70).

Nonoperative Treatment. Once the diagnosis of anterolateral bowing is made, full-time brace treatment is indicated. An ankle-foot orthosis (AFO) is appropriate protection prior to walking, and a KAFO is fit as the infant begins walking. Orthotic support is continued indefinitely during the growing years. Surgical treatment of an intact pathologic anterolaterally bowed tibia in the infant and/or young child should be avoided. Rather, surgical treatment should be deferred until later in childhood after a CPT has developed. Typically, a pathologic fracture occurs which does not readily consolidate despite long-term protective treatment. Once an obvious pseudarthrosis is established, surgical treatment can be considered. Although very uncommon, some forms of anterolateral bowing, such as Boyd type IV, occasionally do not progress (142). These unusual CPT deformities present with a bowed tibia, with or without a previous fracture that consolidates with immobilization. Supplemental bone grafting may be beneficial (151–154). A recent series of 10 patients with neurofibromatosis and pre-pseudarthrosis were successfully managed with fibular allograft and long-term orthotic use (152). These unique patients seem to carry less chance of progression and fracture following the bone graft procedure.

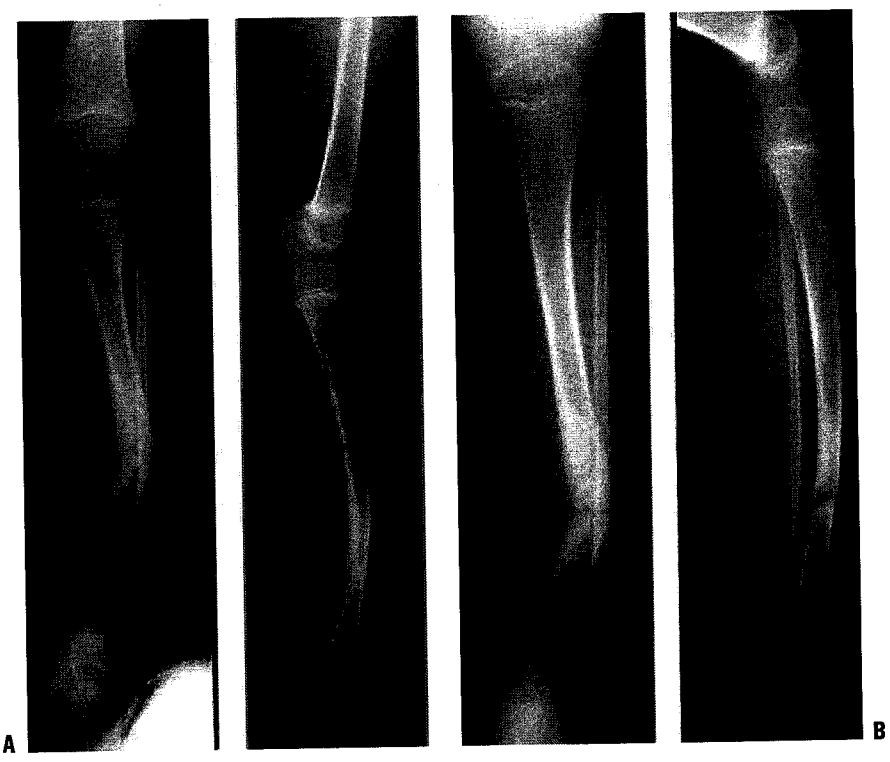


FIGURE 27-69. A: Anterolateral bowing of the tibia may be apparent at birth or may progress with weight bearing. Bowing usually occurs between the middle and distal thirds of the tibia. The adjacent bone may appear sclerotic, with increased density, or it may be atrophic and spindle shaped. Once the deformity is recognized, the leg should be protected with a total contact orthosis. Although fracture is not likely to be avoided, it may be delayed until the child is bigger. **B:** Fracture occurs at the apex of the bow, usually without prodromal symptoms and with minimal or no trauma. Once fracture occurs, surgical management begins.

TABLE 27.3 Classification of Congenital Pseudarthrosis of the Tibia

Boyd Classification		Crawford Classification	
I	Fracture present at birth	I	Nondysplastic type
II	Hourglass constriction of tibia		–Anterolateral bowing with increased density
III	Bone cysts		–Sclerosis of medullary canal
IV	Sclerotic segment of tibia, no constriction, stress fracture results		–May convert to dysplastic type following osteotomy
V	Dysplastic fibula	II	Dysplastic type—Anterolateral bowing
VI	Intraosseous neurofibroma		A–With failure of tubulation
			B–Cystic prefracture or canal enlargement from prior fracture
			C–Frank pseudarthrosis with atrophy "sucked candy" narrowing of ends

Operative Treatment. Despite a gradual improvement in the outcome of treatment in the past 100 years, CPT remains one of the most challenging problems in pediatric orthopaedics. Even with consolidation, the tenuous status of the atrophic bone markedly limits functional potential (144–146). A major improvement in outcome can be traced to Boyd's use of dual onlay grafts, Moore's use of staged bone graft and external fixator, McFarland's bypass graft, and Sofield and Millar's innovative use of IM rod stabilization (154–156). Less invasive technical innovations were developed by Brighton and Bassett (157, 158) utilizing implanted cathode leads or pulsed electromagnetic current, either alone or in combination with surgical stabilization.

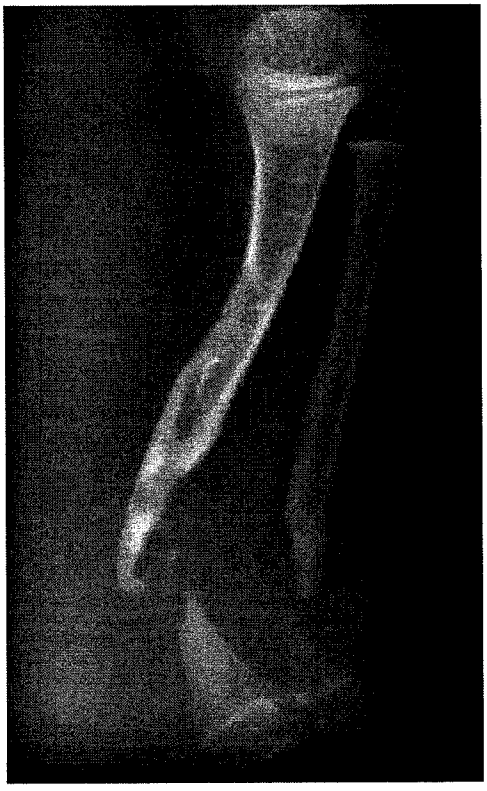


FIGURE 27-70. Early (Boyd type II, Crawford II-C) congenital pseudarthrosis of the tibia and fibula in a patient with neurofibromatosis.

Currently, three surgical approaches are being used successfully in the treatment of CPT (Fig. 27-71). All techniques include excision of the pseudarthrosis site. Techniques used to achieve union of the pseudarthrosis include IM fixation with autogenous iliac crest bone graft, circular ring fixation with bone transport, and vascularized fibular graft. However, even after obtaining consolidation with any of these techniques, long-term follow-up is critical to address associated deformities that frequently occur later in the course of the disease. These include refracture, persistent or increasing valgus deformity, and limb-length inequality.

Solid Intramedullary Rod Fixation. Charnley is credited with the first reported innovative use of an IM rod that both stabilized the pseudarthrosis site and transfixed the ankle joint (159). In a similar technique, Umber et al. (160) popularized the use of the two-part Peter Williams IM solid rod in North America (161). This IM rod technique, in conjunction with pseudarthrosis excision and iliac crest bone grafting, has been further refined in dealing with all aspects of the deformity (162–165). It is our approach of choice in treating CPT. A posterior iliac bone graft is obtained consisting of adequate corticocancellous strips and cancellous bone graft. The pseudarthrosis is excised and the bone fragments stabilized with a Williams rod (162, 165). The entire rod assembly is inserted at the pseudarthrosis site into the medullary canal of the distal fragment and is advanced in an antegrade direction through the distal tibia and across the talus and calcaneus exiting through the heel pad (Fig. 27-72). During the passage of the rod across the ankle joint, it is imperative that the foot be positioned to correct the calcaneus position of the foot and valgus deformity of the distal tibia. The desired foot position is neutral dorsiflexion/plantarflexion verified clinically and with the C-arm. The tibial fragments are anatomically reduced at the pseudarthrosis site, and the rod is driven retrograde into the proximal fragment.

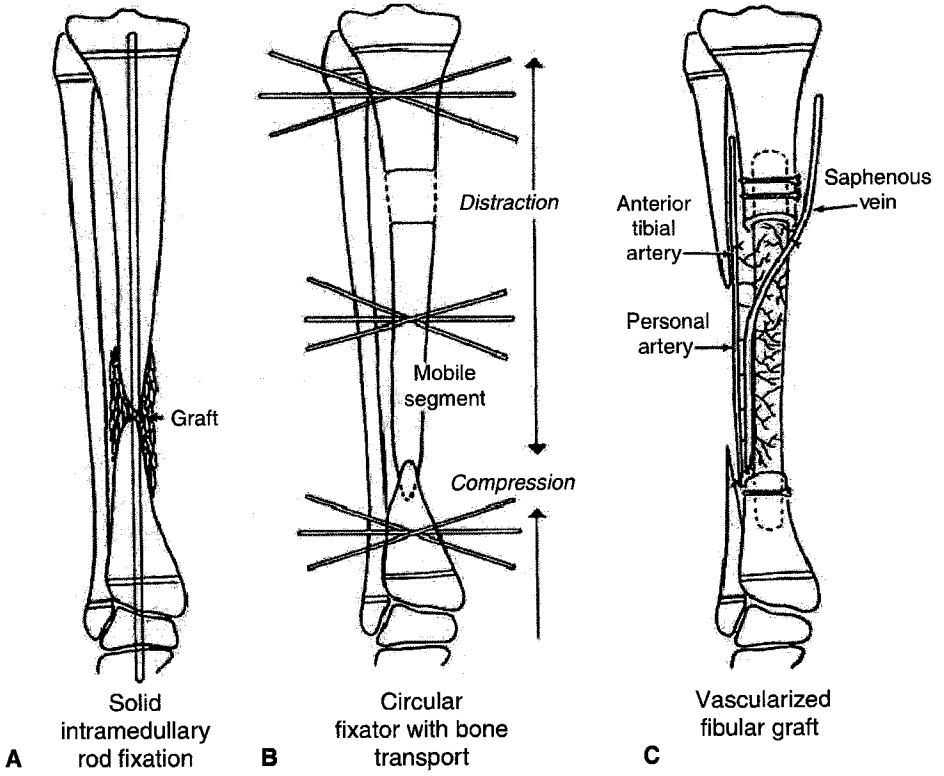


FIGURE 27-71. Operative options for pseudarthrosis of the tibia. **A:** Solid IM rod fixation. **B:** Circular fixation with bone transport and compression. **C:** Vascularized fibula graft.

In selecting an appropriately sized rod, consideration should be given to the desired length of rod based on the need to transfix the ankle joint and the amount of growth remaining in the distal tibia (Fig. 27-73). In smaller children and those with distal defects, fixation across the ankle joint for 1 to 2 years may be desirable to minimize stress on the pseudarthrosis site, which facilitates consolidation. Distally, the rod should extend into the talus, calcaneus, or both. Proximally, the rod should remain within the proximal tibial metaphysis and not cross the physis.

The rod may be advanced across the ankle joint once the defect has united (typically not until ≥ 2 years following placement) to allow ankle motion. Ideally, there will have been sufficient growth in the proximal tibia so that the rod can be

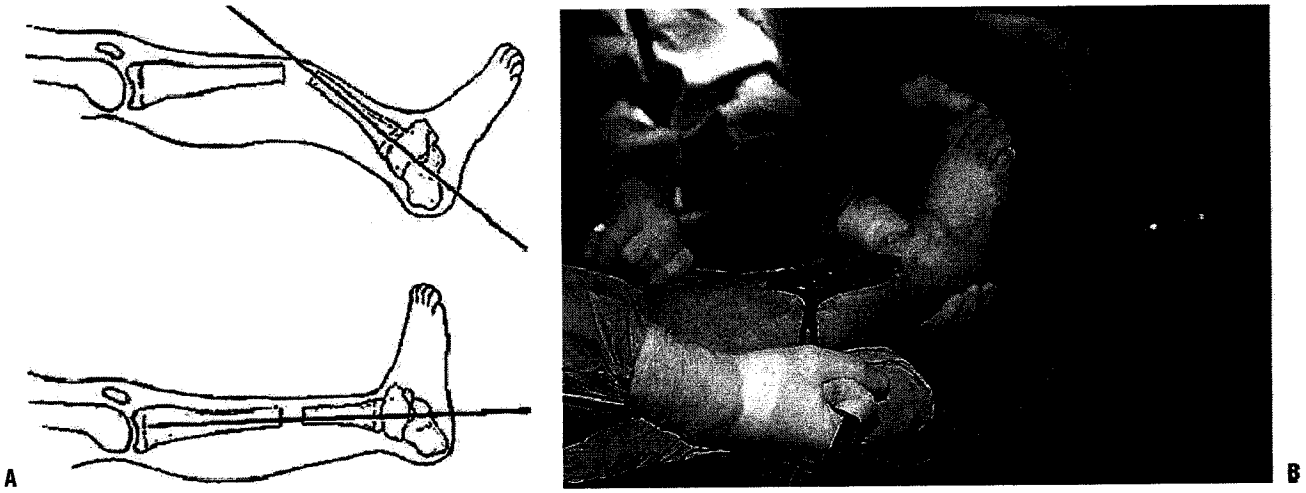


FIGURE 27-72. Technique of solid IM rod fixation. **A:** After excision of the pseudarthrosis, the Williams rod is inserted, antegrade, through the distal tibia, talus, and calcaneus and exits through the heel pad. Care is taken to maintain the foot in a neutral, plantigrade position as the rod passes across the ankle and subtalar joints. The rod is then passed into the proximal fragment, just below the proximal tibial physis. If the tibia is distracted, a fibular osteotomy is performed to allow contact across the tibia. **B:** The tibial surfaces are opposed.

advanced into the tibia and not cross the proximal tibial physis. Occasionally, the presence of deformity in the proximal tibia necessitates an additional osteotomy in the proximal tibia to assure IM passage of the rod and anatomic alignment of the tibia. An intact fibula is not osteotomized unless it distracts the tibial fragments. If the fibula is not intact, it may be possible to stabilize it with an IM rod. A small-diameter K-wire is used for fibular fixation and is placed into the distal fragment through a separate incision. The wire is directed antegrade and out of the distal tip of the fibula, then in a retrograde direction into the proximal fragment. Fibular fixation adds stability to the construct (162, 163).

The previously harvested iliac bone graft strips are then placed circumferentially around the pseudarthrosis site and secured with absorbable suture as a barrel-stave construction. Bone morphogenic protein (BMP) (approximately 6 to 10 mg (166, 167)) may be incorporated into the placement of the autograft. By protocol for children ≥ 5 years and younger, a one and one-half spica cast is applied to assure minimal rotational stress at the pseudarthrosis site. The spica cast is replaced with a long-leg cast after 6 to 8 weeks, and cast immobilization is discontinued approximately 3 to 4 months post-op. Older children are treated with long-leg casts for the entire 3 to 4 months. Once cast protection is discontinued, the involved extremity is protected with a custom-fabricated KAFO with a locked ankle joint and free knee joint (Fig. 27-73F). With longitudinal growth of the distal tibia, the distal end of the rod "migrates" proximally. Therefore, the anticipated remaining growth determines the appropriate placement of the distal end of the rod at the time of surgery.

The presence of the rod across the ankle joint and in the hindfoot has a considerable advantage in providing optimal immobilization and protection of the consolidating pseudarthrosis. Refracture may occur; although spontaneous healing with plaster immobilization may occur it is not always assured, and repeat grafting, with or without rerodding, may be required. With longitudinal growth of the tibia, the distal end of the rod "migrates" more proximally and eventually will be positioned in the distal tibia. As the tip of the rod crosses the ankle joint, the potential for disruption of articular cartilage exists. To minimize such an occurrence, the rod can be surgically pushed across the ankle joint as the tip approaches the articular surface of the talus. This adjustment is easily accomplished with a slightly larger diameter, concave-tipped, IM pusher rod inserted through the hindfoot and guided with C-arm assistance until it docks into the distal end of the indwelling Williams rod. Simple tapping on the "pusher" rod will drive the Williams rod proximally out of the hindfoot, across the ankle just to the new distal extent in the tibial metaphysic (Fig. 27-73G–I).

On occasion, despite consolidation of the pseudarthrosis and growth of the tibia, the rod does not migrate. If this occurs, the rod can be stabilized to the shaft of the proximal tibia with either a small portion of methylmethacrylate or small-fragment interference screws. If consolidation does not occur, the pseudarthrosis site should be explored and regrafted. If the rod is grossly loose, it should be replaced in a larger diameter rod. A fresh autogenous bone graft along with BMP is placed around the pseudarthrosis site (166, 167) and the above post-op immobilization protocol is adhered to.

Valgus deformity of the tibia or the ankle is common and can compromise the functional result. This valgus deformity is part of the natural history of CPT that has a deficient fibula, and therefore lacking lateral support. It is not a result of traversing the physis with the rod. Long-term bracing protects the distal tibia and ankle and is mandatory during growth to minimize the risk of valgus deformity. This is particularly true once the rod no longer crosses the distal tibial physis. Valgus has been satisfactorily treated by the placement of staples or an eight-plate across the medial tibial physis, either proximally, distally, or both (Fig. 27-73J). The valgus deformity usually improves over a 1- to 2-year period. Once correction is achieved, the staples are removed. A transverse tibiofibular syndesmosis screw is inserted at the time of staple insertion or removal if the distal fibula remains nonunited or has migrated proximally, compromising ankle stability. With this approach, symmetric growth of the distal tibia has generally continued and the valgus deformity has not recurred.

Leg-length inequality secondary to CPT is often significant (162, 164). In a recently reported review of our CPT treatment experience, 11 of 21 patients had a notable limb-length inequality (164). The average discrepancy in these 11 patients was 5 cm and ranged from 2 to 9 cm. Six of these patients were treated by epiphysiodesis for an average predicted leg-length discrepancy at maturity of 4 cm. Two patients underwent a proximal tibial lengthening. Two patients with leg-length discrepancies of 6 and 9 cm underwent amputations at parental request, one at 8 years of age and the other at 15 years of age.

A satisfactory functional outcome has been achieved in 16 of the 21 patients who were followed up for an average of 14 years (164) (Fig. 27-73K,L). The remaining five patients have had an amputation because of limb-length inequality (two patients), refracture with persistent nonunion (two patients), or significant residual angulatory deformity (one patient). The quality of ankle motion and of gait has varied considerably. The best results have been noted in those patients in whom the tibia is anatomically aligned and the foot is plantigrade. Successful management requires prolonged stabilization of the pseudarthrosis which may require replacement of a smaller IM rod with a larger rod and use of a clamshell orthosis to reduce stress on the pseudarthrosis (Figs. 27-74 to 27-80, 27-81).

Two comparable reports document the outcome for a total of 44 patients utilizing the Williams rod technique (163, 164); results were generally satisfactory. More recently treated patients fared better than those patients treated earlier in both of these two series of patients. This might be anticipated, given the modifications made in techniques based on earlier experience. If a functionally stable consolidation does not occur, a repeat attempt at achieving a union should be attempted sooner than later. Surgical advancement of the rod across the ankle (after clinical consolidation is present) seems to optimize ankle range of motion and function. Secondary deformities such as ankle valgus and leg-length discrepancy are anticipated and managed surgically in a timely fashion. More recently,

(*Text continued on page 1322*)

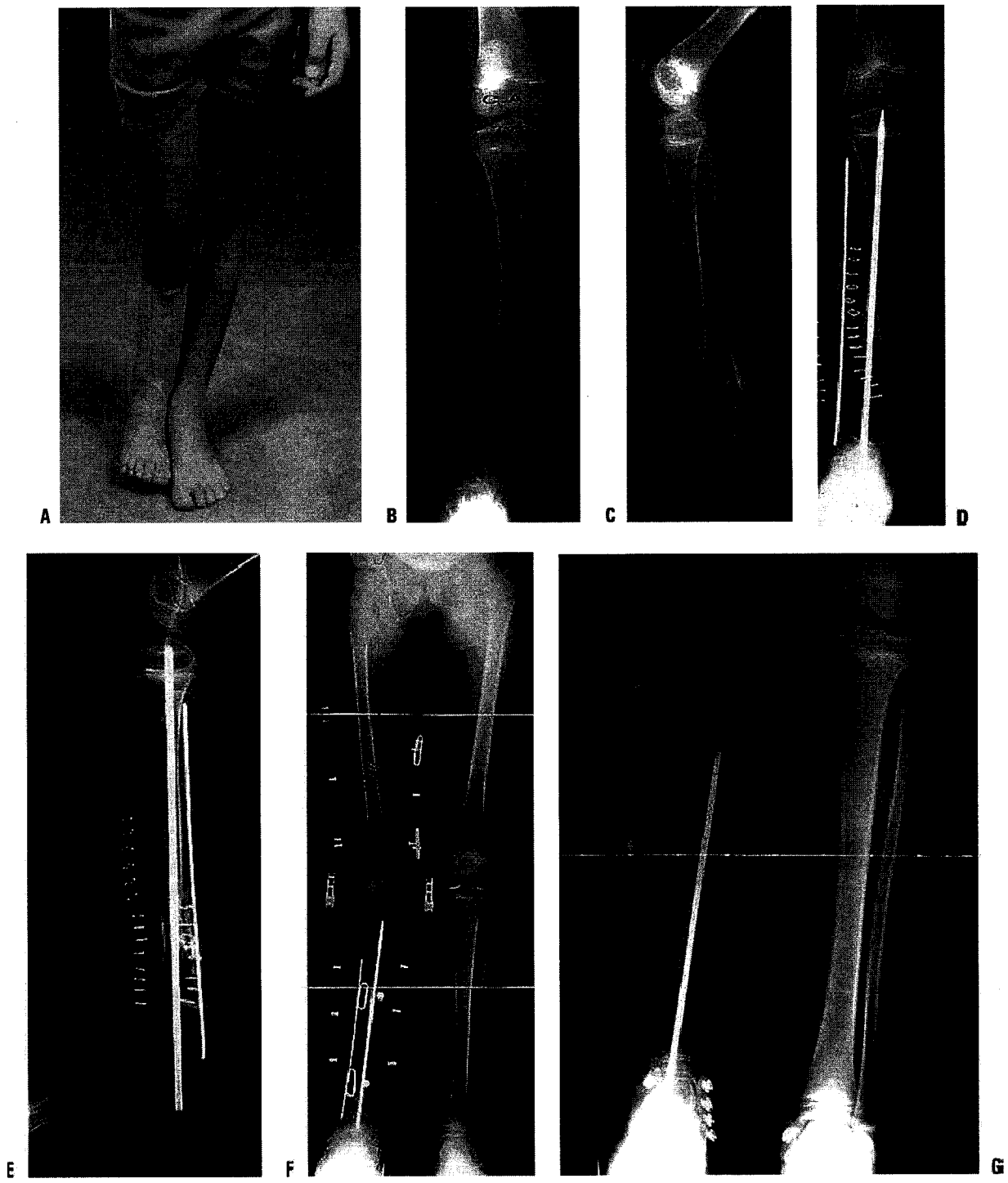


FIGURE 27-73. **A:** Treatment of a tibial pseudarthrosis with a solid IM rod. Treatment includes stabilization of the fracture, establishment of a source of healthy bone, and maintenance of alignment. **B:** Atrophic pseudarthrosis of the tibia and fibula. **C:** Boyd type II or Crawford II-C dysplasia. **D:** The pathologic bone was resected; a Williams rod was used in the tibia and a Steinman pin in the fibula. Iliac crest graft was packed around the pseudarthrosis. **E:** The ankle and foot are held in a neutral position during the placement of the rod. Transfixation of the ankle and subtalar joints increases the stability of the pseudarthrosis. **F:** A spica cast is applied postoperatively and a total contact orthosis used once union is established. Ankle motion is prohibited as long as the rod remains across the subtalar and ankle joints. A KAFO is used in smaller children. A patellar-tendon-bearing (PTB) orthosis can be used in most children over 7 years of age. **G:** With growth, the rod typically is drawn proximally and comes to lie within the tibia. In this case, the rod has remained with the distal fragment and continues to cross the ankle. Note the increased distance from the rod tip to the proximal tibial physis.

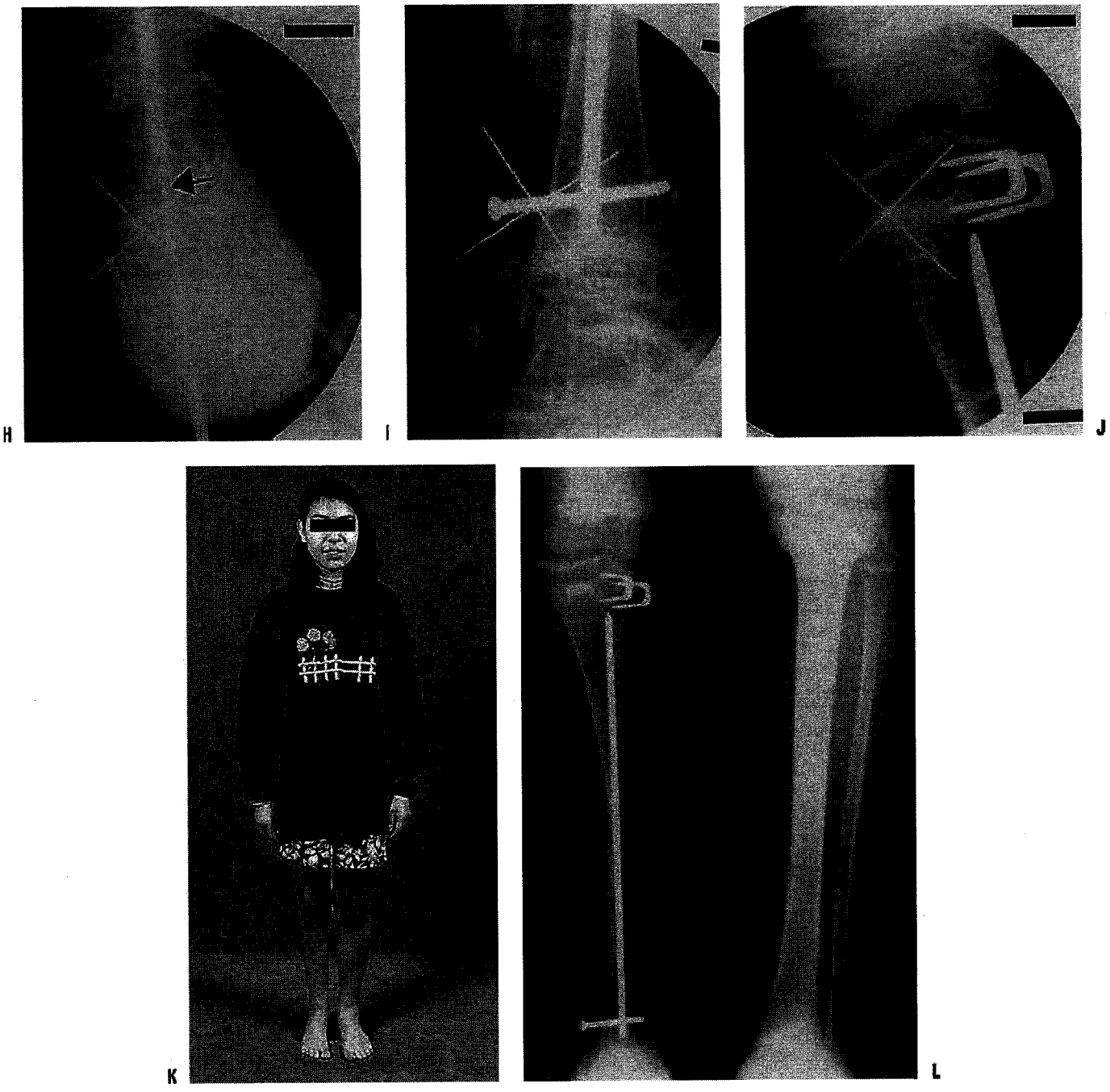


FIGURE 27-73. *(continued)* **H:** A second rod can be used to push the Williams rod across the ankle. Image intensification is helpful in guiding placement. **I:** A syndesmosis screw was added to stabilize the persistent fibular pseudarthrosis. **J:** Hemiepiphyseal stapling of the proximal and/or distal medial tibia is used to correct valgus. **K:** This comprehensive treatment has resulted in a stable, healed pseudarthrosis. **L:** Satisfactory tibial alignment and stabilization of the pseudarthrosis have been achieved. Limb-length inequality can be managed with contralateral epiphysiodesis. Lengthening of the affected leg may be complicated by delayed bone formation and healing.

Repair of Congenital Pseudarthrosis of the Tibia Using the Williams Intramedullary Rod (Figs. 27-74 to 27-80)

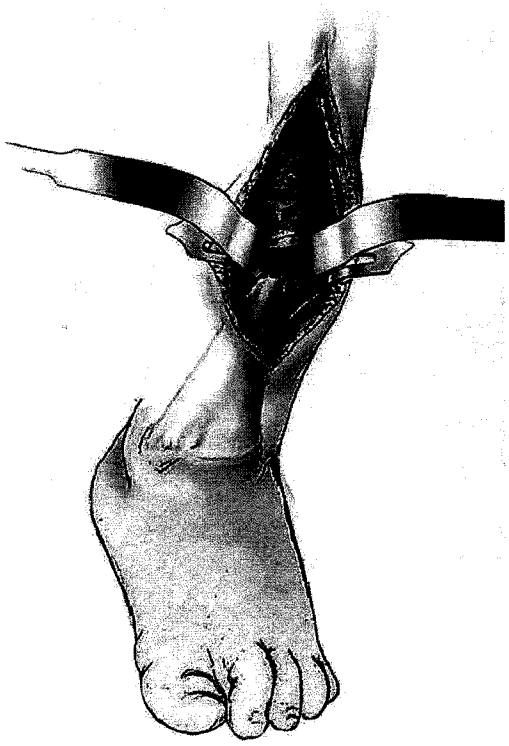


FIGURE 27-74. Repair of Congenital Pseudarthrosis of the Tibia Using the Williams Intramedullary Rod. The patient is placed supine on a radiolucent table after obtaining an iliac crest bone graft. An 8 to 10 cm anterior incision is made centered over the tibial pseudarthrosis. The tibia is exposed subperiosteally and curved retractors placed around the tibia. Fibrous tissue within the pseudarthrosis is removed using sharp dissection and rongeurs. It may be necessary to remove some of the bone at the pseudarthrosis, but radical resection of the pseudarthrosis is neither necessary nor desireable.

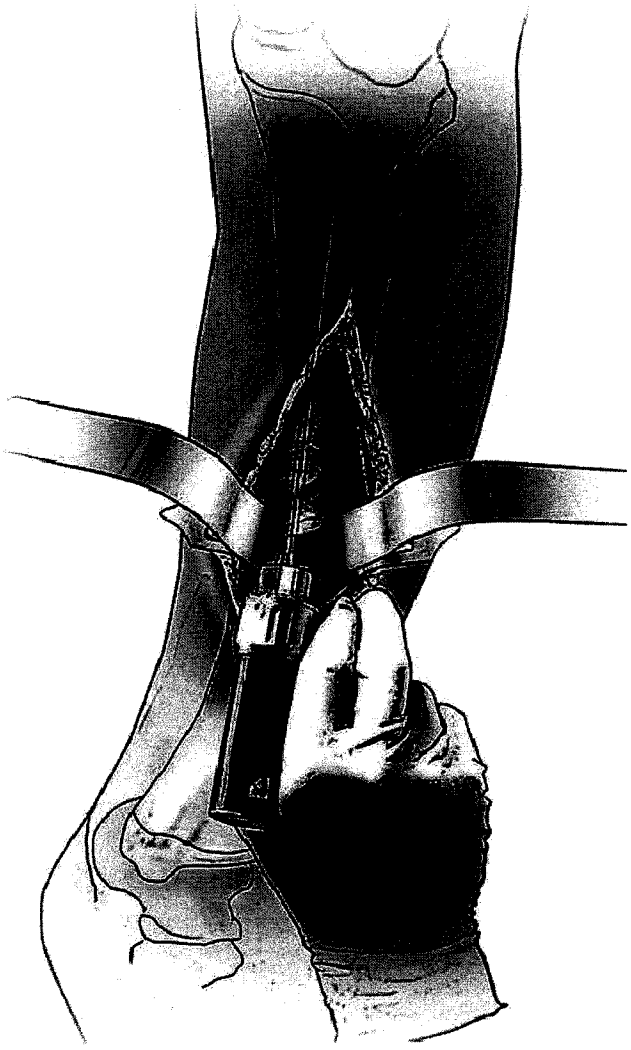


FIGURE 27-75. A drill bit is used to establish entry into the medullary canal. Longer, larger drill bits are used to enlarge the medullary canal. The image intensifier is used to assure that the drill bit remains within the central canal on both the AP and lateral views and remains perpendicular to the tibial physes. Drilling extends proximally to the tibial physis, but does not breach it.

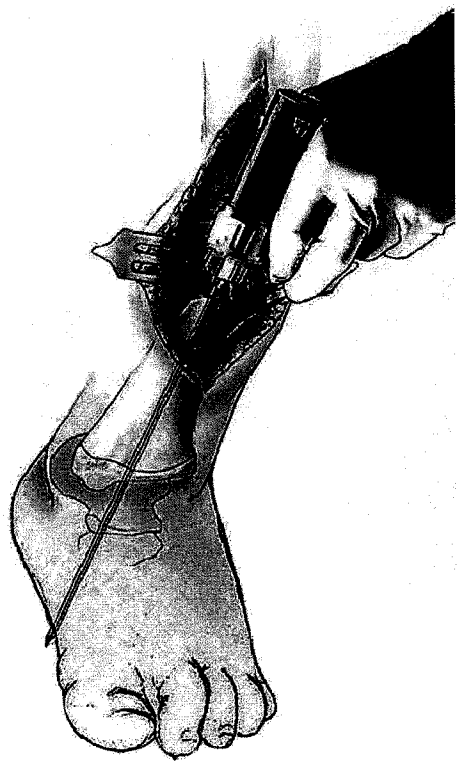


FIGURE 27-76. Distally, it continues across the tibial-talar and subtalar joints, taking care to hold the foot in neutral in both the AP and lateral views.

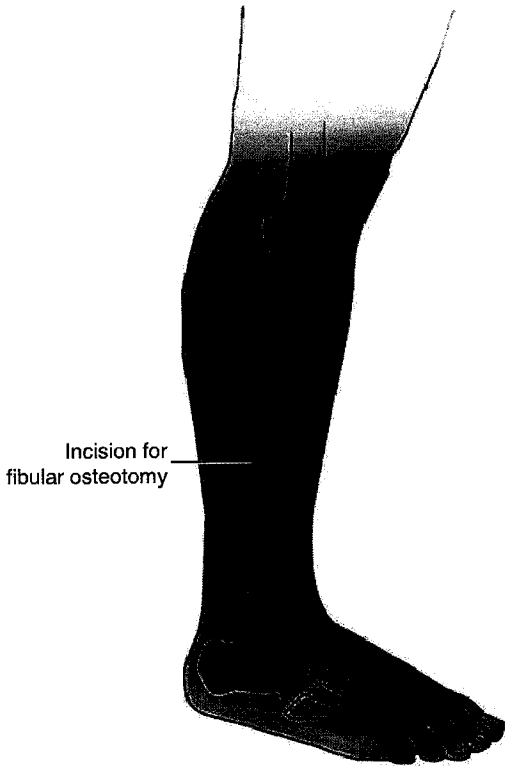


FIGURE 27-77. If the fibula is intact, it may be necessary to complete an osteotomy through a separate lateral incision. At times a portion of the fibula will be resected to facilitate manipulation of the tibial for drilling the medullary canal and provide contact between the reduced tibial fragments. If feasible, the fibula is later stabilized with an intramedullary Kirschner wire.

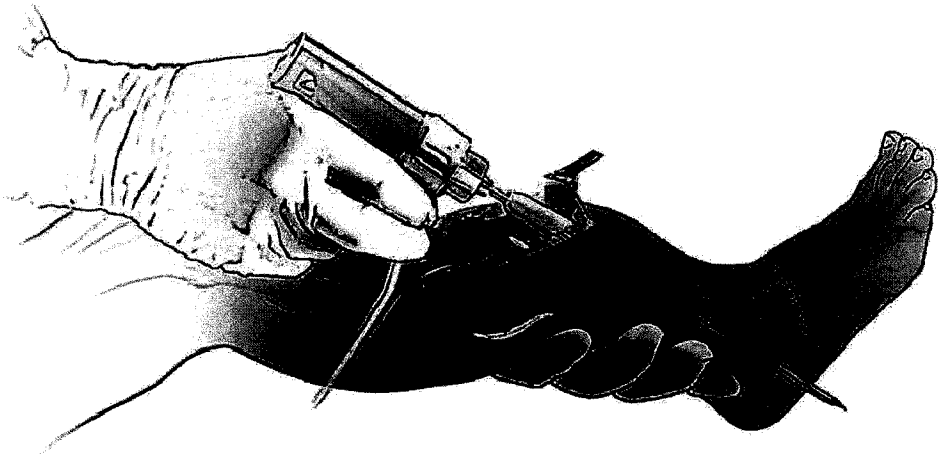


FIGURE 27-78. The Williams rod consists of two sections which are joined by a threaded connector: one section with a male connector is used to introduce and maneuver the proximal section of the rod which will remain to stabilize the tibia. The length of rod needed is estimated based on the lateral radiograph. Ideally the Williams rod abuts, but does not breach, the proximal tibial physis and the distal, female connector is within the talus. The optimum diameter is chosen based on the width of the canal after resection of the pseudarthrosis. Once the medullary canal is prepared the assembled rod is drilled, antegrade, into the distal fragment. The foot and ankle are held in neutral position as the rod passes across the joints and exits the bottom of the foot. A small incision facilitates exit of the rod.

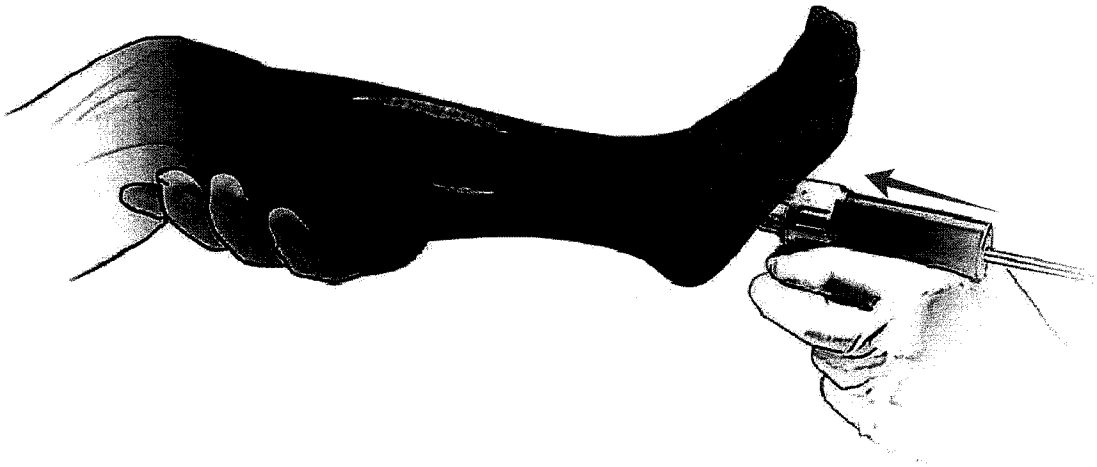


FIGURE 27-79. The drill is placed on the male/distal section and the rod drawn distally to allow reduction of the tibial fragments. The proximal/female section is passed into the proximal tibia. The rod should be central within the canal in both segments and in both the AP and lateral views. The connector is partially disengaged to assess the position of the rod within the calcaneus. It may be necessary to distract the tibial fragments in order to grasp the rod as the distal end is unscrewed. Changing the drill setting to "ream" and reversing the power makes this easier.

FIGURE 27-80. Once the rod is in the optimal position, the male end is removed. Bone graft is placed circumferentially around the pseudarthrosis site. The fibula is stabilized with a Kirschner wire. A suction drain is used. A spica cast is applied in children <6 years of age. A long leg cast is used in older children.

rh BMP-2 (INFUSE; Medtronic Sofamor Danek, Memphis, TN) has been used. In comparison to our previous reported results, earlier (and lasting) consolidation was reported. We have also noted earlier callus formation in a small number of our patients with similar use of BMT-2.

A recent gait analysis assessment of the outcome of treatments of CPT cited relatively poor push off following IM rod treatment (168). Gait analysis of our more recently treated patients has shown a better outcome concerning push-off ability. We now utilize an active ankle-strengthening program once the rod is positioned within the tibia.

Circular External Fixation and Bone Transport. Ilizarov pioneered the use of a circular external fixator that used a combination of compression, distraction, resection of the pseudarthrosis, and bone transfer (Fig. 27-82). Subsequently, numerous authors have refined this technique (198–172). The report by Paley et al. (171) on their initial experience with 16 patients cited a primary union rate of 94% after one procedure and 100% after two. The mean age at treatment was 8 years. Five refractures occurred, and all were successfully treated with additional procedures. Paley now incorporates the use of an IM rod along with the frame assembly in the treatment of pseudarthrosis. The rod is left in place at the time of fixator removal, providing additional protection against refracture and recurrent deformity.

In a multicenter study, Boero et al. (173) reported failures in 33% of patients with CPT managed by Ilizarov technique. In their study, all 21 patients had neurofibromatosis. The best results were obtained with sclerotic and normotrophic bone where all six tibias had early consolidation (10 to 12 months) and did not refracture. In contrast, only 5 of 11 tibias with an hourglass appearance eventually healed. In the same series, consolidation was obtained in 86% of those patients who were older than 5 years at the time of operation and only 14% of those younger than 5 years.

Dahl (174) reported on 21 of his surgical patients, followed up to maturity. To date, he has observed a satisfactory outcome of treatment, that is, sustained consolidation and independent ambulation in 20 of these patients. One patient had an amputation. The average age at the time of treatment was 11 years (range,

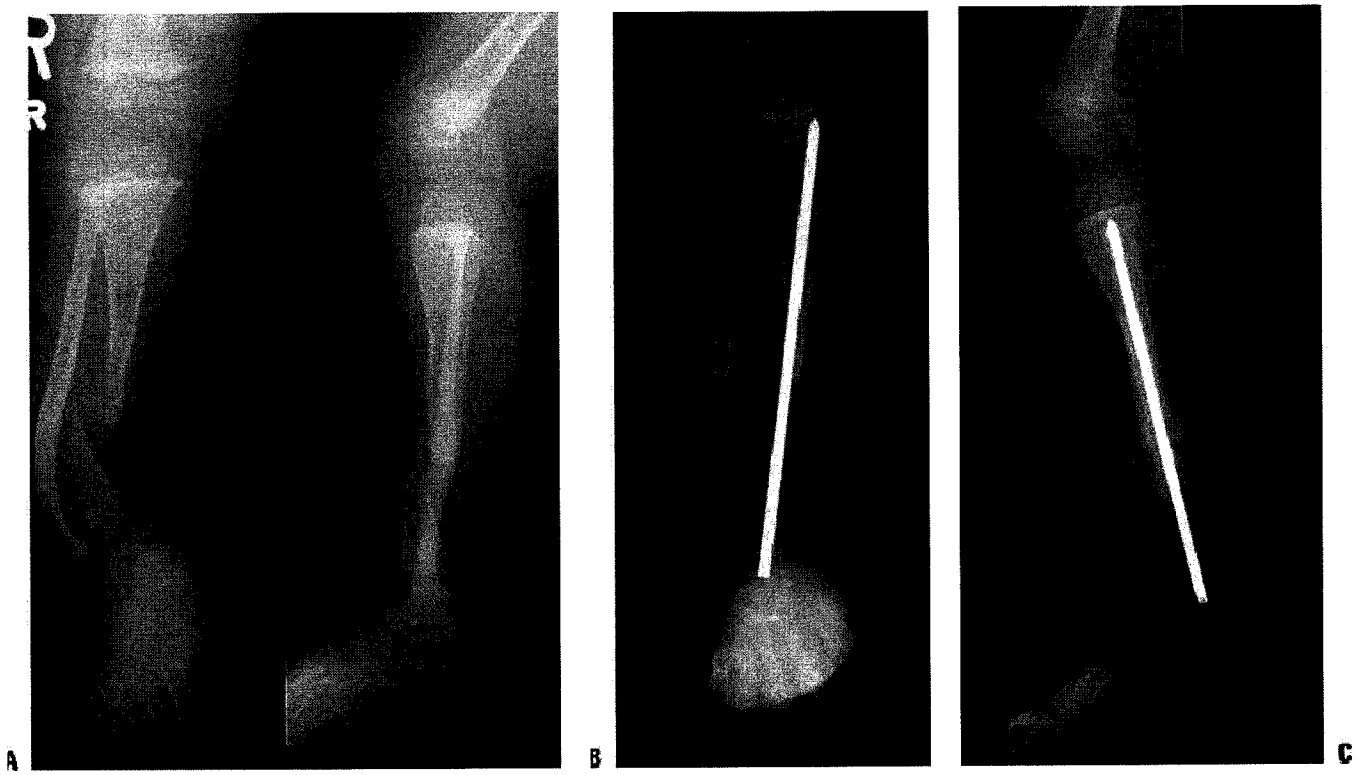


FIGURE 27-81. Tibial pseudarthrosis occurring in an infant without neurofibromatosis. Fracture was first noted at 1 month of age, no healing noted despite immobilization and use of total contact orthosis. **A:** AP and lateral radiographs at 10 months of age show well-established tibial pseudarthrosis. Walking was impeded by the unstable tibia. **B, C:** AP and lateral radiographs at 15 months of age, 3 months following operative treatment with a Williams rod and autologous bone graft. **D:** The need for revision to a larger rod is anticipated as growth proceeds. The rod is no longer sufficient to stabilize the pathologic bone and pseudarthrosis recurs. **E**: Revision using similar technique with replacement by a larger diameter, longer IM rod. **F.** With continued growth of the tibia, the rod no longer stabilizes the ankle and subtalar joints, increasing stress at the pseudarthrosis site. Without the additional protection of a total contact orthosis, recurrent fracture is anticipated as demonstrated here. **G, H.** Three years after revision and use of a PTB total contact orthosis, healing is maintained as seen in the AP and lateral radiographs.

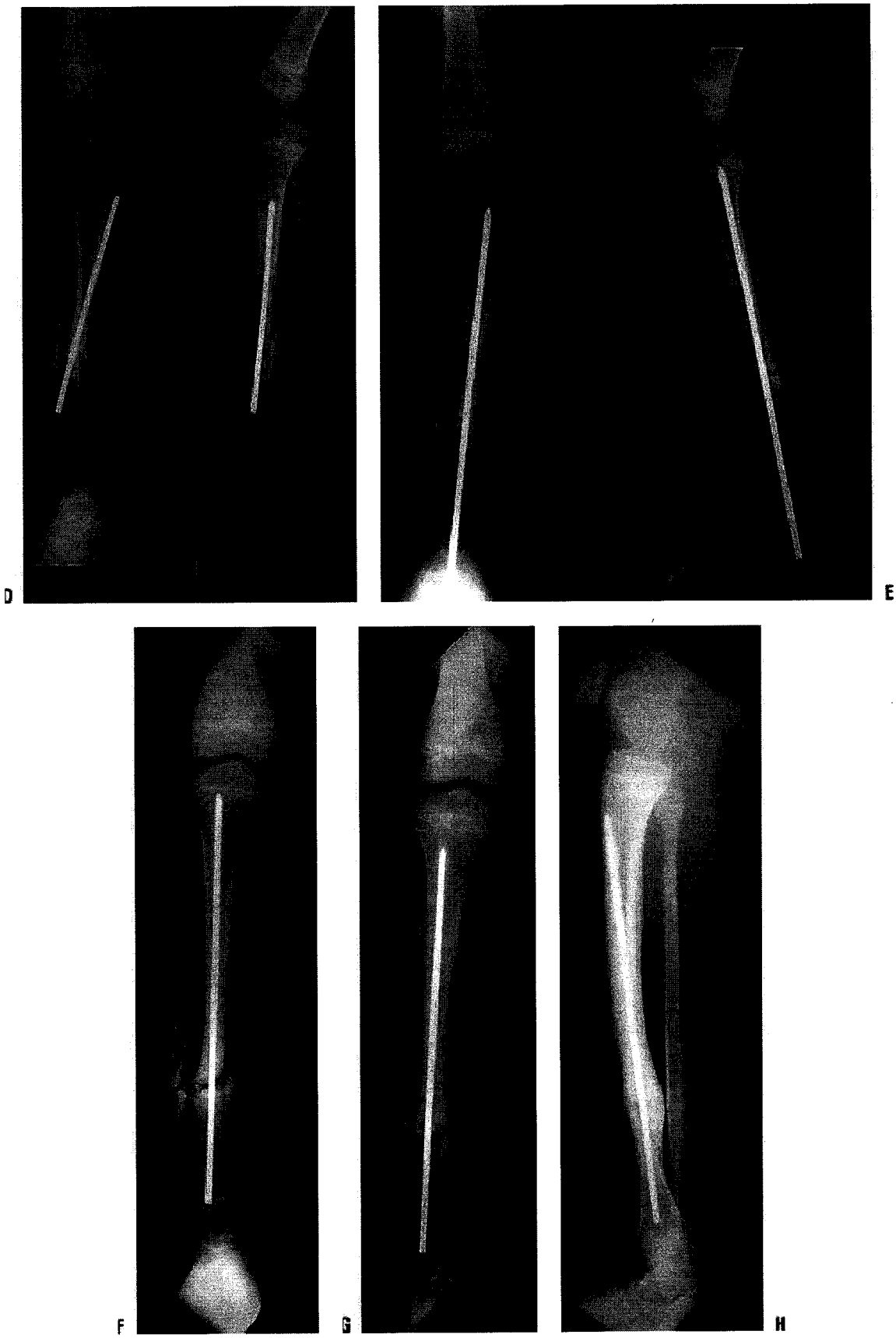


FIGURE 27-81. (*Continued*)

8 months to 29 years), and 18 of 21 patients had multiple prior surgical procedures. Dahl noted refractures in 33% of the first 12 patients he treated. Refinements in his techniques led to fewer fractures. To achieve prompt and lasting union, he made the following recommendations: (a) resection of the pseudarthrosis and pathologic periosteum, (b) creation of a stable intrinsic fit of the bone end, (c) bone graft of the pseudarthrosis to maximize the cross-sectional area, (d) ideal axial alignment to eliminate bending forces, (e) judicious correction of length and angulatory deformity through the proximal tibia, and (f) prophylactic IM pinning after fixator removal. The IM rod is placed 8 weeks after fixator removal to reduce the risk of contamination.

Vascularized Fibula Graft. Vascularized composite donor tissue transfers have been utilized for the past 100 years in the surgical treatment of CPT (175–181). In the last 30 years, there have been notable refinements in microsurgical techniques applicable to the treatment of CPT. Early reports demonstrated that a free vascularized fibular graft taken from the opposite extremity could successfully be implanted to provide a biologic bridge across a CPT. Tolo's current indications for use of a vascularized fibula graft are cases of CPT in which other techniques have failed and/or there is marked bony atrophy or measurable gap at the pseudarthrosis site (178). His recommended technique for implanting a free vascularized fibular graft for a CPT includes the following essential steps (Fig. 27-83). Preoperative arteriography of both legs is obtained. Two surgical teams are used to facilitate treatment by allowing simultaneous harvest of an autologous bone graft from the contralateral fibula and preparation of the pseudarthrosis site. The distal fibula on the involved side is stabilized with a screw into the tibia. The pseudarthrosis is resected extraperiosteally to expose normal bone. Next, the harvested fibula is dowel fitted into the host tibia and fixed with a plate or an external fixator. Vessels are anastomosed, and a skin paddle is used to monitor blood flow. A spica cast is used for 2 to 3 months and a clamshell orthosis for several years.

Using the above protocol, Weiland and Tolo et al. (178) were able to achieve union in 18 of 19 pseudarthroses, observed at an average follow-up of 6.3 years. Several recent series have reported on treatment of CPT by a vascularized fibula graft. In a recent report of six patients with Crawford type IV atrophic pseudarthrosis, Dimeglio et al. (181) added an IM rod to his technique of fibular transfer to maintain length and improve stability of the reconstruction.

CPT has been and will continue to be a very challenging problem. A stable consolidation is essential for a long-term satisfactory functional outcome. Each case is unique, and as such, the treatment plan must often be modified. The newer techniques of IM stabilization, external fixation with bone transport, and vascularized fibular graft have been refined and successfully used by a few. All of these authors have had considerable experience in learning how to apply and adapt their particular surgical technique to the variables of each individual case. Early results demonstrate satisfactory outcomes with these refined surgical techniques and are encouraging. However, as Boyd and Sage (182) suggested years ago, the true success of treatment of CPT in the growing child can only be known by following up these patients until maturity.

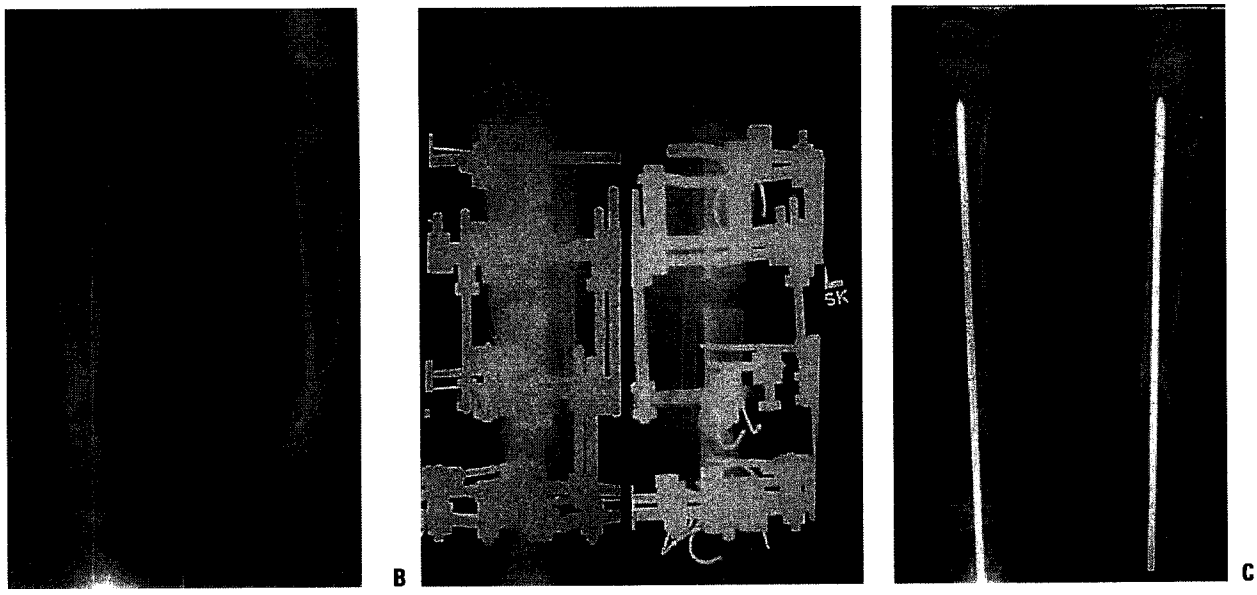


FIGURE 27-82. **A:** Tibial pseudarthrosis recurred following multiple bone graft procedures and temporary IM pinning in this 6-year-old with neurofibromatosis. **B:** The pseudarthrosis was resected. The circular frame was used to apply compression across the distal site and to lengthen proximally. **C:** Subsequently, an IM rod was placed across both osteotomy sites in the tibia and the ankle. A solid AFO has also been used. Alignment and bone union have been maintained as shown in these radiographs 2 years later.

Amputation. Amputation can be a viable and prudent alternative. Amputation should be considered when there is failure to obtain consolidation despite application of these described surgical techniques, by surgeons comfortable in their use or if the outcome is otherwise unsatisfactory for the patient as in those with poor limb function or severe limb-length inequality. Traditionally, a below-knee amputation is performed. Crawford and Jacobsen et al. (183) recommended preserving the hindfoot with a Boyd or Syme procedure, which preserves the length of the residual limb and uses a prosthesis to stabilize and protect the pseudarthrosis. We have found this approach to amputation to be successful only in one of three cases. In one satisfactory outcome, we were able to stabilize the pseudarthrosis and consolidation was achieved. In this unique circumstance (i.e., despite previous failed surgical attempts), the remaining tibial fragments were sufficient for stabilization with an IM rod and small plate.

Congenital Pseudarthrosis of the Fibula

Definition. Congenital pseudarthrosis of the fibula (CPF) usually occurs in association with CPT. It may also occur as an isolated entity, but very rarely (Fig. 27-84). Early in childhood, CPF can present with a varus deformity of the ankle. Once a fibular pseudarthrosis becomes established, the deformity converts from varus to valgus. Older children who present with CPF usually have complaints of an abnormal gait or because a valgus deformity of the leg and a prominent fibula are noted (184–188). The condition is frequently linked to neurofibromatosis. The tibia may appear either normal or abnormal.

Pathoanatomy. As with CPT, CPF may occur after a fracture through pathologic bone or through an area of mesodermal maldevelopment (184). Dooley et al. (184) reported on four patients with gradations in the severity of the condition: (a) fibular bowing without pseudarthrosis, (b) fibular pseudarthrosis without ankle deformity, (c) fibular pseudarthrosis with ankle deformity, and (d) fibular pseudarthrosis with late development of tibial pseudarthrosis. Dooley grades 1, 2, and 3 are forms of isolated CPF and grade 4 begins with a fibular pseudarthrosis, often following simple fracture, and later develops a tibial pseudarthrosis CPT (184).

Treatment. Isolated pseudarthrosis of the fibula in a growing child (Dooley grades 2 and 3) can be associated with increasing ankle valgus deformity. Ideally, the osteosynthesis should be performed before ankle valgus has developed (excision of fibular pseudarthrosis, autologous bone graft and IM rod or small plate fixation). Growth modulation of the distal, medial tibia should be considered if ankle valgus is present or develops subsequently. This can be accomplished with an eight-plate or epiphyseal staples at the same time as treatment of the fibular pseudarthrosis or as a second stage. Osteosynthesis should not be done if there is distal varus deformity. If osteosynthesis is not possible because of severe involvement of the fibula (181), a distal tibia to fibula synostosis should be done to prevent further ankle valgus deformity. In skeletally mature patients with residual valgus deformity, a correcting osteotomy is recommended, utilizing a circular frame (181, 185).

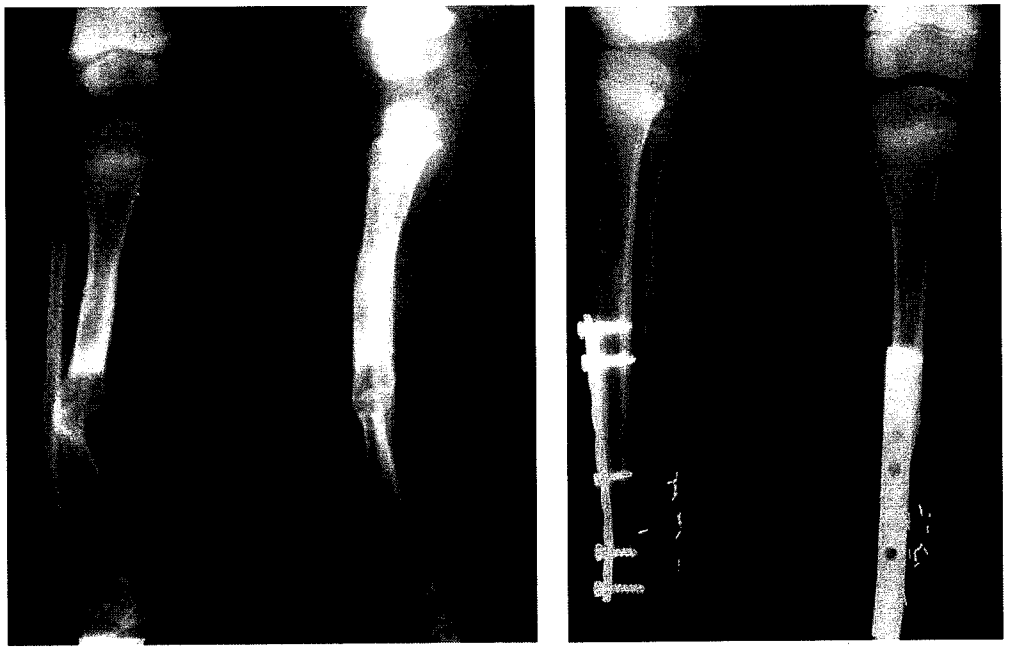


FIGURE 27-83. A: This film shows another fracture resulting from anterolateral bowing. Note the quality of the bone at the pseudarthrosis site. **B:** A contralateral vascularized fibular graft has been used to bridge the pseudarthrosis. Healing proximally and distally has occurred.

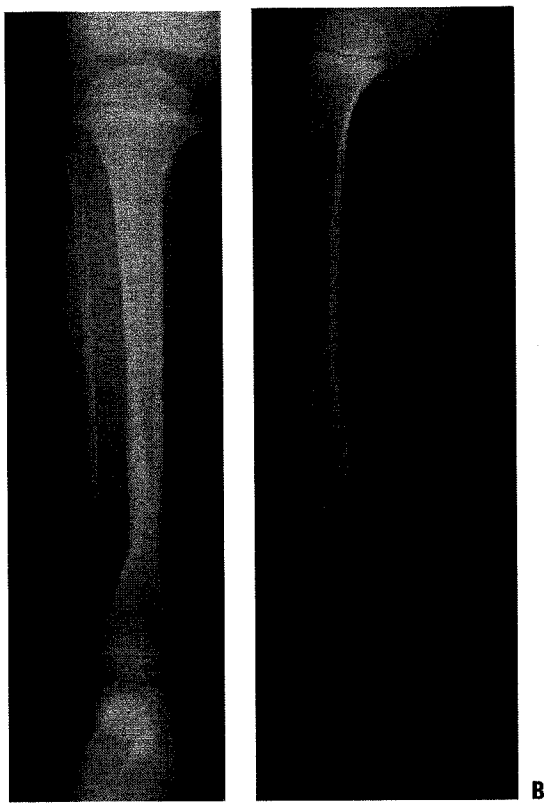


FIGURE 27-84. A: Rare presentation of a fibular pseudarthrosis. **B:** The tibia is also abnormal. Most are associated with neurofibromatosis.

Posterior Medial Bow of the Tibia

Definition. Posterior medial bow (PMB) of the tibia is a congenital anomaly, associated with a calcaneovalgus foot deformity (189–192) Posterior medial bowing typically presents as a more notable deformity in infancy than anterior lateral bowing. However, unlike its counterpart, posterior medial bowing is not associated with pathologic fracture or pseudarthrosis of the tibia. Predictably, the posterior medial bowing of the tibia and fibula resolves. However, considerable leg-length discrepancy typically develops (189, 190). This residual deformity presents the greatest need for orthopaedic management.

Etiology. The pathogenesis of PMB is unclear. Mechanical forces (the dorsiflexed foot against the tibia) and embryologic vagaries of tibial development (circulatory or limb bud anomaly) have been suggested as causes but remain unproven. The rapid decrease of bow in the tibia in the first 6 to 12 months supports mechanical factors as a cause of bowing (189, 191). However, it cannot account for the growth inhibition.

Assessment. What is obvious at birth is the extreme dorsiflexed position of the foot against the tibia (Fig. 27-85). Plantar flexion of the foot may be limited. The bow is most easily felt by palpation of the anterior border of the tibia. A normal infant has an anterior bow, which is distinct from the posterior defect palpated in infants with PMB. A skin dimple is often present over the posterior apex of the bow. Shortening of the affected tibia may not be readily apparent in newborns, but is expected to increase as the child grows.

Evaluation should include AP and lateral radiographs of both tibias. The severity of the posterior and medial deformity can be measured and a percent inhibition of tibial growth calculated. Serial measurement of tibial length in infants is more accurate when the lateral tibial radiograph is used. Orthoradiographs or similar radiographic techniques can be used for serial assessments of limb-length inequality. The posterior angulation usually remodels, often producing a mildly "S-shaped" tibia (Fig. 27-86). The medial angulation is less likely to resolve completely, and significant residual valgus may remain. Growth inhibition is constant as the absolute leg-length difference increases with growth (190).

Differential Diagnosis. There is little to consider in the differential diagnosis of posterior medial bowing. Its direction is clearly different from the more serious pathology of anterolateral bowing. Posterior medial bowing may initially be overlooked in the presence of severe calcaneovalgus foot deformity. Occasionally, adolescents will present with limb-length inequality and mild ankle valgus, the result of previously unrecognized posterior medial bowing. Metabolic bone disease such as osteogenesis imperfecta rarely results in this type of bowing deformity.

Treatment. Initial treatment of infants is primarily passive stretching of the foot. Serial cast application may be occasionally used for severe deformities. The bowing generally corrects rapidly in the first few years (189–191). Rarely, extreme dorsiflexion and valgus persist such that plantigrade weight bearing cannot be accomplished. In such cases, a solid AFO may facilitate weight bearing for walking-aged children (190, 191). As tibial length inequality increases, a shoe lift may be needed to balance the pelvis. Gradual contracture of the plantarflexors may occur as a compensation for leg-length discrepancy. Passive stretching is usually adequate treatment in young children.

Recently, 43 patients with PMB were reviewed at the Shriners Hospital for Children in St. Louis. All had some degree of limb-length inequality. The minimum discrepancy was 1.4 cm at 1 month of age, and the projected difference at maturity ranged from 3 to 8 cm. Pes planovalgus that was seen in some children resulted in decreased foot height as well. This degree of inequality is best managed by surgical equalization, either by shortening the long tibia by epiphysiodesis or by lengthening the short tibia. Residual valgus deformity can also be corrected. In the past 10 years, most patients have chosen lengthening and about half have had bi-level osteotomies to allow lengthening proximally and deformity correction distally. The others have been treated with epiphysiodesis, often preceded by proximal medial tibia hemiepiphyseal stapling to correct residual valgus deformity (190).

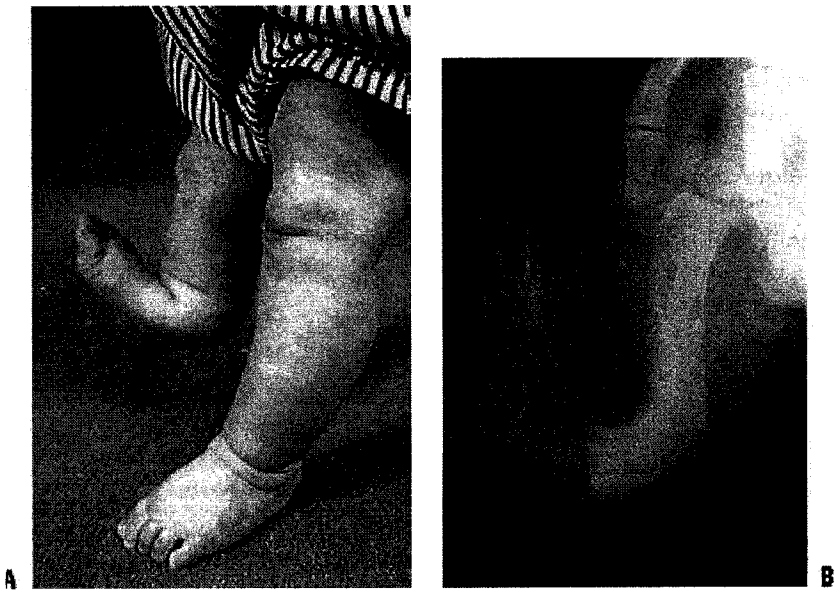


FIGURE 27-85. **A:** Infants with posteromedial bowing usually present because the foot is in an abnormal, severely dorsiflexed position. The bow can be palpated along the subcutaneous border of the tibia. A skin dimple is usually present over the apex of the bow. Shortening of the leg may not be as obvious as the bowing deformity. **B:** This infant's lateral radiograph shows how the foot seems to nestle against the curve of the tibia. The bone appears normal or may show signs of remodeling with thickening of the anterior cortex and smoothing posteriorly.

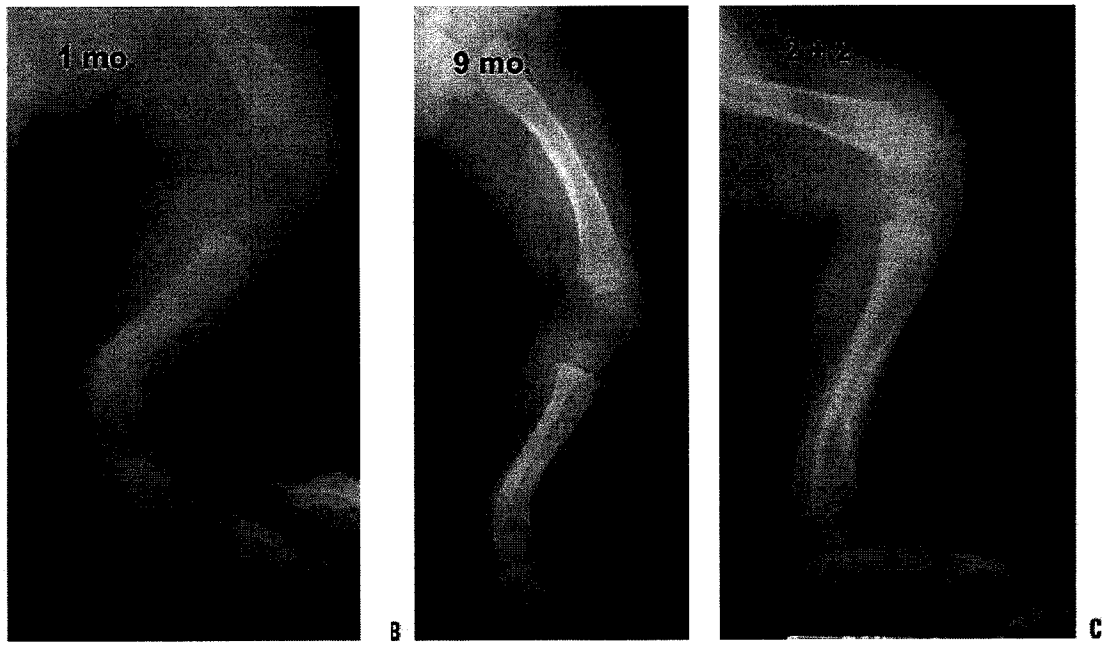


FIGURE 27-86. **A–E:** Composite serial lateral radiographs show the degree of spontaneous resolution of the posterior bow. Improvement is often very dramatic within the first year. Similarly, there is improvement in the medial component; however, this bow may not fully resolve, resulting in residual valgus. Posteromedial bow is not associated with risk of pathologic fracture.

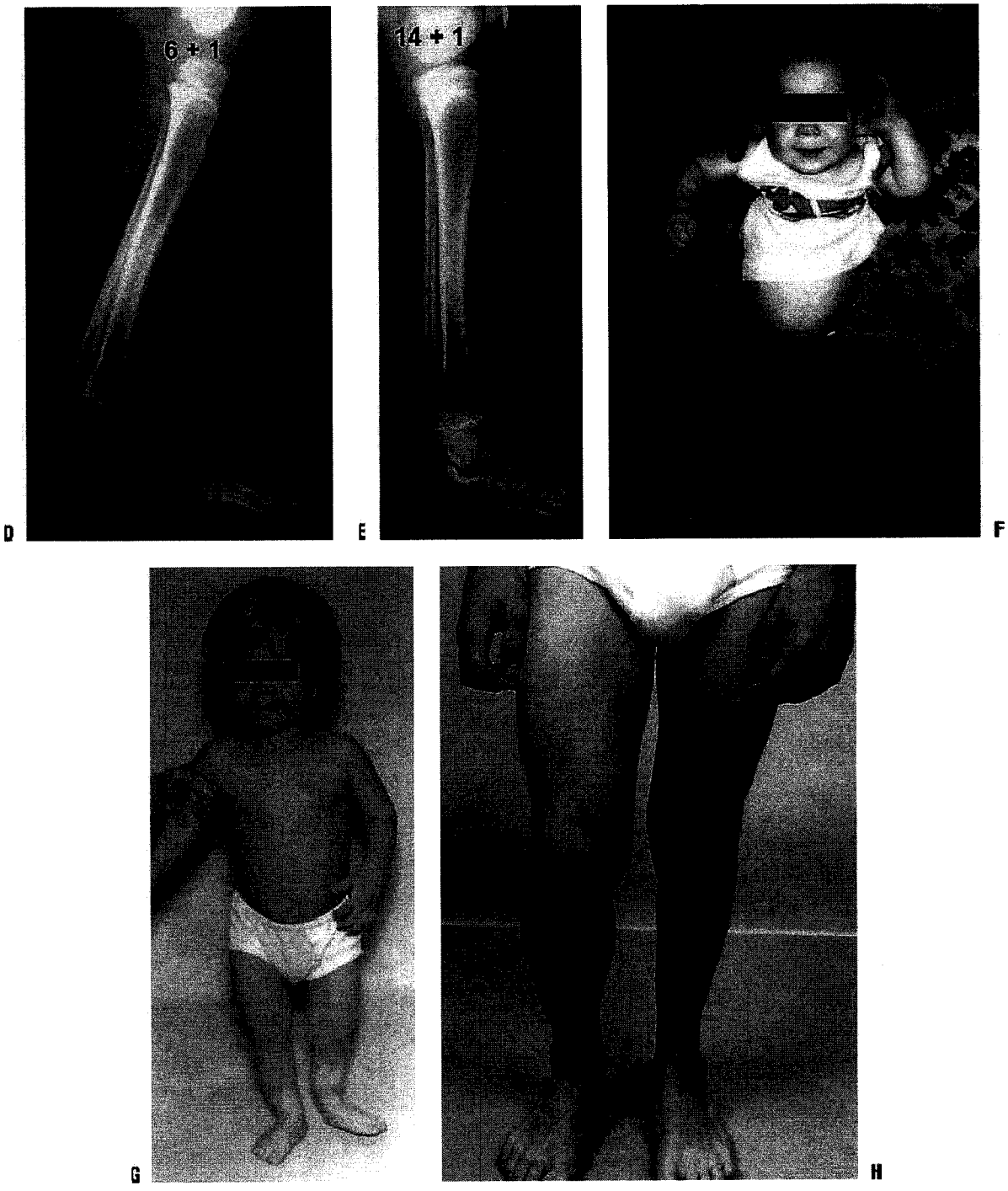


FIGURE 27-86. *(Continued)* **F–H:** Shortening of the involved tibia is expected and increases with growth as seen in these serial photographs. The percent inhibition remains fairly constant after 3 years of age.

Appropriately timed epiphysiodesis has been used for differences as great as 4 to 5 cm. Limb shortening is usually confined to the tibia. Epiphysiodesis of the proximal tibia is usually sufficient. There are several techniques that can be employed. A staged hemiepiphysiodesis may be used to correct residual angulation prior to completion of the epiphysiodesis.

Lengthening techniques have been used for those children with projected discrepancies >4 cm and for those with residual valgus angulation (Fig. 27-87). Lengthening alone in this group can exaggerate a valgus deformity, particularly when a unilateral frame is used. Circular frame fixation allows better control of valgus (198). Bi-level osteotomies in the tibia

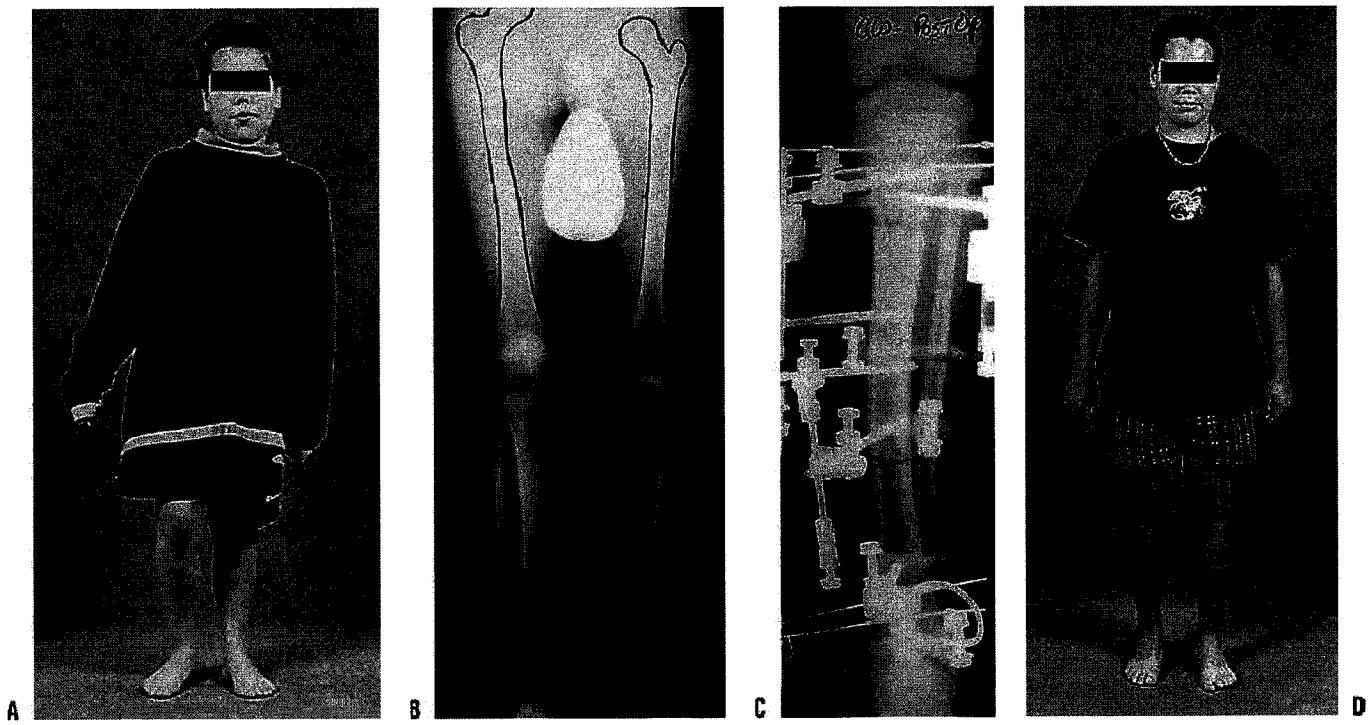


FIGURE 27-87. A: This 10-year-old boy had posteromedial bowing of the left tibia. He had 4.3 cm shortening and a 13% growth inhibition in the tibia. **B:** A long cassette radiograph demonstrates the limb-length inequality as well as the residual valgus in the distal tibia. **C:** A bi-level tibial osteotomy was performed. Residual valgus was corrected through the distal tibia, and limb-length equalization was accomplished with proximal lengthening. **D:** Valgus has been corrected and the pelvis balanced as shown in this follow-up photograph at 16 years of age.

(lengthening proximally, deformity correction distally) provide optimum management of both length and angulation. The foot may assume a varus position to compensate for residual tibial valgus and require modification of the frame if the foot deformity is rigid. Lengthening and deformity correction in our patients with PMB has been successful, with few complications compared to procedures in children with other forms of congenital shortening.

Occasionally, the limb-length inequality (>5 cm) and ankle valgus are so severe in very young patients that ambulation is impeded even with the use of an AFO and shoe lift. In these cases, deformity correction and lengthening through a distal tibial osteotomy has been performed in children younger than 5 years of age. A second lengthening in early adolescence is usually necessary to achieve limb-length equality with these extreme deformities.

CONGENITAL DISLOCATION OF THE KNEE

Definition. Congenital dislocation of the knee (CDK) is a relatively rare deformity that varies from simple hyperextension to anterior dislocation of the tibia on the femur. The spectrum of deformity in CDK has been classified as recurvatum, subluxation, and dislocation (193–195) (Fig. 27-88). The incidence of CDK is estimated at 1 per 100,000 live births, that is, 1% of the incidence of developmental hip dysplasia in North America (196, 197). Although there are some reports of occurrence within families, most cases are sporadic (198, 199). The deformity may be unilateral or bilateral.

Etiology. Several etiologic factors have been proposed for CDK. The familial occurrence suggests a possible genetic basis. CDK has also been seen in association with developmental hip dysplasia, idiopathic clubfoot, and congenital vertical talus (193–195). All of these have a genetic basis or polygenic mode of inheritance, which suggests a genetic link for CDK as well.

Milder forms of CDK occur in association with breech position *in utero*. In one study, 41% of otherwise healthy newborns with CDK were of breech presentation. These are generally believed to be positional, not pathologic deformities (194). Severe CDK often occurs in the presence of muscle imbalance and/or ligamentous laxity, such as that occurring in myelodysplasia, arthrogryposis, Larsen syndrome, and oligohydramnios (192, 194, 200–202).

Imbalance about the knee created by a relatively strong or contracted quadriceps muscle can, along with deficient hamstrings, lead to anterior dislocation of the knee. These infants typically have severe hyperextension *in utero* and, presumably, decreased fetal mobility. Chronic knee hyperextension

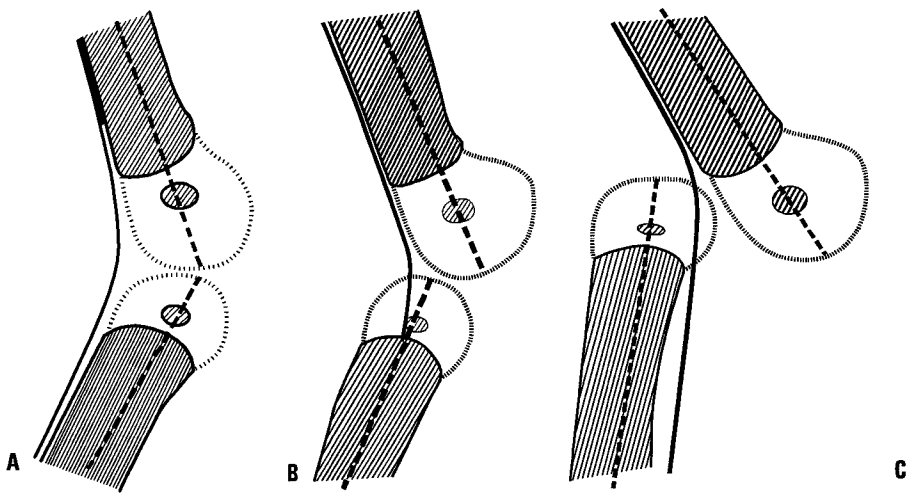


FIGURE 27-88. Congenital knee dislocation can range from simple hyperextension (recurvatum) **(A)** to subluxation to **(B)** complete anterior dislocation of the tibia on the femur **(C)**.

results in anterior subluxation of the hamstrings, allowing them to function as knee extensors (203). The quadriceps muscle is short and contracted. Uhthoff and Ogata (204) were able to study a 19½-week-old fetus with such a deformity. They found fibrosis of the quadriceps, absence of the suprapatellar pouch, and incomplete patellofemoral cavitation. The authors suggest that knee subluxation resulted from these abnormalities, intrinsic to the extensor mechanism, rather than from some secondary, extrinsic cause. The pathologic findings in this fetus are the same as those found in patients treated surgically.

Clinical Presentation. The hyperextended knee deformity is obvious, but of variable severity (Fig. 27-89). In cases of subluxation, passive flexion is limited, but improves with splinting and gentle stretching. Milder forms, such as hyperextension or recurvatum, are usually isolated abnormalities. In the case of dislocation, there is inability to flex the knee actively or passively. The quadriceps tendon is often severely contracted. A dimple or deep crease may be present over the anterior aspect of the knee. The patella is difficult to palpate and often laterally displaced. Those with a more severe variant of CDK are more likely to have hip dysplasia and congenital foot deformities. When it occurs in association with a neuromuscular or genetic syndrome, CDK is typically very severe and difficult to manage (193, 194, 205, 206). Radiographs help to differentiate the mild hyperextension deformity from the more severe type with fixed anterior dislocation of the tibia on the distal femur (Fig. 27-90).

Nonoperative Treatment. Treatment for hyperextension deformity or mild subluxation begins with gentle stretching. The tibia is easily manipulated over the femoral condyle as flexion increases. Serial casts are used to hold the knee in flexion. They are changed every few days in neonates and then weekly as the knee position improves. This is followed by the use of removable splints to maintain flexion. Mild deformities may be treated with splinting alone. These knees often show rapid improvement in flexion. A Pavlik harness has been shown to be useful for maintaining knee flexion achieved by stretching, splinting, or casting (207–209). The femoral condyles should be easily palpable once flexion beyond 90 degrees is achieved. Once this degree of flexion is obtained, it is unlikely that additional treatment will be needed. A lateral radiograph

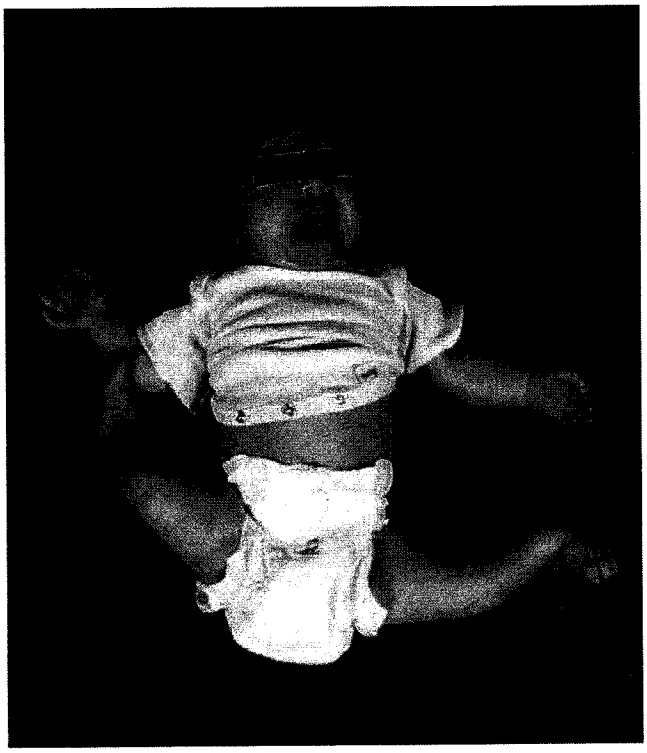


FIGURE 27-89. This infant has bilateral anterior knee subluxation and clubfoot deformities. These deformities are often associated with intrauterine breech position. Deep skin creases are often found across the front of the knee. The skin may be dimpled posteriorly.

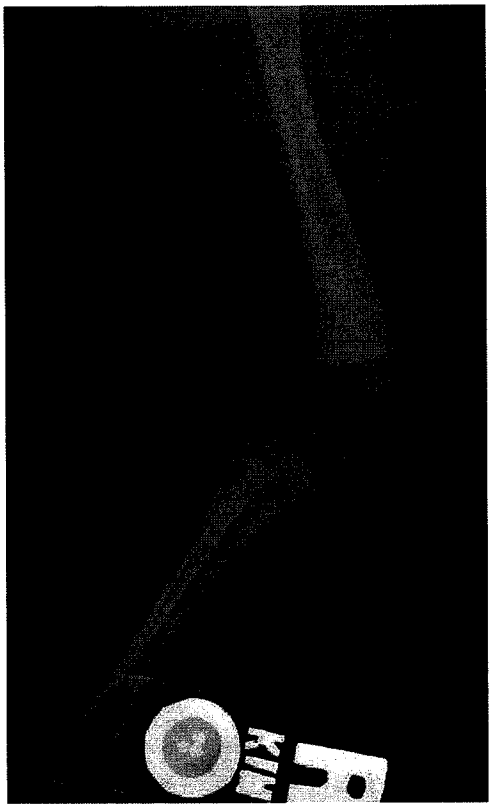


FIGURE 27-90. A lateral radiograph differentiates among simple hyperextension, subluxation, and anterior dislocation. The anterior aspect of the knee is to the left. Note the deep skin crease anteriorly. The ossification center of the proximal tibial epiphysis is anterior to that of the distal femur. Serial lateral radiographs should be used to document anatomic reduction of the knee. Failure to achieve anatomic reduction by closed manipulation and the inability to flex the knee more than 45 degrees are indications for surgical treatment.

or ultrasound image of the knee can be obtained to document anatomic restoration of the femoral–tibial articulation.

In contrast, knees with more severe subluxation or dislocation do not respond to passive stretching or splinting. Traction has been suggested as a means to achieve gradual reduction (193, 206, 210). During attempted closed treatment, it is particularly important to document restoration of a normal relation of the tibia on the femur with a lateral knee radiograph. Ultrasound can also be used. It is possible to create an iatrogenic physeal separation of the distal femur or to plastically deform the proximal tibia. Rather, the correction obtained must occur through the knee joint, allowing the tibia to translate on the femur. Closed treatment should be abandoned if appropriate reduction of the tibia cannot be confirmed.

Operative Treatment. For infants whose knees fail to gain reduction of the anteriorly dislocated tibia on the end of the femur and therefore lack flexion, surgical treatment in the first few months of life should be considered. As introduced by Roy and Crawford (200) and recently demonstrated by Dobbs (211), lasting correction can be achieved with early surgical intervention. The anterior release is done through a limited incision in the distal thigh. The quadriceps tendon and adjacent medial and lateral retinaculum and capsule, if necessary, are transected to obtain both reduction and flexion of the tibia on the femur. Postoperatively, the knee is casted in 90 degrees of flexion. Range-of-motion exercises, along with intermittent splinting in flexion or extension as needed, are used to maintain the reduction and knee mobility.

If left untreated, the quadriceps contracture rapidly becomes more severe and requires a more extensive release as the infant grows. Some authors have had success correcting moderate contractures using a simple V-Y advancement of the quadriceps tendon (193, 194). This is insufficient for more severe dislocations that require greater lengthening of the quadriceps mechanism and release of contractures. An extensile exposure from the distal half of the quadriceps mechanism to the patella is recommended to allow correction of this complex deformity. A serpentine incision extends from the proximal thigh to slightly past the tibial tubercle. This incision, rather than a straight incision, facilitates wound closure and results in fewer problems related to wound healing. Subcutaneous flaps are raised to expose the quadriceps mechanism. In these cases of severe contracture, fibrosis and scarring of the muscle is more extensive. It may be adherent to the periosteum of the femur.

The patella is usually very small and often laterally displaced. The extensor mechanism is usually malrotated and pulls the tibia into valgus. The quadriceps mechanism requires considerable lengthening, yet it must remain attached both proximally and distally. The release requires extensive dissection through fibrotic tissue. The quadriceps tendon is lengthened using a long Z-plasty or V-Y advancement, depending on the degree of quadriceps contracture present (193, 194). Beginning at the patella–femoral joint, the capsule of the anterior knee joint and the retinaculum are released transversely to the collateral ligaments, which often must be reflected and/or partially released. The knee can usually be flexed to 90 degrees following this release. Occasionally, the medial hamstrings, iliotibial band, and the lateral intermuscular septum must be released to correct valgus and external rotational deformity (196). The cruciate ligaments are typically present but may be attenuated (193, 194, 201, 203). The authors have not found it necessary to release the cruciates to gain flexion. The elongated quadriceps mechanism, which may be tenuous in these infants, is repaired with the knee in approximately 30 degrees of flexion (193, 194, 203). A spica cast is used for immobilization, with the knee placed in enough flexion (approximately 45 degrees) to prevent recurrent tibial subluxation (194, 196). Too much flexion jeopardizes the quadriceps mechanism repair and increases the risk of necrosis of the skin and subcutaneous tissue (193). Long-term orthotic splinting and range-of-motion exercises are essential to maintain maximal flexion and minimize loss of extension. A knee flexion contracture can be more debilitating than a lack of full flexion.

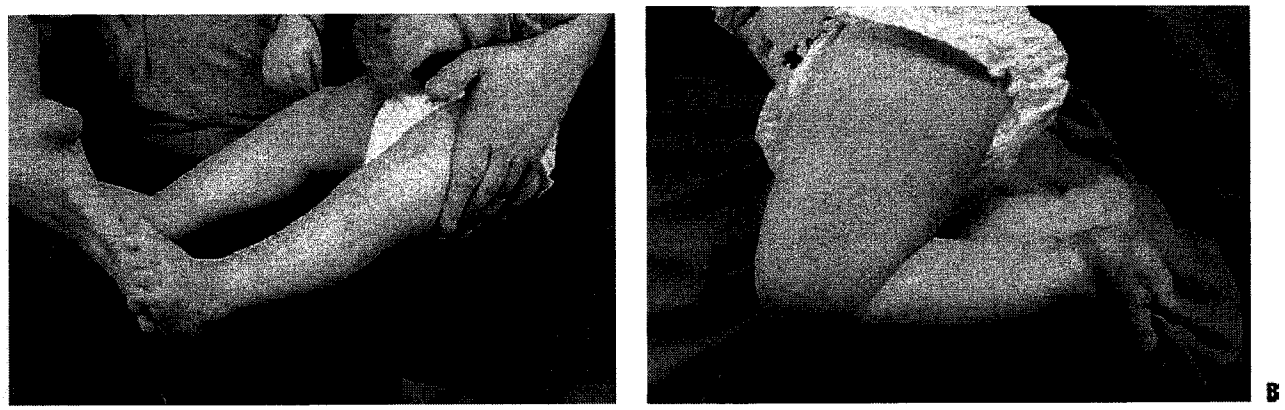


FIGURE 27-91. **A:** The photo shows knee extension following open reduction of these bilateral knee deformities. Hyperextension is no longer evident. **B:** Knee flexion >90 degrees has been accomplished. Range-of-motion exercises and intermittent use of orthotics may be needed to maintain this correction.

Treatment of an ipsilateral hip dislocation is performed either at the time of reduction of the knee dislocation or later as a staged procedure. With prior release of the contracted quadriceps mechanism, the knee can be flexed, facilitating treatment of the hip (193–195, 207). Mild hip dysplasia, which is amenable to simple closed reduction or limited open reduction using a medial approach, can be treated concurrently with the spica cast utilized to immobilize a surgically reduced CDK. More severe hip dysplasia, which requires open reduction by an anterior approach, should be done later. If a coexisting foot deformity requires operative treatment, this can be staged or done in conjunction with the knee reconstruction. Knee flexion facilitates cast application necessary for the treatment of associated foot deformities.

The long-term outcome of treatment is generally good. Those who have had hyperextension or mild dislocation and required only stretching and minimal intervention as infants have the best results. They do not report problems later on. Function is excellent and radiographs appear nearly normal (195, 205, 208, 209). Children with more severe dislocation who required an open reduction, but do not have any other musculoskeletal problems, generally do well (Figs. 27-91, 27-92 to 27-94). In these patients, knee range of motion includes full to nearly full extension and flexion that averages 80 to 120 degrees. This allows very functional, independent ambulation, and participation in most normal play activities; however, activities such as running or bicycling, which requires flexion beyond 90 degrees, may be limited. Radiographic abnormalities are found in some, but not all knees. This usually consists of flattening of the femoral and tibial articular contours (193, 195).

Those with bilateral deformity do not do as well as those with unilateral deformity. These also tend to be children with associated neuromuscular disorders. Early repair generally has a more satisfactory functional result than late repair (193, 194, 210). Recurrent hyperextension deformity is not likely. Although >90 degrees of knee flexion can typically be obtained at surgery, gradual loss of knee motion often occurs and may be problematic. Resultant knee flexion is often much <90 degrees. A knee flexion contracture also can occur and knee joint function is often compromised. The preliminary report of Dobbs following earlier intervention holds promise for lasting improvement in greater range of motion and possible function for these patients.

IDIOPATHIC TOE-WALKING

Definition. Children may present at any age with a history of toe-walking. The habit of doing so is not that uncommon or abnormal in 2- to 3-year-old children. Typically, these habitual toe-walkers, with coaxing, can walk plantar grade. By the age of 3, children should walk with a heel strike (6, 212, 213). Persistent toe-walking beyond this age is abnormal.

Etiology. A toe-toe gait is often observed in children when they first begin weight bearing. If the toe-walking persists, a contracture develops and worsens over time. In the child who is otherwise neurologically normal, toe-walking may be associated with a shortened heel cord; however, this is generally not recognized at birth or within the first year (214–216).

Natural History. Very little is known about the natural history of idiopathic toe-walking (ITW). Stricker and Angulo (216) retrospectively reviewed 80 patients who were evaluated and treated for ITW. Forty-eight of the eighty patients, generally those with the mildest deformity, were observed without treatment from ages 3 to 6 years. The degree of heel cord contracture was mild and remained essentially unchanged in these patients. Only 25% of parents noted a spontaneous improvement; that is, appreciably less toe-walking. For the children with more than 5 degrees of passive dorsiflexion, persistent toe-walking is not a functional problem and does not result in any foot deformity or pain. Children with more severe contracture often develop splaying of the forefoot. External

(*Text continued on page 1334*)

Quadriceps Release for Congenital Dislocation of the Knee (Figs. 27-92 to 27-94)

FIGURE 27-92. Quadriceps Release for Congenital Dislocation of the Knee. The release in infants under 2 months of age utilizes three stab incisions. With the knee held in maximum flexion, the first stab incision is made 1 to 2 patella lengths above the patella, in the midline. The fascia over the rectus portion of the quadriceps is palpated with the tip of the knife and released percutaneously. Two additional percutaneous incisions are made medially and laterally in the retinaculum at the edge of the patella. This typically allows full flexion of the knee. The minimal dissection and young age provides correction and healing similar to that of percutaneous heelcord tenotomy.

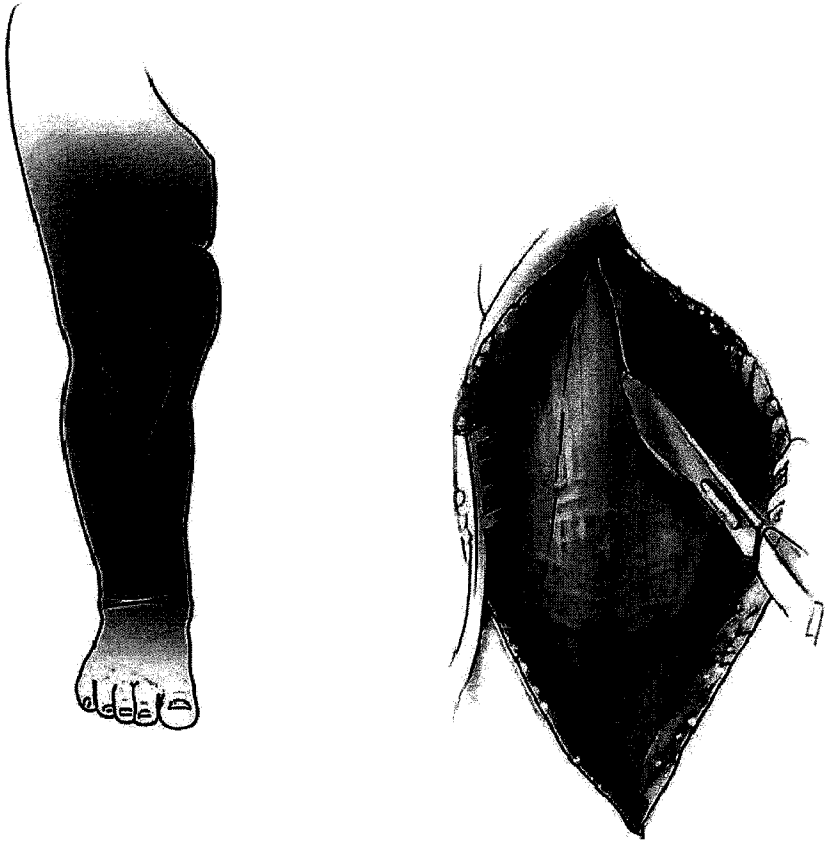


FIGURE 27-93. Congenital knee dislocation in older children or those with recurrent deformity are treated by open release and quadriceps advancement. The child is placed supine. A serpentine incision is made from the tibial tubercle to the mid-thigh. This facilitates wound closure with the knee flexed.

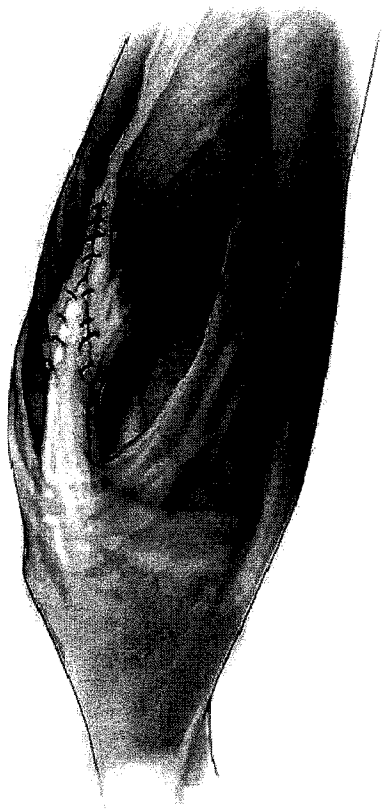


FIGURE 27-94. The quadriceps mechanism is exposed using sharp and blunt dissection. Fibrous bands are noted, often with only thin bands of muscle. A long V-Y advancement is used to gain maximum length of the quadriceps which must remain intact proximally and distally. Adhesions between the quadriceps and distal femur are released as needed to mobilize the quadriceps. Additional release of the retinaculum and collateral ligaments may be needed to achieve 90 degrees of flexion. In some cases the knee is pulled into valgus by the iliotibial band and hamstrings, which also require release. After repair, the knee is casted in 45 degrees of flexion, to reduce the risk of redislocation. Increasing flexion attenuates the repair and may compromise wound healing.

tibial torsion and foot pronation may develop in children with persistent toe-walking in an attempt to maintain foot contact with the floor (215). The development of a mid-foot break to permit foot contact with the floor is frequently seen in neuromuscular conditions, but is not typically seen in ITW (14).

Clinical Features. Patients typically present to the orthopaedist for evaluation of ITW at 3 to 4 years of age (216). The condition predominates in the male sex, and the family history (siblings and generation to generation) is often positive for similar ITW persisting into adulthood (214, 216, 217). The suggested inheritance pattern is autosomal dominant with variable penetrance (218, 219). Although Stricker et al. (216) noted a frequent history of both prematurity and developmental delay, walking was not delayed. On examination, ITW occurs bilaterally and is best seen when the child is walking barefoot (Fig. 27-95). When the child stands still, the feet may be flat on the ground. With time, toeing-out and splaying of the forefoot frequently occur. Idiopathic toe-walkers, in contrast to children with spastic diplegia, do not have a tendency to walk with a back-knee thrust in order to achieve foot flat position.

On bench examination, the range of passive ankle plantar flexion will be normal and dorsiflexion will be limited, secondary to a variable degree of true shortening of the heel cord (214). The posterior calf muscles are typically very well developed; in fact, they may appear to be enlarged. However, the muscle texture will feel normal on examination and there will be no evidence of any weakness, proximal or distal, in the upper or lower extremities. Importantly, no spasticity is present and clonus will not be elicited by a rapid stretch of the triceps surae. The diagnosis of ITW is a diagnosis of exclusion and typically can be made from the child's history and physical examination (214, 217, 220–222).

Differential Diagnosis. The differential diagnosis of early-onset toe-walking includes neuromuscular etiologies such as spastic diplegia (216, 217, 223). ITW that develops in a child with a previously normal gait must be differentiated from primary muscle diseases, such as muscular dystrophy, myotonic dystrophy, dystonia, and tethered cord syndrome, and from central nervous system neoplastic processes (216, 217). Further evaluation by a neurologist may be indicated to exclude such consequential neuromuscular diagnoses.

Usually, the diagnosis of ITW is made without computerized gait analysis or dynamic electromyograph (EMG); however, an EMG may be helpful if it is essential to differentiate between ITW and spastic diplegia (215, 220, 223). Children with mild cerebral palsy who walk on their toes often have out-of-phase gastrocnemius soleus muscle activity, whereas idiopathic toe-walkers will be in phase (222, 223). Both groups show lack of heel strike. Children with mild diplegia show greater sustained knee flexion at terminal swing. Maximal knee extension occurs at ground contact for idiopathic toe-walkers and at mid-to-late stance for diplegics (220). In the ITW gait, ankle dorsiflexion occurs early in maximal swing, followed by plantar flexion. Ankle dorsiflexion occurs throughout swing in diplegics.

Nonoperative Treatment. The treatment of ITW begins with instructions given to the parents regarding the importance of a long-term commitment to assisting the child with both heel cord stretching and dorsiflexor strengthening exercises. This is particularly true in early childhood, when stretching exercises are more likely to make a difference. It is important to maintain inversion of the hindfoot to optimize stretch of the heel cord. If the calcaneus is allowed to evert, the forefoot will be allowed to dorsiflex independent of the hindfoot and create a mid-foot break without effectively stretching the heel cord. A 3- to 4-month course of twice-daily dorsiflexion manipulations may be effective in obtaining increased dorsiflexion. The response to treatment varies with the duration

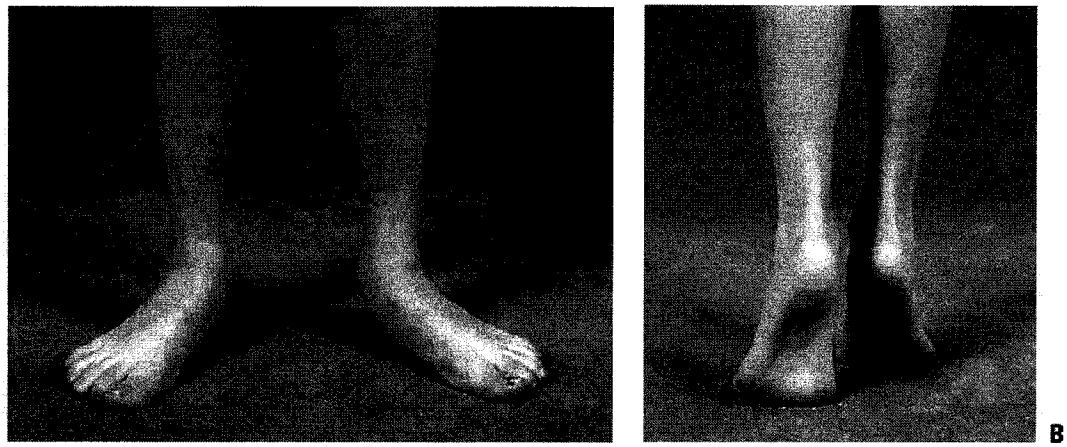


FIGURE 27-95. **A:** Children with ITW assume an externally rotated posture to facilitate a foot flat position. They typically do not hyperextend the knee. **B:** While up on their toes, the heel moves to a varus position. Chronic toe-walking can cause the forefoot to splay because of the overload of the intermetatarsal ligaments. Forefoot splay and tibial external rotation typically do not resolve after heel cord lengthening.

and severity of the equinus deformity and compliance with the exercise regimen. Clinical improvement will be sustained with continued daily heel cord stretching exercises and active dorsiflexion-strengthening exercises supplemented with orthotics. An articulated AFO with a plantar–flexion stop and free dorsiflexion is used to maintain position.

If toe-walking persists, serial ankle dorsiflexion casts should be considered. Predictably, stretching casts will be more effective when there is a "springy" rather than a firm feel of maximal heel cord stretch during foot dorsiflexion. The casts are applied with the foot maximally dorsiflexed and the heel in a neutral position or slightly inverted. Flexing the knee or prone positioning facilitates placement of the cast. A series of two or three sets of short-leg casts will often elongate the heel cord and result in greater passive dorsiflexion. This immobilization also produces short-term weakness. The combination of stretch and slight weakness usually produces a marked decrease in the tendency to toe-walk. After casting, articulated AFOs with plantar–flexion stops are used full-time, and the heel cord stretching and dorsiflexion-strengthening regimen is resumed. If dorsiflexion can be maintained for 3 to 6 months, the children are weaned from daytime use. Nighttime splinting can be discontinued if there is no recurrence of the toe-walking. Although serial casting and subsequent orthotic usage is widely recommended, very little is known of its long-term effectiveness (221). This approach will often be successful in younger patients (under 6 to 7 years), and even in some of the older patients. However, relapse is common due to lack of compliance, often requiring repeat serial casting, AFO use, or surgical treatment. Compliance with a comprehensive program of heel cord stretching, dorsiflexor strengthening, and bracing is essential for long-term success.

Operative Treatment. If the use of serial stretching casts does not realize a satisfactory clinical improvement in the tendency to toe-walk, then heel cord lengthening procedures will be necessary to effect a change in gait (214, 216). Age also becomes an important determinant in treatment recommendations. The authors feel that by 7 to 8 years of age, children should have improved sufficiently to consistently demonstrate a normal heel-toe, rather than toe-heel or toe-toe gait. Far too often, parents are inappropriately advised that ITW will resolve on its own. In reality, toe-walking after 6 years of age often does not improve, and the heel cord contracture slowly worsens. Persistent toe-walking secondary to a heel cord contracture can potentiate both forefoot splay and a disproportionately wide forefoot compared to the heel. Standard footwear may not accommodate the wide forefoot and narrow heel. External tibial torsion frequently develops to compensate for the lack of foot flat contact. This external tibial torsion deformity becomes more obvious once the heel cord has been lengthened. It may be severe enough to warrant corrective osteotomy.

The heel cord lengthening can be done by a variety of techniques depending on the severity of the contracture. If the foot can be brought within 5 degrees of neutral with the knee flexed, the authors prefer performing a fractional lengthening through a 6- to 8-cm longitudinal incision centered at approximately the junction of the middle and distal third of the calf. The triceps surae complex is exposed and lengthening effected by a "sliding tendon" technique. Transverse incisions, one proximal and one distal, are made cutting through the tendons only of both the gastrocnemius and soleus musculature. The two incisions (depending on the severity of the triceps surae contracture) are separated variably by 4 to 6 cm of intact triceps surae tendon. Typically, the proximal transverse incision is made first completely cutting through approximately 60% of the medial triceps surae tendon (only) from medial to lateral. The plantaris tendon is also completely transected. With the foot forcefully dorsiflexed, the second transverse incision is carefully made distally from medial to lateral through the palpably tight distal triceps surae tendon (usually 50% to

60% of the tendon complex). A controlled sliding (longitudinal) lengthening will typically occur allowing for the desired increase in ankle dorsiflexion. On occasion, the two longitudinal halves of the triceps surae tendon do not slide sufficiently to affect lengthening of the tendon. To correct this, either two or three small (2 to 3 mm) separate incisions are made transversely across the intended site of the slide lengthening. Alternatively, the intended longitudinal separation between the two halves of the tendon is directly incised down to triceps surae muscle. Typically, a slide lengthening will occur that allows for satisfactory dorsi flexion, that is, 10 degrees of dorsiflexion with the knee extended. If necessary, additional tendon lengthening can be achieved by performing a third (50% to 60%) transversal incision through the medial triceps surae tendon, 3 cm distally. Short-leg walking casts are used for 5 to 6 weeks, after which the child is fitted with AFOs, which are used 22 of 24 hours for 4 to 6 weeks. Heel cord stretching and ankle-strengthening exercises are performed twice daily. The AFOs are gradually weaned during daytime but used at night for up to 6 months postoperatively.

For those with more severe contracture (lacking >10 degrees with the knee flexed), release of the posterior ankle ligaments may be necessary to achieve correction. This is facilitated by a Z-lengthening of the tendon which also provides access to the posterior ankle and subtalar joints. The posterior talofibular ligament is typically thickened and the primary source of limited motion. In a recent review of 108 patients (average age 7.9 years) surgically treated for ITW at the St. Louis Shriners Hospital for Children, half of the patients required a posterior ankle and subtalar release to achieve satisfactory dorsiflexion.

Surgical correction predictably has a satisfactory outcome. Generally, parents are very satisfied with the improved gait following heel cord lengthening; however, the parents need to be well informed as to the anticipated postoperative course. The child's postoperative gait (relatively weak plantar flexor power) will be considerably different from the preoperative gait (relatively strong plantar flexion power). The predominately equinus gait is replaced by a gait with relatively weak push off, initially. Quick cadence is replaced by a slower cadence gait. It takes time for the push-off power to recover to near-normal levels (214). Younger children regain a relatively normal gait pattern soon after weaning from orthotics, whereas those older than 8 years at the time of surgical treatment may take a year or more to normalize their gait. Hall et al. (214), at an average length of follow-up of 3 years following heel cord lengthening, reported a satisfactory outcome for all 20 patients. In a review of all treatment methods, Stricker and Angulo (216) noted that surgical lengthening of the heel cord was the only treatment that permanently improved ankle dorsiflexion. Although 33 of 56 patients still exhibited some degree of toe-walking, most parents were satisfied with the outcome of heel cord lengthening. A study by Stott et al. (224) of toe-walkers evaluated at skeletal maturity concluded that, although kinematic studies continued to demonstrate some gait abnormalities, no abnormalities were apparent clinically. In our series of 108 patients, only one had recurrent deformity requiring repeat lengthening.

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