27

The Lower Extremity

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ROTATIONAL VARIATION

Definition. Rotational profiles vary widely among healthy children (1–3). Differences in appearance related to foot position during walking or running are most often just that, differences, not pathologic conditions. Foot position during walking is described by the direction of the foot relative to the body's line of progression during the gait cycle (internal, external, or neutral). This is *torsion*. It results from the summation of several factors that include version of the bones, capsular pliability, and muscle control (1, 3–5). *Version* is tilt or inclination within a bone, such as the relation of the femoral head/neck to the shaft of the femur. Contracture of a joint capsule may restrict rotation. Similarly, capsular laxity may allow a greater than normal arc of motion. Arthrosis or incongruity may also restrict motion. The balance between opposing muscle groups is also a determinant of foot position and may introduce a significant, dynamic component to the rotational profile. Age is another important variable because version, soft-tissue pliability, and muscle coordination change as the child matures (1–8).

Assessment. Assessment of rotational alignment includes static and dynamic components. The static examination describes the available range of rotational motion. The dynamic examination displays the effect of various torsional forces at play during the walking cycle (Fig. 27-1). The static examination should be performed on a firm examining table, with the child in comfortable, loose clothing such as shorts or a diaper. Rotation is best assessed with the child in the prone position, keeping the pelvis flat and level on the examination table (3–5). Flexion of the knee to 90 degrees allows the leg to be used like a goniometer relative to the thigh. Young children often will not allow examination other than on a parent's lap. This is usually adequate although not as controlled as in the prone position. The arc of rotation may be more generous if measured with the hip flexed as in a sitting position (5).

Rotation of the leg laterally or medially is used to assess the degree of available hip rotation. When there is a greater degree of internal or medial rotation (outward movement of the leg in the prone position) than external or lateral rotation, a toed-in gait is more likely to be observed. Similarly, if there is greater external rotation than internal rotation, the gait pattern is usually toed-out. A greater ability to rotate the thigh internally rather than externally is frequently

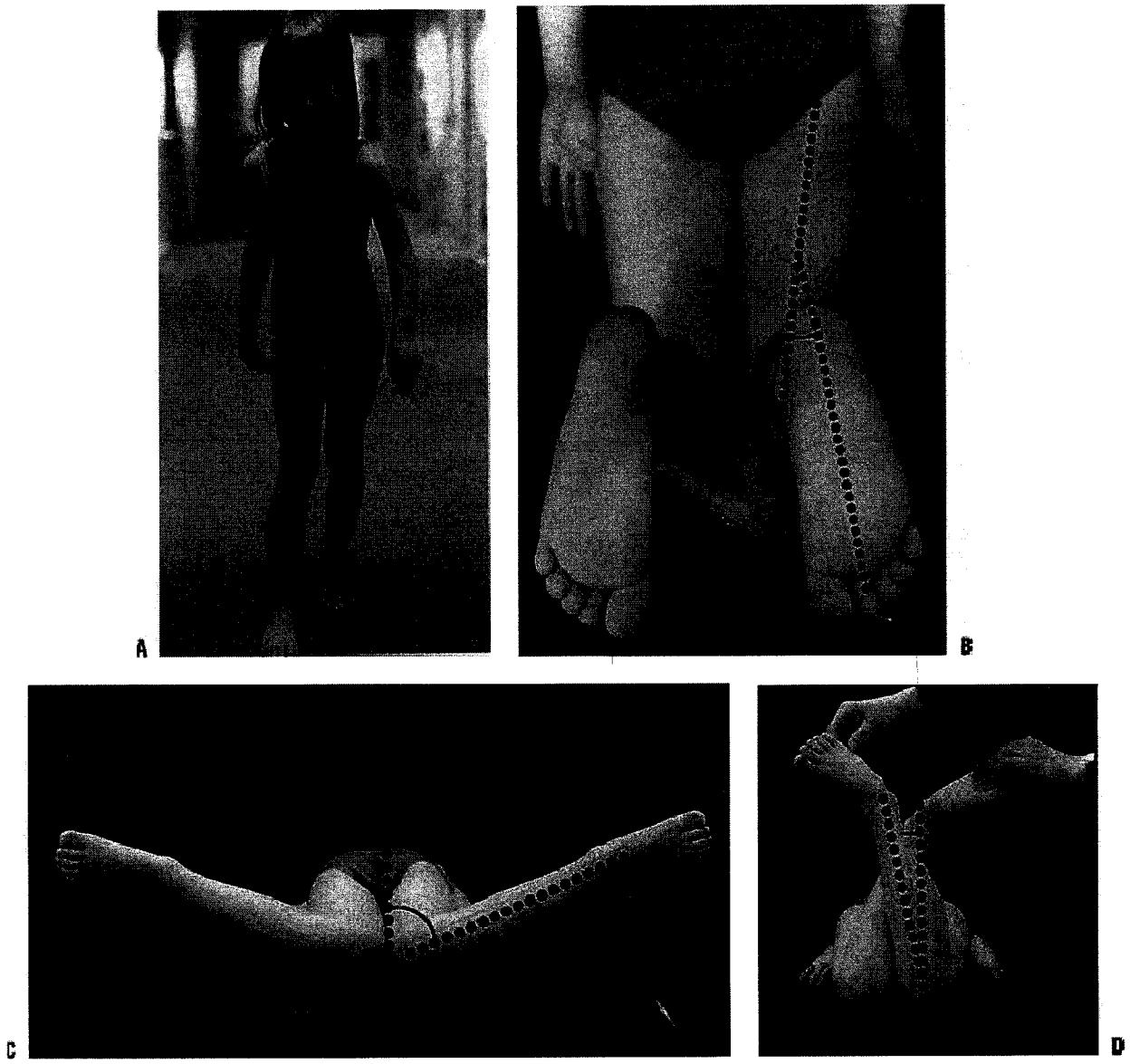

FIGURE 27-1. How the rotational profile measurements are made. **A:** The FPA is estimated by observing the child's gait. It is defined as the angular difference between the axis of the foot and the line of progression. This child's FPA is 0 degrees. **B:** The TFA is the angular difference between the axis of the foot and thigh as viewed from above. The TFA in this child is 18 degrees. From this view, the shape of the foot is apparent. **C:** Medial hip rotation is the maximum angular difference between the vertical and the axis of the tibia. In these hips, this measurement is 70 degrees. **D:** Lateral hip rotation is the corresponding measurement. On this child, the angle is 10 degrees.

referred to as *anteversion*. It should correctly be called *antetorsion* because hip rotation is the combined effect of version of the femur, joint mobility, and muscle function (1, 3, 5). True femoral torsion can be accurately assessed by noting the position of the leg while palpating the greater trochanter laterally.

Medial hip rotation is generally greater in girls than in boys (Fig. 27-2). Variability is greater in younger children. Static medial hip rotation averages 40 degrees in infants, but can range from 10 to 60 degrees. It increases slightly by the age of 10 years and then decreases gradually in adulthood. Lateral hip rotation is greater than medial rotation in infants; it averages 65 degrees (range, 45 to 90 degrees), compared to children over the age of 10 years who average 40 degrees (range, 20 to 55 degrees) (1–3, 5, 9, 10). It increases slightly in adults.

Observation of the alignment of the axis of the hindfoot relative to the thigh, which is held in neutral rotation, determines the thigh-foot angle (TFA), as shown in Figure 27-1B. This relation also describes the contribution of the

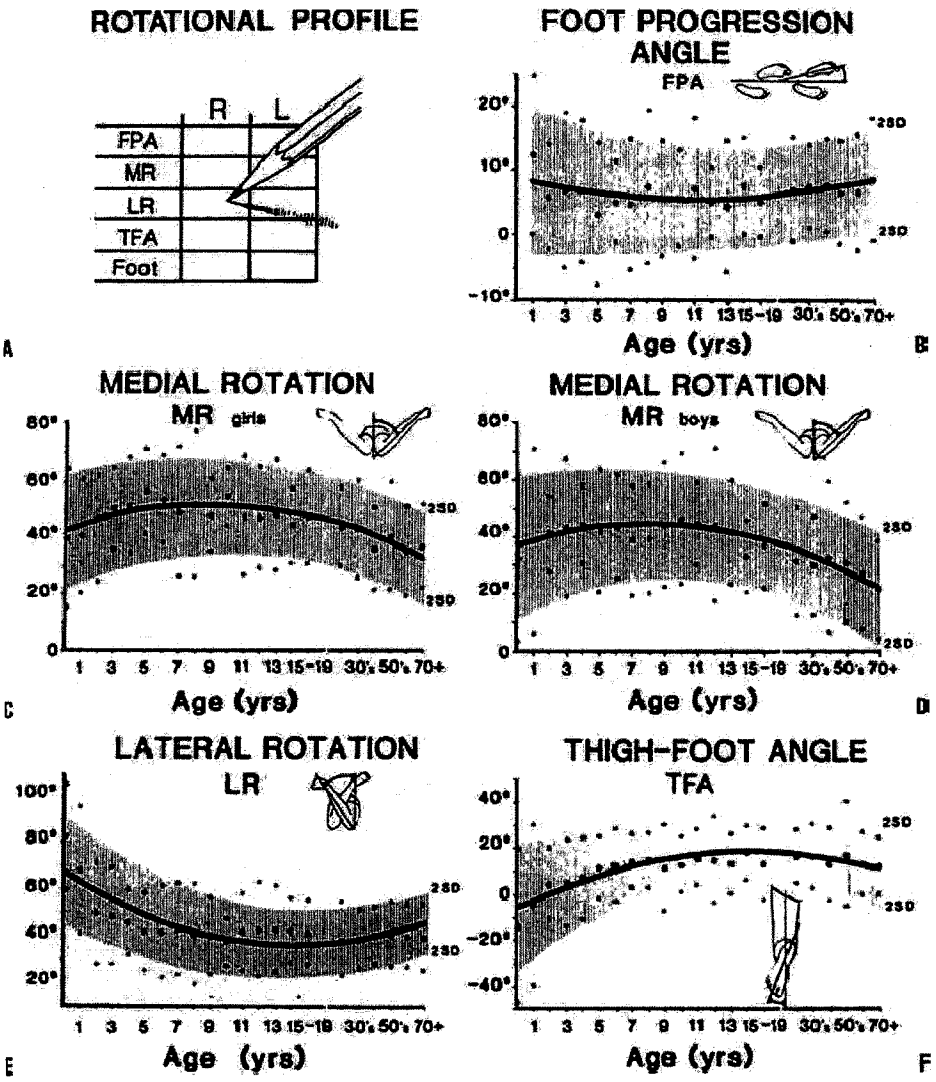

FIGURE 27-2. The rotational profile. **A:** The method of recording the degree measurements for each element of the profile is depicted. This simple chart includes the vital information necessary to establish the diagnosis and to document severity. **B–F:** Normative values for the profile based on 1000 healthy limbs are shown. In each figure, the age is listed on the abscissa on a logarithmic scale and the degrees are shown on the ordinate scale. Mean values are shown by the solid line with ±2 standard deviations; reference range is shown in shaded areas. A gender difference was found to affect the values for medial rotation, so the values are shown independently for males and females.

leg segment or the degree of tibial torsion. Foot deformity, which may contribute to rotational abnormalities, can also be assessed easily in this position. Forefoot adduction or abduction and hindfoot varus or valgus is noted. Many young children have significant rotational laxity through the knee. Internal and external rotation of the tibia with the knee flexed demonstrates the degree of knee joint laxity. This may contribute to variation in foot position. The average TFA is 5 degrees internal in infants (range, −30 to +20 degrees) and increases to 10 degrees external by 8 years of age (range, −5 to +30 degrees) (1–3, 5). TFA changes very little after 12 years of age.

Correlation between the static examination and the dynamic examination is important. The child's walking pattern should be observed in an area large enough to allow comfortable and safe walking and running. The child should be able to walk alone (i.e., not holding someone's hand). It is often helpful to observe the child in shoes as well as barefoot. Variations are common with change in speed or direction of walking. Foot and knee position should be observed over several cycles of gait. The relation of foot position to an imaginary line along the path being walked describes the foot-progression angle (FPA). Variability is considerable in children up to 5 years of age. An out-toed position predominates in older children. Once a mature gait pattern is established, usually by 5 years of age, FPA changes very little (1–6, 9, 10).

The child's rotational profile includes the contribution of each of these components to the gait pattern. The FPA, TFA, and position of the knee relative to the body (femoral torsion), all contribute to the sum of rotational factors. Each area needs to be assessed along with its contribution, either positive (internal rotation) or negative (external rotation), to the overall gait pattern. Those children whose rotational profiles are beyond two standard deviations of the mean are considered abnormal according to Staheli's criteria (3, 4) (Fig. 27-2).

Differential Diagnosis. Infrequently, pathologic conditions will cause a rotational abnormality. Residual foot deformities,

disorders of the hip, and neuromuscular diseases are the most common causes of pathologic in-toeing or out-toeing. In-toeing may be caused by residual foot deformity from metatarsus adductus, clubfoot, or skewfoot (1, 4, 5). These conditions are discussed in detail elsewhere in this text. In-toeing, which is only apparent during swing phase, may be the result of overpull of the posterior tibial tendon, often seen in spastic hemiplegia (11, 12).

Femoral antetorsion is often seen in spastic diplegia or quadriplegia. This may be a combination of excess femoral anteversion with contracture of the adductor and medial hamstring muscles (4, 5, 13). Excess valgus and pronation of the foot, which contribute to an out-toed foot progression, may also be seen (13). For some children with spasticity, extremes in rotational posture are a compensatory mechanism for limited hip, knee, or ankle motion. The combination of excess internal femoral rotation and external tibial rotation (malicious malalignment) (13, 14) is often observed in children with spasticity. Children with diplegia and quadriplegia often have heel cord tightness. To maintain foot contact with the floor, the calcaneus tends to rotate laterally beneath the talus, which allows the talar head to drop plantarward, producing a valgus deformity (15). If the peroneal tendons are also spastic, the forefoot will also be pulled into an abducted position creating a planovalgus deformity. If the child is unable to clear the foot during swing phase, the foot is repeatedly dragged along the floor, adding to the external torsional force applied to the foot. This produces a malalignment, with the foot externally rotated from the planovalgus deformity and the knee internally rotated from femoral antetorsion.

Pathologic out-toeing may result from the severe pes planovalgus often associated with external tibial torsion (16) (Fig. 27-3). This may be secondary to tarsal coalition, but may also be seen in adolescents with rigid flat feet without a coalition. It is unclear whether the out-toed position is an adaptation to a rigid flat foot, or whether the lack of foot flexibility promotes the development of external rotation. A rigid deformity may occur with or without a tarsal coalition. The combination of femoral retrotorsion, external tibial torsion, and pes planovalgus can also be seen, particularly in large adolescents, which produces a striking out-toed gait. Slipped capital femoral epiphysis (SCFE) should be considered in a differential diagnosis of out-toeing, particularly when the deviation is asymmetric or of recent onset (4, 17). Hip dysplasia can alter rotation, but its effect is highly variable (7). Asymmetric hip rotation may be apparent upon examination, but is not reliable in detecting hip dysplasia. In such instances, further evaluation with radiographic hip examination is warranted (3, 4). Coxa vara may also present as an out-toed gait.

Radiographic Evaluation. It is recommended that any child who presents to an orthopaedic surgeon with concerns of a gait abnormality have an anteroposterior (AP) pelvis radiograph. Children older than 8 years with a recent change in gait or with complaints of hip or knee pain should also have a frog lateral radiograph of the hips (3, 4, 17). A cross-table lateral film should also be obtained to detect a minimally displaced SCFE. Although the incidence of otherwise occult pathology

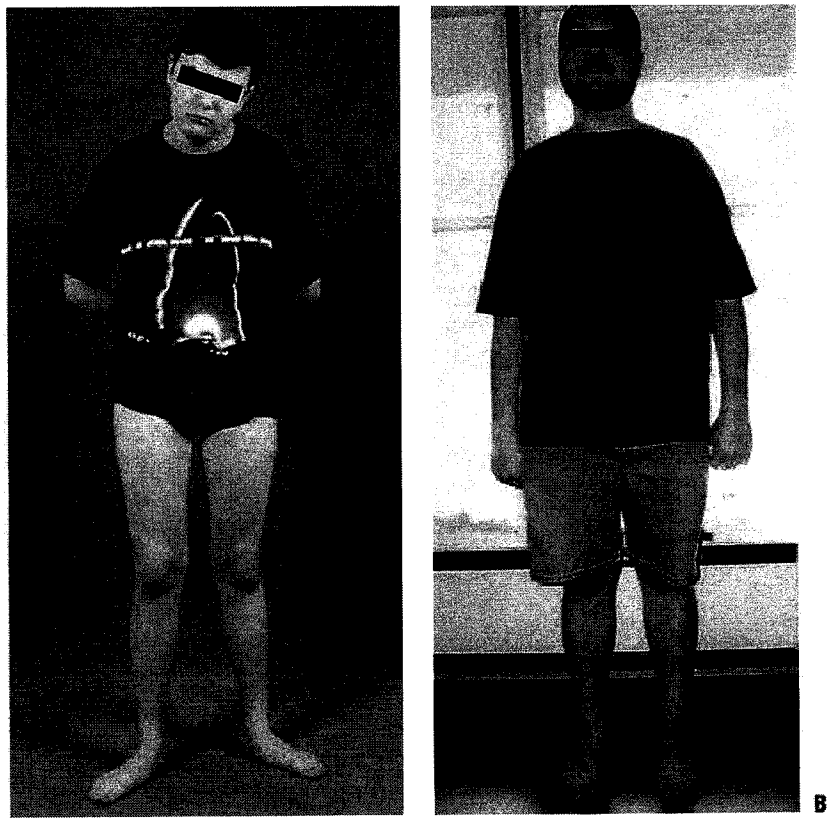

FIGURE 27-3. A: Excess external rotational deformity may not resolve. It may be associated with symptomatic flatfoot, with or without tarsal coalition. The use of medial support orthotics may reduce symptoms, but will not alter rotation. **B:** Alignment at 18 years of age following tibial internal rotation osteotomy to correct excessive external tibial rotation.

is low, the consequence of a missed diagnosis, such as hip dysplasia or an SCFE, is significant for the child.

It is not necessary to obtain serial radiographs of the hips or lower extremities to follow the course of normal rotational development (4, 5). Special views to quantify version of the femur or tibia are not indicated in the routine evaluation of rotation (3–5). Three-dimensional imaging studies [computed tomography (CT) and magnetic resonance imaging (MRI)] are typically not indicated in the assessment or follow-up of rotational variations, but are more accurate in quantifying rotation than clinical or biplane radiography (18).

Natural History. Most children brought in for concerns of in-toeing or out-toeing are normal. Rotational profiles are highly variable, particularly in toddlers who have not mastered the basic skills needed for normal walking, which includes just about every child younger than 2 years and many of those who are 2 to 5 years of age (1, 2, 6, 10). Internal and external rotational variations should be considered just that, variations of normal, not pathologic conditions. The natural history of rotational variations is gradual normalization, usually accomplished by 6 to 7 years of age. There are no conclusive studies to show that any nonsurgical intervention speeds up or assures the normalization of gait (4, 5, 19, 20).

Internal tibial torsion is more common than external tibial torsion in toddlers (4, 5) (Fig. 27-4). It is often associated with physiologic bowlegs and decreases 1 to 2 years after the resolution of the bowing. Occasionally, it will persist into preadolescence. External tibial torsion is less common, but is more likely to persist through adolescence (4, 5).

The assessment of hip range of motion in newborns and infants is highly variable (2, 3, 5, 7). Most healthy infants have an external rotation contracture about the hip, which is likely a result of intrauterine positioning. This may not fully resolve until they become established walkers at 18 to 24 months of age. At that age, an in-toed gait may be more apparent. Lateral hip rotation gradually decreases as medial rotation increases. Paradoxically, anteversion in the femoral neck typically decreases from 30 degrees (range, 15 to 50 degrees) at birth to 20 degrees (range, 10 to 35 degrees) by 10 years of age (1–5, 7, 8). A decrease in anteversion of the femoral neck would be expected to produce greater external rotation of the hip; however, changes in muscle balance and hip capsule pliability appear to have greater influence on gait. By 8 years of age, a child who toes in while walking, but has at least 20 degrees of hip external rotation, is within normal limits as defined by the mean plus or minus two standard deviations. Similarly, one who toes out while walking, but has at least 20 degrees of hip internal rotation, has motion within a normal range (4, 5, 10).

Variations in rotation have not been linked directly to the risk of degenerative joint disease (9, 10, 21–27). Several authors have tried to correlate the degree of femoral anteversion with the presence of osteoarthritis of the hip using postmortem studies or by preoperative CT scan. Most studies have shown a similar measure of anteversion in hips with and without arthritic changes (22–26). One study measured anteversion in hips of patients undergoing proximal femoral osteotomy or total hip replacement. Patients with bilateral disease had an average 9 degrees greater anteversion than patients with healthy hips. Patients with unilateral arthritis averaged 4 degrees more anteversion in the arthritic hip than in the healthy hip (26). Some authors have demonstrated a relation of anteversion with degenerative changes in the knee, presumably from increased shear loads (27). Hip pain is not a typical complaint in children with increased femoral anteversion alone (1). Anterior knee pain may be associated with increased medial rotation of the femur, but not generally with patellofemoral changes (23, 27). Although some recent publications have suggested that torsional variations may increase the risk of osteoarthritis, anatomic studies have not conclusively shown a causal

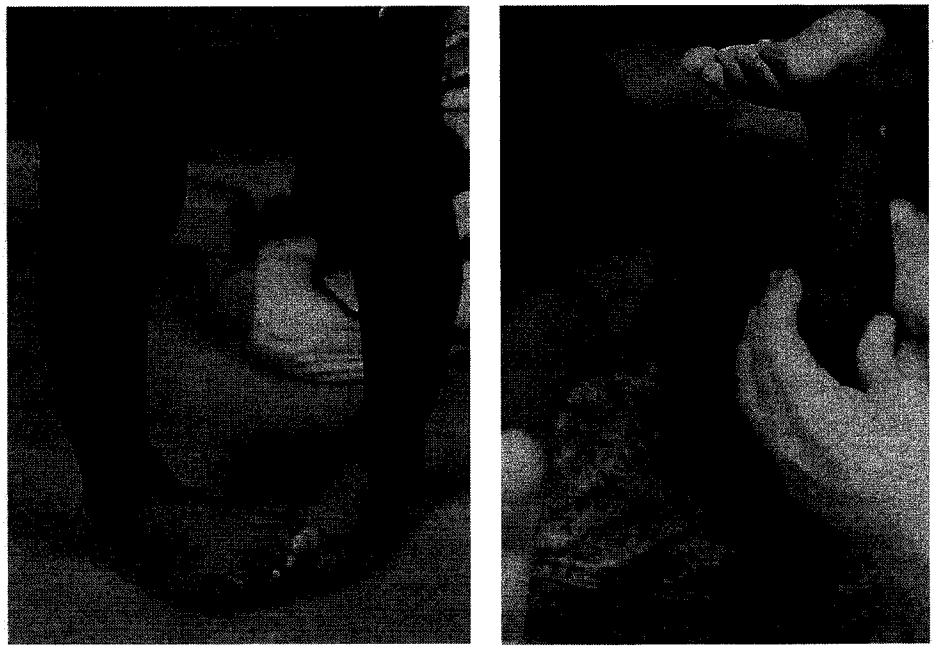

FIGURE 27-4. A: Internal tibial torsion is often seen in toddlers in association with physiologic bowlegs and results in an in-toed gait. **B:** The TFA is best assessed in the prone position.

relation between femoral anteversion and osteoarthritis. A subset of patients exists in whom the limits of tolerance in hip or knee range of motion is exceeded and for whom the risk for early degenerative changes may be increased (27, 28). In these patients, the alteration in rotation places increased stress across the hip or knee, which can promote the development of osteoarthritic changes. The precise limit of tolerance remains undefined. However, the presence of hip or knee pain should be considered as indications for osteotomy (29).

Although the presence of excessive hip external rotation may augment posterior shear loads, an increased incidence of slipped epiphysis has not been found in patients with femoral retroversion without other contributory factors being present (17). Athletic ability does not correlate with the position assumed during normal walking, although some activities may be hindered by rotational variations, particularly hip or tibial external rotation (30–32). High-performance sprinters, however, tend to adopt a toed-in position during running regardless of their walking style (32). Functional impairments such as tripping, clumsiness, or lack of running ability, although often attributed to rotational differences, have not been shown to correlate with rotational profile (30).

There are some children with such extreme variation in rotation that the appearance of their gait is unacceptable to them or their parents. The natural history of rotational variation, the lack of evidence for musculoskeletal sequelae, and the absence of objective functional disability must be kept in mind and the family educated in this regard (1, 3–5). The natural history of rotational variation should be clearly communicated to the parents and understood by them prior to any recommendation for active treatment.

Treatment. The natural history of rotational variations is gradual normalization. No treatment is necessary in most children who present with concerns of in-toeing or out-toeing. The use of shoe modifications, orthotics, or positioning devices is ineffective (5, 17). Although these measures are not harmful, there is no data to show any positive effect. Their use reinforces the errant notion that in-toeing or out-toeing is an abnormal condition or disorder that requires treatment. The cost of orthopaedic shoes and orthotics can be considerable. Muscle-strengthening exercises or activities may diminish the dynamic component that produces variation in gait; however, no studies have addressed this specific topic. Treatment options for foot and ankle abnormalities are covered in Chapter 29.

Rotational osteotomy may be considered for those otherwise healthy children who have persistent rotational abnormality into later childhood and adolescence and find the appearance of their gait or their function unacceptable (4, 5, 27, 33, 34). Gait may appear less awkward following osteotomy. Patients and their parents often express satisfaction with the change in appearance following osteotomy. Improvement in function is variable and less predictable. Those with in-toeing typically note less tripping. Those with out-toeing are more likely to notice an improvement in running ability.

Pain, although rarely a complaint, may be improved following surgical treatment (27). Most often, this occurs in patients with malicious malalignment or the combination of femoral internal rotation with tibial external rotation (27, 35) (Fig. 27-5). These patients may experience knee symptoms preoperatively, likely related to the increased shear forces through the knee. This combination of rotational abnormalities has been associated with some risk of patellofemoral arthritis (36, 37).

The authors preferred technique for correcting rotational deformities of the tibia/fibula is a supramalleolar osteotomy of the tibia and at times also of the fibula (Figs. 27-6 to 27-9). A distal correcting osteotomy has less potential for serious neurovascular complication than does proximal tibial osteotomy (33, 38). The tibia should be cut 2 to 3 cm above the physis and parallel to the ankle. It is essential that the plane of the osteotomy be perpendicular to the longitudinal axis of the tibia (rotation of the distal on the proximal fragment through an oblique cut may introduce problematic angular deformity). For rotational deformities >30 degrees, the addition of a fibular osteotomy facilitates the ability to rotate the tibia without inadvertent translation of the distal fragment relative to the proximal tibia. The degree of correction is determined by aligning the foot and ankle, such that the second toe is in line with the tibial tubercle and the center of the patella. As the foot is dorsiflexed and knee bent, the foot should remain in line with the lateral thigh. This aligns the flexion–extension axes of the ankle, knee, and hip.

For fixation in younger patients, the authors prefer crossed K-wires supplemented with a long leg, bent knee cast. Two or three stainless steel wires of appropriate size are inserted; one from proximal medial to distal lateral and avoiding crossing the medial growth plate of the distal tibia and the second from distal medial to proximal lateral. A third wire is used if rotational stability does not seem adequate with two wires. A long leg bent knee cast is used for 6 weeks. Healing is usually sufficient at that time for pin removal and application of a short-leg weight-bearing cast for an additional 4 weeks.

In older (>8 to 9 years of age) and/or larger patients, a small-fragment T-plate or cloverleaf plate can be used for tibial fixation. The T-plate is placed anteriorly just proximal to the distal tibial growth plate. If a cloverleaf plate is used, it can be placed medially. A short-leg cast is worn for 5 weeks. Toe-touch weight bearing is allowed. The short-leg cast is changed to a moon boot at 5 to 6 weeks and progressive weight bearing allowed. Plate removal later may be necessitated by the subcutaneous position of the plate.

Correction of excess femoral internal or external rotation is obtained by equalizing the degree of internal versus external rotation. The amount to be rotated can be estimated during the prone examination, comparing internal and external hip rotation, preoperatively (5). Femoral osteotomy may be performed proximally, distally, or midshaft depending on the surgeon's preference and the type of fixation to be used (34, 39) (Figs. 27-10 to 27-15). Proximal femoral osteotomy is preferred if there is also varus, valgus, flexion, or extension deformity of the hip. Similarly, angular deformities about the knee are better addressed by a distal femoral osteotomy. A standard lateral approach to the

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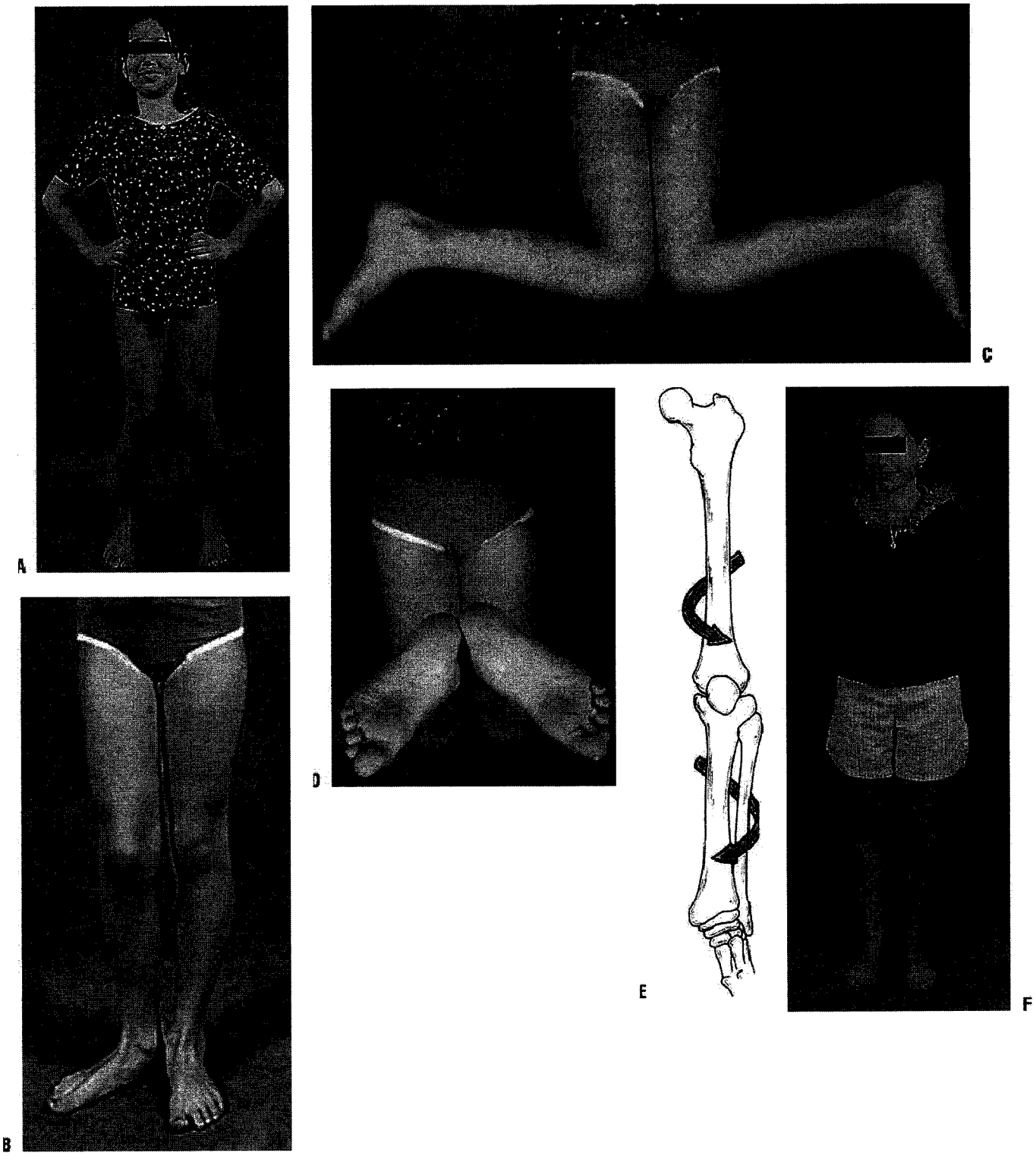

FIGURE 27-5. **A:** This 10-year-old girl is attempting to stand with her feet directly forward. The patellae face medially, and with effort she can direct the feet straight ahead. **B:** When the limb is positioned with the patella facing forward, the outward rotation of the foot becomes apparent. **C:** Examination in the prone position demonstrates approximately 80 degrees of internal rotation of the thigh, or medial femoral torsion. **D:** With knees flexed, the outward direction of the foot can also be appreciated. If the rotational deformities are complementary, foot progression may be deceptively normal. **E:** The combination of increased medial thigh rotation and external rotation of the lower leg segment may result in symptomatic torsional malalignment. This deformity may be a cause of nonspecific knee pain in adolescents because of the increased shear forces through the knee. **F:** Combined femoral external rotation and tibial internal rotation osteotomies correct the malicious malalignment. Knee symptoms are predictably improved.

Supramalleolar Rotation Osteotomy of the Distal Tibia and Fibula (Figs. 27-6 to 27-9)

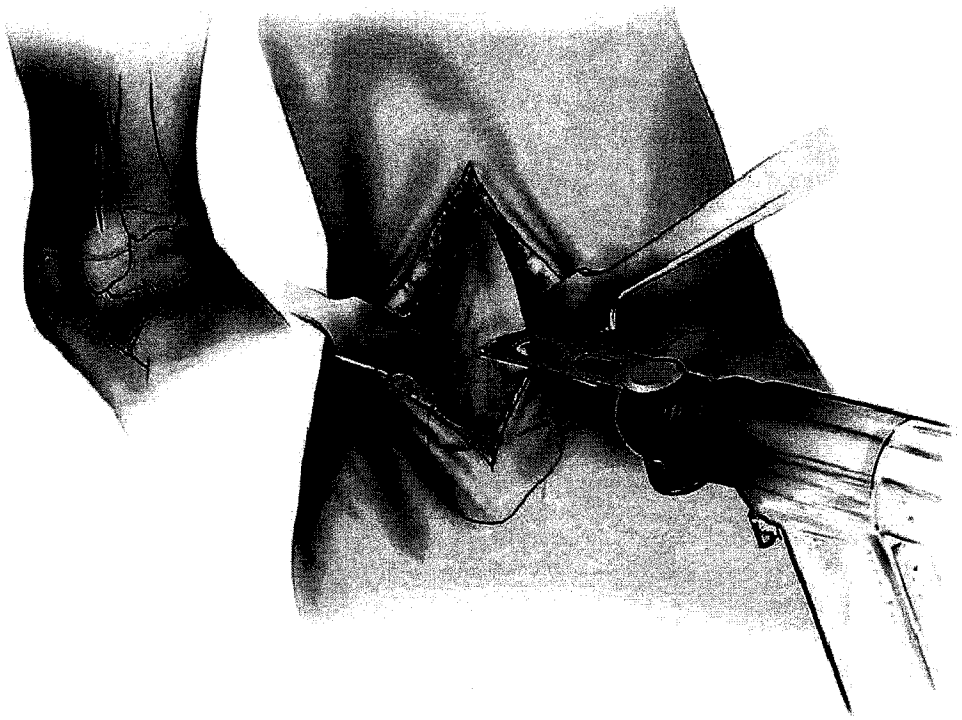

FIGURE 27-6. Supramalleolar Rotation Osteotomy of the Distal Tibia and Fibula. The fibula can be cut first, using a 3 cm longitudinal incision along the lateral, subcutaneous border, above the level of the ankle. Small metacarpal retractors are placed subperiosteally. A transverse osteotomy is completed using a power saw with a small, thin blade.

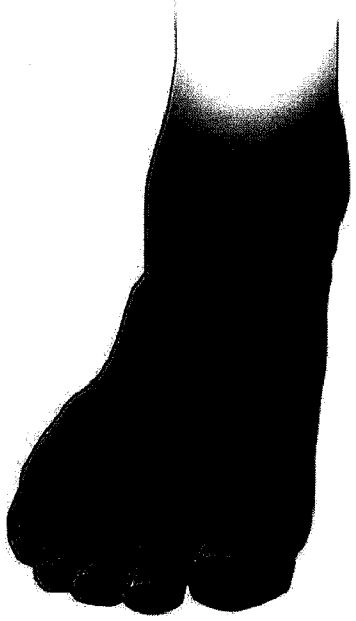

FIGURE 27-7. The incision for the tibial osteotomy is made along the anterior border of the tibia, extending proximally from the ankle crease 4 to 5 cm.

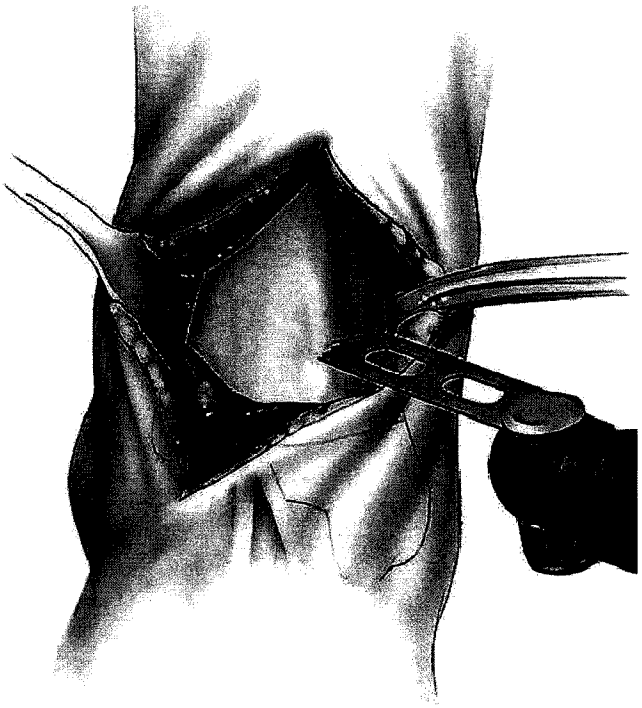

FIGURE 27-8. The tibia is approached medial to the anterior tibial tendon. The periosteum is incised and Crego retractors placed under the periosteum, medially and laterally. In skeletally immature patients the growth plate can be identified by the thickened, adherent periosteum or with use of an image intensifier. A transverse osteotomy perpendicular to the axis of the tibia is completed using a power saw 1 to 1.5 cm proximal to the physis. If the cut is made obliquely, rotation with result in an angular deformity.

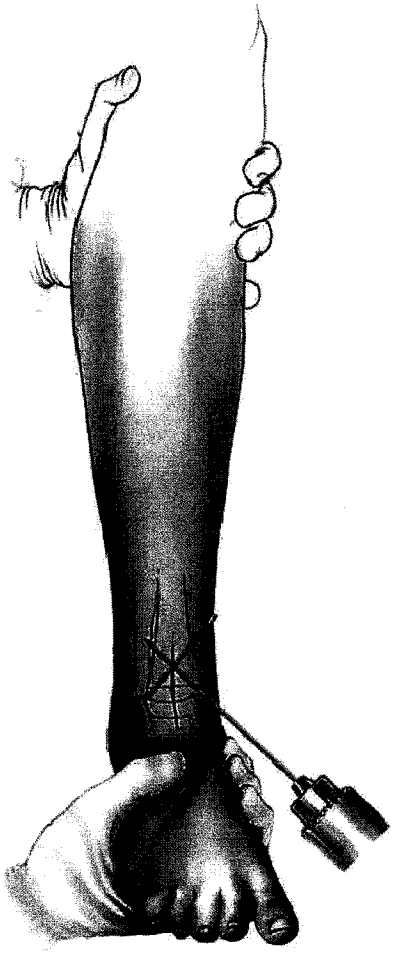

FIGURE 27-9. The foot and ankle are rotated to the desired position. With the knee flexed to 90 degrees, the second toe should align with the shaft of the tibia as the ankle is dorsiflexed. The osteotomy is fixed using two smooth stainless steel wires, avoiding the physis if possible. A long leg, bent knee cast is applied.

Femoral Rotation Osteotomy Using an Intramedullary Nail (Figs. 27-10 to 27-15)

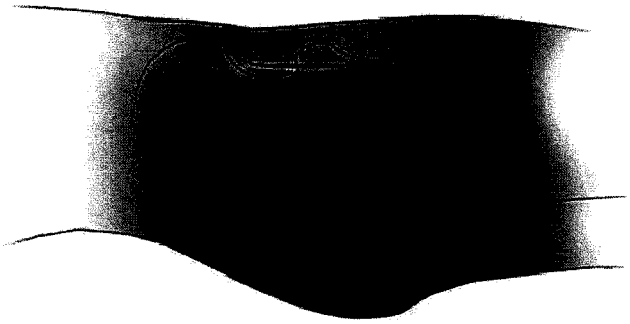

FIGURE 27-10. Femoral Rotation Osteotomy Using an Intramedullary Nail. The patient is placed supine on a radiolucent table. A 4-cm longitudinal incision is made over the greater trochanter. The lateral aspect of the greater trochanter is exposed, using blunt and sharp dissection.

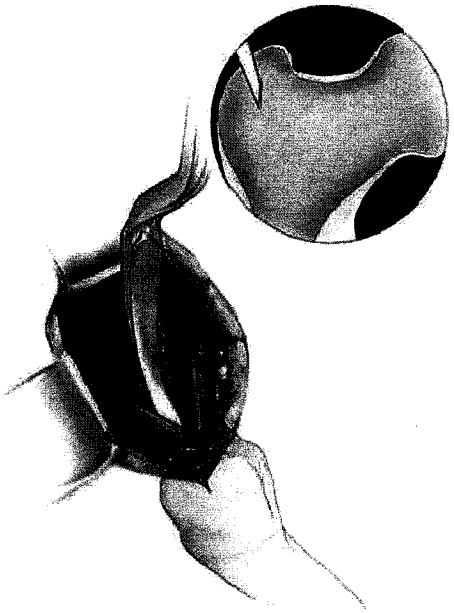

FIGURE 27-11. An awl is used to create an entry point in the lateral aspect of the greater trochanter taking care to avoid penetration of the medial aspect of the trochanter which can injure the medial circumflex vessels. The position is confirmed using image intensification.

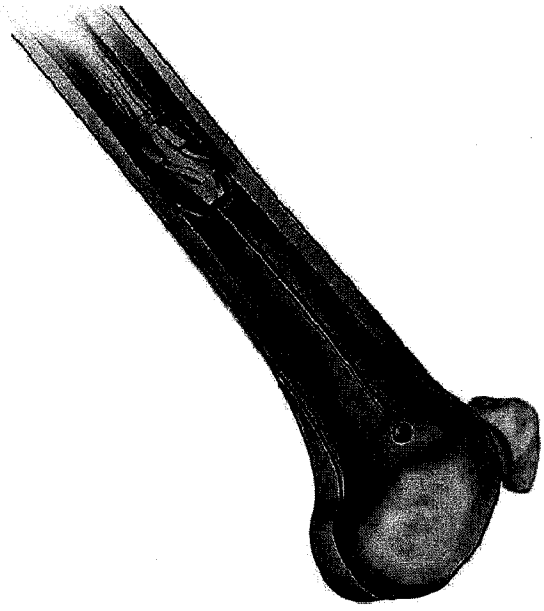

FIGURE 27-12. A guide-wire is passed and the canal is reamed 1.5 mm greater than its diameter.

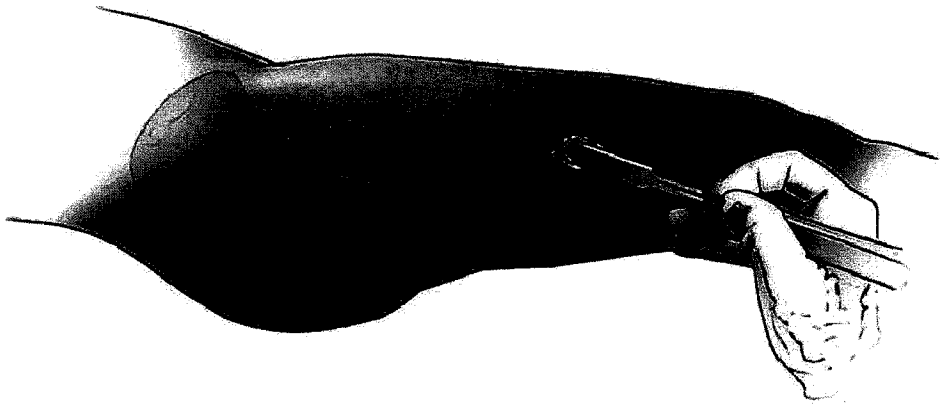

FIGURE 27-13. A 5-cm lateral incision is made at the mid-shaft of the femur and minimal subperiosteal exposure completed. Multiple drill holes are made using a 3.2-mm drill-bit. An osteotome is used to complete the cut.

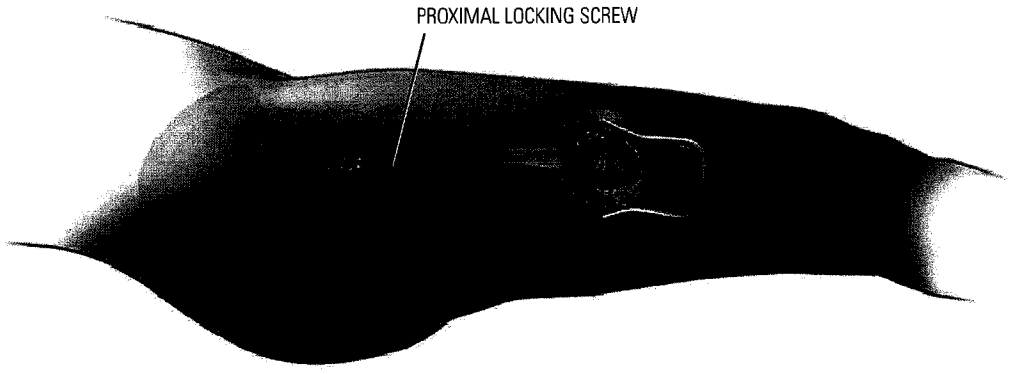

FIGURE 27-14. The nail is then inserted and passed across the osteotomy under direct vision. The nail length is chosen by measuring the distance from the greater trochanter to 2 cm proximal to the distal femoral physis on the lateral radiograph. The proximal locking screw is inserted.

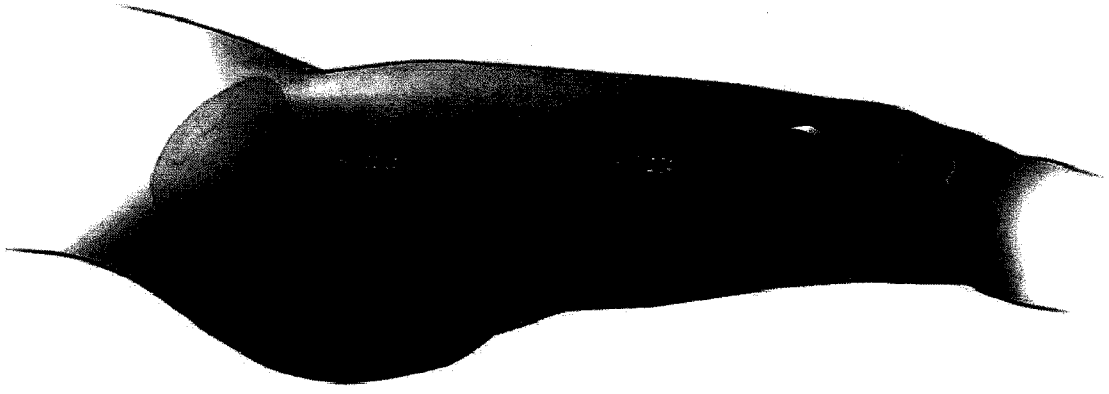

FIGURE 27-15. The femur is rotated to the desired version and a distal locking screw inserted. The range of internal and external rotation can be assessed and adjusted if needed. The second locking screw is inserted. Weight-bearing is allowed as tolerated.

femur is used, whether proximal or distal. In proximal osteotomy, a pediatric or adolescent blade plate is used for fixation. If a distal femoral osteotomy is performed in a skeletally immature patient, a small straight compression plate or 95-degree condylar (adolescent) blade plate may be used for fixation. The use of cast or orthotic immobilization is at the discretion of the surgeon. Alternatively, a medial approach can be used along with K-wire fixation (34). This latter technique should be reserved for smaller children and must be supplemented with a spica cast. The desired amount of rotational correction is typically that which achieves an equal amount of internal and external rotation.

In children 9 years of age or older, intramedullary (IM) fixation can be used for either the tibia or the femur (39, 40). Locking screws or similar mechanisms are needed proximal and distal to the osteotomy because the osteotomy has no intrinsic stability. In the skeletally immature and in those with a relatively narrow medullary canal, the osteotomy is generally performed by a limited open technique. The proximal femur entry site is made lateral and distal to the tip of the greater trochanter. Great care is taken to avoid any dissection (including penetration) on the medial side of the trochanter. A recent modification in femoral nail design (proximally angulated 15 degrees) facilitates correct nail placement. This lateral trochanter entry site is necessary to avoid injury to the medial portion of the trochanteric growth plate and injury to the terminal branches of the medial circumflex artery in the trochanteric fossa. Neither coxa valga nor avascular necrosis has occurred in our early experience with this approach (40). Fixation with an IM rod does not allow for any concomitant correction of varus, valgus, flexion, or extension. However, IM fixation does allow for early weight bearing, a particular advantage if bilateral procedures are performed.

Increased femoral internal rotation and tibial external rotation may coexist, producing a rotational malalignment (35, 41) (Fig. 27-5). Knee pain, which is usually nonspecific, may be present. Patellar maltracking usually is not present. Because the deformities are complementary, foot progression may be normal, but the static examination will demonstrate the abnormality. Combined osteotomy of the femur and tibia may be necessary to correct symptomatic malrotation (4, 35, 41). Femoral rotation is corrected as the first step of the procedure. The foot is then aligned with a tibial osteotomy completing the correction. Satisfactory correction aligns the planes of motion of the hip, knee, and ankle. Correction of bilateral deformities can be performed as staged unilateral procedures 6 to 12 months apart.

Complications. The risks and complications of in-toeing and out-toeing are related to its treatment, not its presence (3–5, 17, 19, 20, 30). Because most patients who have surgical alteration of their rotation do so to effect a change in the appearance of their gait, the surgical procedure must accomplish the desired change in rotation. Functional change is noted in some children, but not consistently.

Complications of rotational osteotomy are the same as for other osteotomies. Problems related to nonunion, infection, blood loss, joint stiffness, scarring, and anesthesia are the most serious (33–35, 38, 42). Distal tibial osteotomy has less risk of compartment syndrome and peroneal nerve injury than proximal osteotomy. Whether performed proximally or distally, the use of a blade plate for fixation of a femoral osteotomy may inadvertently produce undesirable frontal or sagittal plane deformity. Similarly, inadvertent deformity can be produced in the distal tibia if an oblique osteotomy is made, rather than a transverse cut, in performing a distal tibial osteotomy. The authors avoid crossing the distal tibial physis when using K-wires to fix a supramalleolar tibial osteotomy. We have observed distal tibial physeal growth arrest and deformity following K-wire penetration of the medial tibial physis. Asymmetric growth arrest can occur from periosteal stripping and injury to the lateral distal femoral physis. Injury to the greater trochanteric apophysis can produce valgus deformity in the proximal femur.

Angular deformity may be less problematic when a locked IM fixation device is used; however, adjustments in position can be difficult once the rod is locked. Use of a lateral entry point helps minimize the risk of avascular necrosis to the femoral head or disruption of normal growth of the proximal femur (40, 42). Recent changes in pediatric IM nail design permit safer entry through the lateral aspect of the greater trochanter, minimizing both of these complications (40). In the skeletally immature patient, use of this lateral entry site is imperative.

PHYSIOLOGIC BOWING AND GENU VARUM

Physiologic Bowing

Definition. Infants and children frequently present to the orthopaedic surgeon for evaluation of bowing (43). Often, these children are early walkers, achieving independent ambulation before their first birthday (44, 45). The normal knee alignment at birth is 10 to 15 degrees of varus, which remodels to a neutral femoral–tibial alignment at approximately 14 months of age (1, 46–48) (Fig. 27-16). Levine and Drennan (49) have defined physiologic bowing, radiographically, as more than 10 degrees of bilateral femoral–tibial varus is noted after the age of 18 months. These children will often have associated internal tibial torsion which results in a characteristic bowed, intoed gait.

Clinical Features. Parents are concerned with both the cosmetic appearance of the bowing, in-toeing deformity, and the associated problems of excessive tripping. A family history of bowing is common (45, 50). Examination reveals bowing of both the lower extremities with in-toeing (Fig. 27-17). Although the bowing deformity is bilateral, it may be asymmetric. Despite their bowlegged, toed-in gait, these young children are characteristically very agile walkers. The child should be observed walking, both toward and away from the examiner, to assess the severity of the dynamic varus and associated internal rotation deformity. Internal rotation of the extremity permits contact of the foot with the floor as the child stands. This also maintains the body center over the midline as the child walks. The presence of a lateral thrust should be noted. This is a brief,

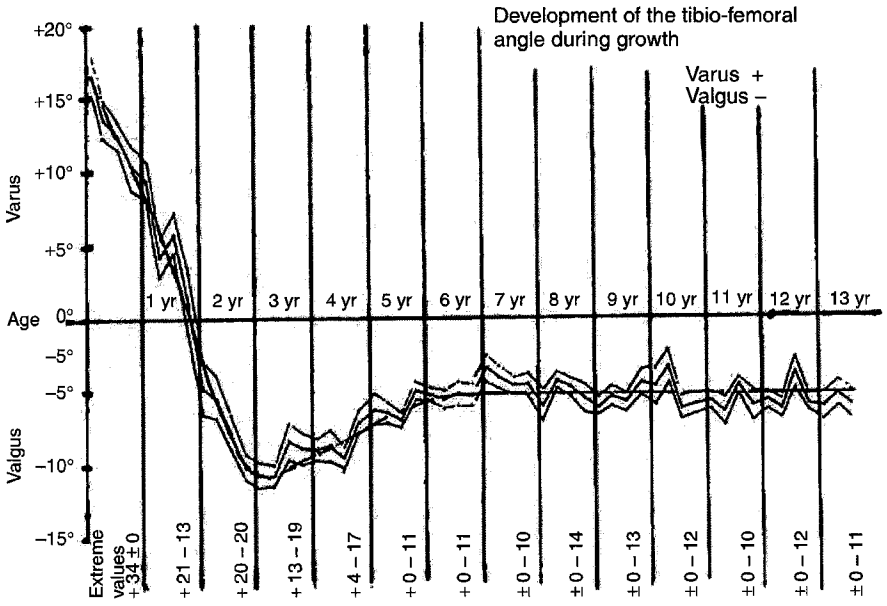

FIGURE 27-16. The graph depicts the expected change in genu varum and genu valgum with age. Children with bowlegs after 2 years of age are outside the normal range and should be thoroughly evaluated. (From Salenius P, Vankka E. The development of the tibiofemoral angle in children. *J Bone Joint Surg Am* 1975;57: 259, with permission.)

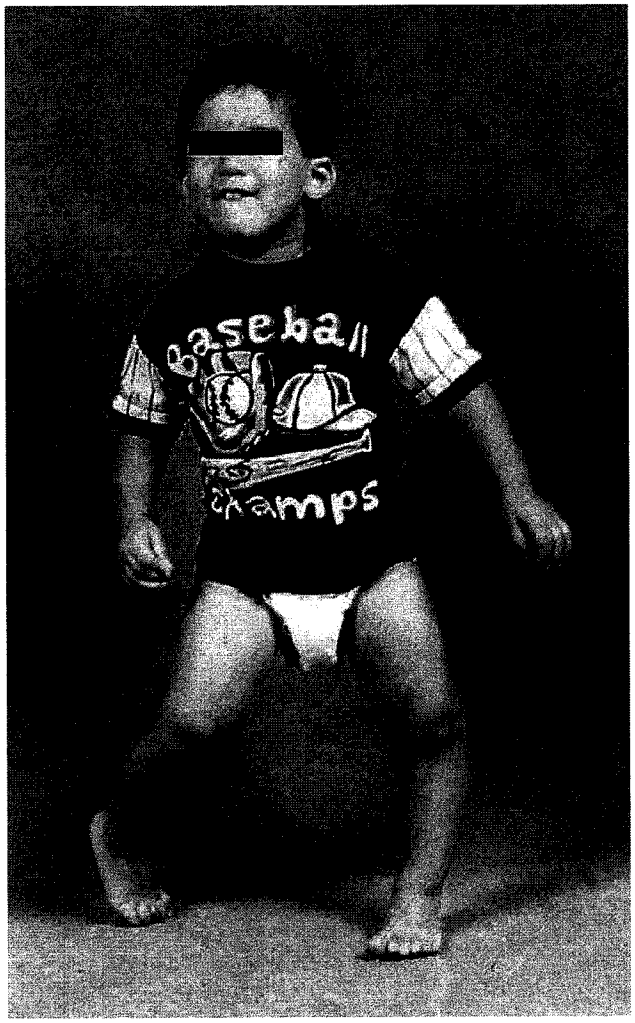

FIGURE 27-17. Examination of the child with physiologic bowing shows symmetric bowing throughout the tibia and internal tibial torsion which is often more noticeable with walking.

dynamic, lateral, knee movement that occurs during single-leg stance. It can represent a lateral subluxation or shifting of the femur on the depressed medial tibia or lateral ligamentous laxity. A lateral thrust is characteristic of pathologic bowing. The amount of varus deformity of the lower extremity can be measured with a goniometer, with the knees extended and patellae facing forward. The distance between the knees when the patient stands with the ankles together is noted. Photographs are helpful in documenting the deformity. Angular and rotational alignment and joint range of motion of the entire lower extremity are assessed. Medial–lateral knee joint laxity is not usually present in physiologic bowing.

In younger children, those <18 months of age, radiographs can document the degree and location of the varus deformity, but usually will not distinguish between physiologic bowing and early Blount disease. Radiographs are an essential part of the evaluation in the older child (over 18 months of age). Radiographs are also indicated for those with more pronounced deformities (clinical femoral–tibial angle >20 degrees), when a lateral thrust is observed, if the child is of short stature (below fifth percentile), or if a metabolic bone disease is suspected (Fig. 27-18). The radiograph is taken with the patient standing, if possible, and the patellae pointing straight ahead. The relative degree of varus deformity is noted by observing the shaft-to-shaft angle of the femur and tibia (51, 52). More importantly, the distribution of bowing deformity is noted (53). When physiologic, the bowing occurs throughout the distal femur, proximal tibia, and distal tibia. In contrast, in early Blount disease, the varus deformity is more focally limited to the proximal tibia.

Differential Diagnosis. The differential diagnosis of bowing in the young child includes physiologic bowing and pathologic bowing (Table 27.1). Pathologic bowing occurs in infantile tibia vara (Blount disease), metabolic bone disease, skeletal dysplasias (Fig. 27-18B–D), and focal fibrocartilaginous dysplasia. The clinical and radiographic features

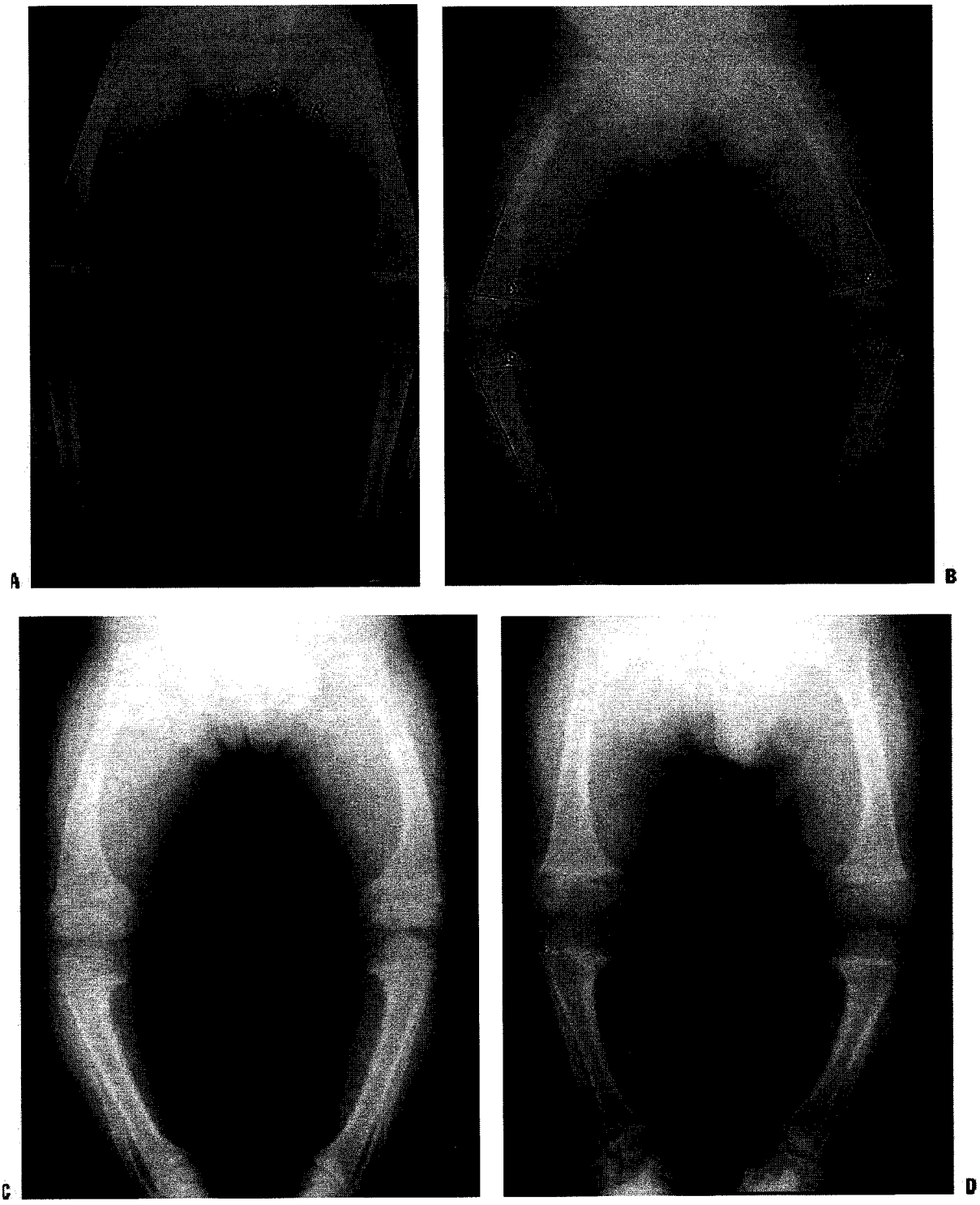

FIGURE 27-18. Standing AP films of both lower extremities help distinguish physiologic bowing from pathologic causes. **A:** Tibial MD angles are typically 11 degrees or less. A similar angle constructed in the distal femur is the same or greater, indicating that the femur and tibia contribute similarly to the bowing. The ratio of femoral to tibial MD angle is >1. **B:** Early Blount disease may be difficult to distinguish from severe physiologic bowing. The MD angle in Blount disease is usually >16 degrees and the ratio of femur to tibia is <1. Fragmentation of the medial tibial metaphysis may not be evident. **C:** This patient with XLH has multiple widened physes. Osteopenia is evident in the adjacent metaphysis, which is also flared. Bowing tends to be more diffuse throughout the bone rather than focal in the proximal tibia. **D:** Skeletal dysplasia, such as chondrometaphyseal dysplasia, may cause genu varus. These children are usually of short stature. Skeletal abnormalities are multifocal as in this example of Schmid metaphyseal chondrodysplasia. The proximal and distal metaphyses of the femur and tibia are all abnormal. The epiphyses, physes, and bone density are normal.

TABLE 27.1 Differential Diagnosis of Bowed Legs

- Physiologic bowing
- Blount disease
- Metabolic bone disease
  - XLH rickets
  - Nutritional rickets
- Skeletal dysplasia
  - Achondroplasia
  - Pseudoachondroplasia
  - Metaphyseal chondrodysplasia
- Neoplastic disease

associated with metabolic bone disease or skeletal dysplasia readily differentiate these pathologic conditions from physiologic bowing. Most often, the necessary differentiation is between physiologic bowing and infantile Blount disease. If the bowing is physiologic, the entire lower extremity will appear to be bowed. If the varus results from a relatively greater deformity of the proximal tibia, infantile tibia vara or Blount disease may be present (54–56). Children with either physiologic bowing or Blount disease usually are early walkers and typically present for evaluation at 15 to 18 months of age. Often, there is a positive family history of bowing deformity (in siblings, parents, uncles, and aunts) (45, 54). Physiologic bowing and Blount disease are two points within the same spectrum, with Blount disease being the pathologic result of unresolved infantile bowing (51, 54). Frequently, one extremity will have physiologic bowing, with Blount disease affecting the contralateral tibia.

Radiographic Evaluation. Radiographic distinction between physiologic bowing and Blount disease is not obvious in very young children. The Langenskiöld changes, diagnostic of Blount disease, are not always distinct before 2 to 3 years of age (47, 50, 51, 53, 56). Measuring the metaphyseal–diaphyseal (MD) angle of both the proximal tibia and distal femur helps to identify the location and relative severity of varus deformity (51, 55, 56). Although an absolute MD angle is not diagnostic, it does serve as an early guide in differentiating Langenskiöld stage I infantile Blount disease from physiologic bowing (44, 49, 50, 53) (Fig. 27-19). Measurement can be affected by limb position (56). A study of the proximal tibial MD angle in patients with bowing (physiologic bowing or Blount disease) identified two distinct populations with considerable overlap (54, 55) (Fig. 27-20). On the basis of this study by Feldman and Schoenecker, when the MD angle is 10 degrees or less, there is a 95% probability that the diagnosis is physiologic bowing. Conversely, if the MD angle is 16 degrees or more, there is a 95% probability that Blount disease is present. Bowen et al. (52) noted that all children with a tibial MD angle >16 degrees showed progression of the varus deformity. For those patients with an MD angle between 10 and 16 degrees, follow-up for at least 1 to 2 years is necessary to determine whether the bowing resolves (physiologic bowing) or progresses (Blount disease).

The ratio of the distal femoral MD angle relative to that of the proximal tibia can be helpful in differentiating physiologic bowing from early Blount disease. This is measured on the AP lower extremity x-ray film by constructing a distal femoral MD angle similar to that measured in the proximal tibia. This angle represents the contribution of varus in the distal femur to the overall measure of femoral–tibial varus in the limb. The distal femoral MD angle is divided by the proximal tibial MD angle. This quotient represents the proportion of varus found in the femur relative to the tibia. A ratio of >1 suggests that the bowing is physiologic, that is the femur contributes as much as the proximal tibia to the varus, and resolution is expected to occur (55). A ratio of <1 indicates that the bowing is predominantly within the tibia and is more likely to evolve into Blount disease.

Bowing can be associated with metabolic bone disease or skeletal dysplasia (Fig. 27-18C,D). Rickets [usually X-linked hypophosphatemic (XLH) rickets] is the most common metabolic bone disease to present as a bowed leg deformity in a toddler (57, 58). Nutritional rickets should be suspected if the child was breast-fed and did not receive supplemental vitamin D. Infants presenting with rickets are short; the measured

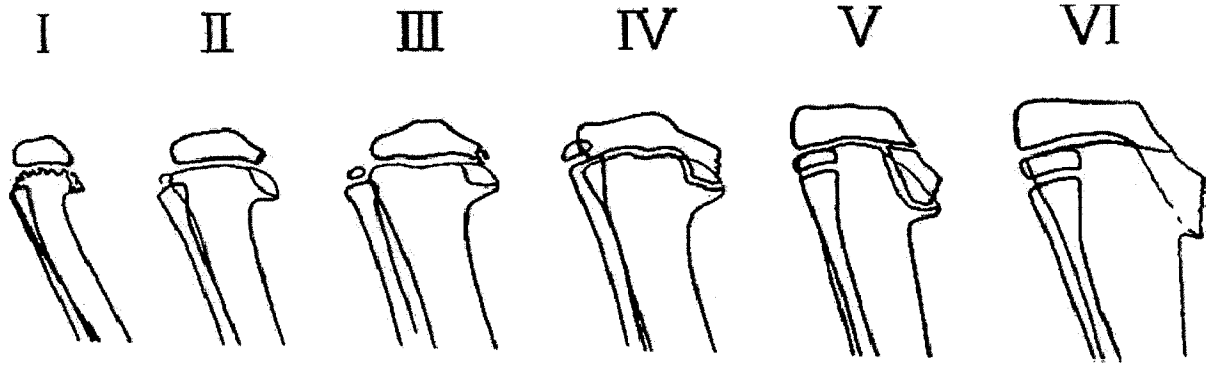

FIGURE 27-19. Depiction of the six stages of radiographic changes seen in Langenskiöld classification of tibia vara. (From Langenskiöld A. Tibia vara: a critical review. *Clin Orthop Relat Res* 1989;246:195, with permission.)

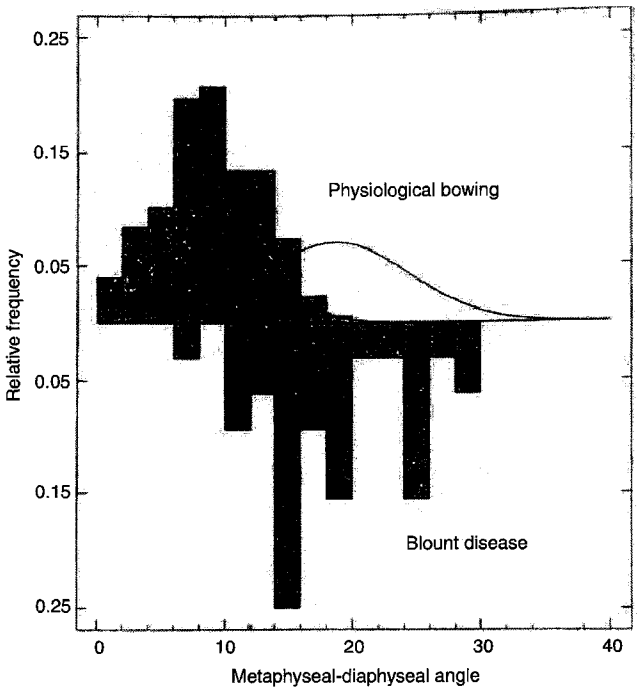

FIGURE 27-20. The relative frequency of MD angle measured in children with physiologic and Blount disease is presented. MD angle in physiologic bowing is graphed above the horizontal line; similar measurements in Blount disease are graphed below. The bell curve to the left shows the distribution in physiologic bowing. The bell curve to the right is the distribution in Blount disease. Although peak distributions are clearly separate, there is significant overlap between MD angles of 10 and 16 degrees. Below 10 degrees, there is a 95% probability that the bowing is physiologic. Above 16 degrees, there is a 95% probability that the bowing observed is in fact Blount disease. Angles in between are indeterminate. Additional risk factors such as obesity, instability (lateral thrust), and family history must be considered.

height is often below the tenth percentile. Radiographs of infants with bowing deformity secondary to rickets should not be mistaken for physiologic bowing. In patients with XLH, the physis appears abnormally wide, and the metaphysis is flared and curves like a trumpet around the physis. Similar changes are found within all growth plates. Bone density will be diminished overall, with thinning of the diaphyseal and metaphyseal cortices. The severity of changes in bone morphology and the degree of osteomalacia is variable. The diagnosis of XLH is made by analyzing calcium and phosphate in serum and in urine (57, 58). Patients suspected of having rickets should be referred to an endocrinologist for a thorough metabolic workup.

The child who presents with bowing deformity in association with a skeletal dysplasia will be short, typically below the 5th percentile. The radiographic changes for each skeletal dysplasia varies with the site of involvement which may be principally epiphyseal, physeal, metaphyseal, or diaphyseal or involve multiple sites and may also involve the spine. Achondroplasia, the most common of the skeletal dysplasias, typically presents with bowing deformity. On a standing AP x-ray, characteristic findings include a knee centered varus deformity with an elongated fibula. Patients with pseudoachondroplasia may present with a varus deformity in association with ligamentous laxity. Metaphyseal chondrodysplasia (Schmid's or McKusick's type) typically presents with persistent bowing and short stature in an otherwise normal-appearing child (Fig. 27-16D). While the radiographic changes about the physis and metaphysis include flaring and widening of the medial metaphysis, the changes are distinct from those of osteomalacia and bone density will appear normal (see Chapter 8).

Focal fibrocartilaginous dysplasia is a very rare, but progressive, unilateral, focal deformity that can occur either in the proximal tibial metaphysis or in the distal femoral metaphysis (59–65). The clinical presentation is similar to unilateral infantile Blount disease. The lesion consists of a focus of fibroblastic and cartilaginous tissue, usually below the insertion of the pes anserinus on the tibia (Fig. 27-21). This produces an acute angulation below the metaphysis. The diagnosis is made radiographically. A characteristic indentation is noted in the medial cortex at the junction of the metaphysis and diaphysis, and a focal varus deformity is associated with it. The lesion is radiolucent and often well circumscribed, often with a rim of reactive bone. The physis and epiphysis are normal. An identical process has also been observed in a corresponding location in the distal medial femur (63). Some authors have reported spontaneous improvement in angulation. Simple curettage is recommended for persistent lesions or those in unusual locations (64).

Natural History of Physiologic Bowing. Parents should be informed that spontaneous correction of physiologic bowing is anticipated as predicted by Salenius and Vankka and Sabharwal et al. (1, 46, 47) (Fig. 27-16). Bowing, although present in infants, is often not noticed until the child begins standing. The bowing resolves, typically by 2 years of age, and physiologic valgus develops between 3 and 4 years of age (Fig. 27-22). Nonoperative treatment (orthotics, shoe modification, or nighttime splinting) is both unnecessary and ineffective. In mild deformities, the bowing and its associated internal tibial torsion predictably resolve; follow-up visits may not be necessary. For those patients with more pronounced or persistent deformities, follow-up visits are scheduled at 3- to 6-month intervals. Resolution or progression of the varus that occurs with growth can be documented by subsequent physical examination. Serial photos can be compared with the initial image to determine the degree of resolution or progression of the bowing deformity. Follow-up standing AP radiographs should be obtained if the varus does not appear improved on clinical appearance or by serial goniometric measurement. Uncommonly, varus may persist into late childhood without progressive physeal changes. Varus which does not resolve warrants continued follow-up and may require treatment before skeletal maturity with growth modulation.

Infantile Blount Disease

Definition. In 1937, Walter Blount (65) published his classic review of tibia vara or osteochondrosis deformans of the proximal tibia, noting the progressive course of both the varus

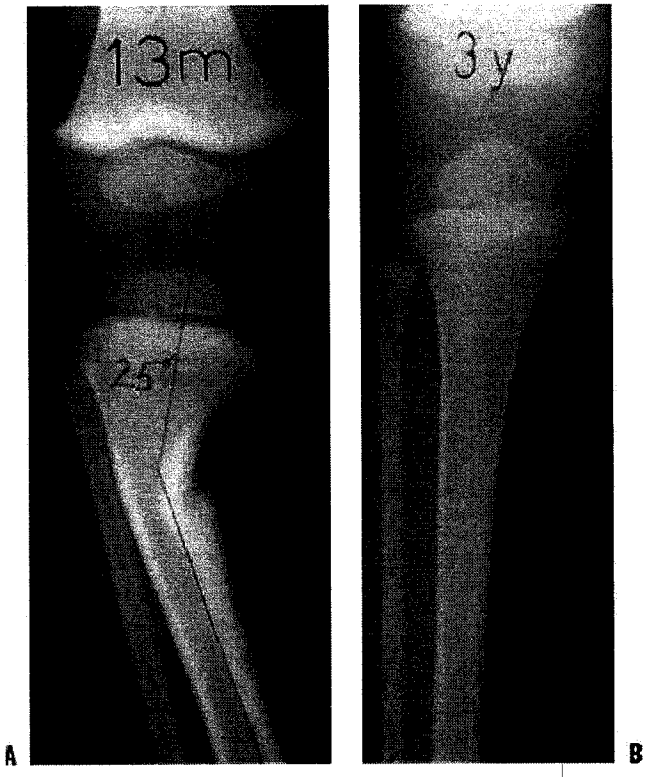

FIGURE 27-21. Focal fibrocartilaginous dysplasia. **A:** Initial radiograph of a patient at 13 months of age shows anterior and lateral bowing of the tibia, but bowing is more proximal than in congenital pseudarthrosis. **B:** The deformity resolved spontaneously, as seen in a radiograph made at 3 years of age.

clinical deformity and the correlative radiographic pathology. The distal femur is typically normal, but occasionally a valgus deformity will develop later (52, 53, 66). Both the clinical and radiographic pathology described by Blount and histopathologic changes described by Langenskiöld (44, 65, 67–70) (Fig. 27-19) were felt to be secondary to a disruption of normal growth of cartilage and bone. These progressive changes are caused by excessive focal pressure on the proximal medial tibial growth plate and adjacent bone from chronic abnormal weight bearing. Avascular necrosis of bone in Blount disease has not been observed (69). Progression of this developmental, pathologic tibia vara can be corrected with treatment (65, 67–70).

Etiology. Early on, infants with physiologic bowed leg deformity cannot be clearly distinguished from those with infantile Blount disease. Like physiologic bowing, infantile Blount disease is usually bilateral (48, 53, 54). When unilateral infantile Blount disease is noted, often the contralateral extremity is bowed physiologically. These children typically are early walkers (<10 months of age) and often are overweight (>95th percentile). As with physiologic bowing, there may be a family history of bowing deformity.

Cook et al. (71), using finite element analysis, calculated that the compressive force resultant from weight-bearing stresses on a bowed leg was sufficient to produce a disturbance in growth. Obesity increases the potential for growth disturbance. In Blount disease, the focal pathologic changes in the proximal medial tibial growth plate cause varus to progress. This chronic growth disturbance results from disorganization of the physis and the osteochondrosis of the medial proximal tibial physis and adjacent epiphysis and metaphysis as described by Blount (44, 48, 65, 67–70, 72). The proximal medial tibia fails to grow normally, and tibia vara of increasing severity develops. This results in shortening of the extremity and, if left untreated, ultimately results in depression of the medial tibial condyle and intra-articular deformity.

Pathoanatomy and Radiographic Features. In 1952, Langenskiöld identified six distinct radiographic stages of development of the proximal tibia depicting the natural progression of untreated infantile Blount disease (44, 70) (Fig. 27-19). The

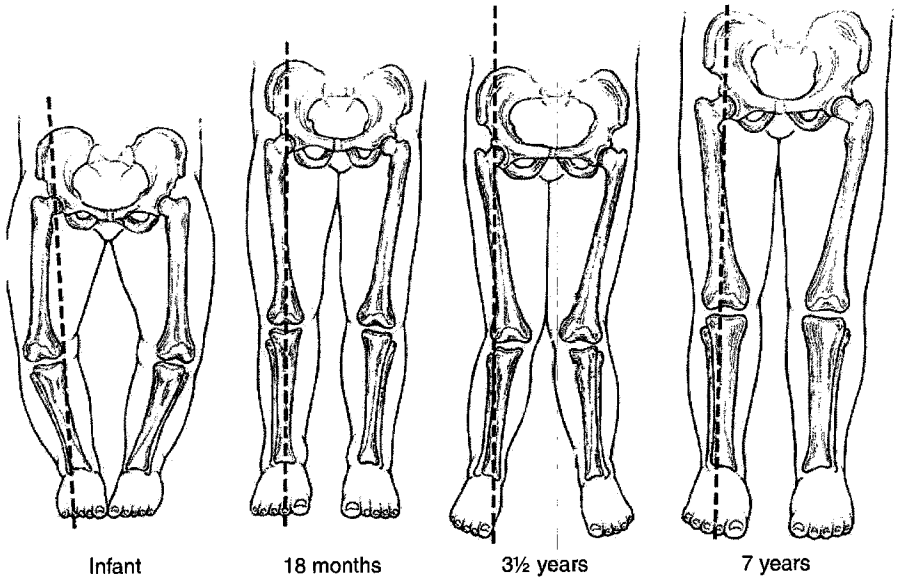

FIGURE 27-22. Lower limb alignment follows a predictable pattern. Infants typically have a gentle varus bow throughout the femur and tibia. By 18 to 24 months, the lower leg is nearly straight with a neutral mechanical axis. Valgus gradually develops and is most apparent between 3 and 4 years of age. By 7 years of age, the lower limb is in slight valgus and changes very little thereafter. Varus should not recur nor should valgus increase.

stage and the age at which it occurs have prognostic significance (48, 50–52, 73). In stages I and II, the irregular metaphyseal ossification changes are often indistinguishable from physiologic bowing. These changes may be reversible. Clear-cut stage I or stage II changes of Blount disease are typically not apparent until the patient is 2 to 2½ years of age. Stage III shows definite deformity in the proximal tibial physis, often with some fragmentation. Stage IV lesions can be associated with early bar formation across the deformed physis, as it assumes a vertical orientation (44, 70). These physeal bars are often difficult to detect. There is profound disruption of the physeal cartilage and abnormal growth in the adjacent bone as stage V develops, usually in children older than 8 years. Eventually, this process results in severe depression of the articular surface and stage VI disease (74). Consistent positioning of the lower extremities is important to detect subtle changes in the physis. Standing AP radiographs with the patellae facing forward are recommended for serial evaluations.

In North America, advanced Langenskiöld stages often occur at a much younger age than in Finland. All of Langenskiöld's patients were Caucasians from Finland, whereas a large proportion of patients in the United States are African American. North American children typically experience more rapid progression with more severe, irreversible changes at an earlier age than their European counterparts. Stage IV changes are often seen in 4- to 5-year-old children in the United States compared to 7- to 8-year-old children in Finland. The greater incidence and severity of disease has been attributed to a higher proportion of overweight children in North America (80).

The distal femur in infantile Blount disease is usually normal. Although distal femoral varus does not occur in infantile Blount disease, valgus does occasionally occur in children with more advanced tibial changes. It may be a response to the asymmetric load across the knee, allowing relative overgrowth of the distal medial femur (52, 66). More often, the valgus appearance of the femur is a consequence of severe tibial bowing and relative abduction of the hip, which creates the illusion of valgus at the distal femur.

Nonoperative Treatment. Brace treatment should be considered either in all patients <3 years of age with unilateral Blount disease changes (Langenskiöld stages I, II) or in patients older than 18 months who have persistent bowing and risk factors for Blount disease. A tibial MD angle of >16 degrees is a radiographic sign of significant risk for Blount disease (49, 54, 55). A sign of relative risk is an MD angle between 10 and 16 degrees along with the clinical appearance of a varus deformity or progression of varus. Additional risk factors include obesity, ligamentous instability, or the presence of a lateral thrust, any of which may potentiate a varus deformity (51, 54). Improvement in the tibial MD angle should be apparent within 12 months of brace treatment.

Studies have demonstrated that brace treatment can correct both the varus deformity and the pathologic proximal–medial tibial growth disturbance (75–77). In these three reports, 79 extremities were treated using a brace. The best results were obtained with unilateral deformity, where brace treatment was successful in 22 of 23 patients. In contrast, brace treatment was less successful for treating bilateral deformities, with only 18 of 28 patients noted to be successfully treated. Compliance was much more difficult to achieve for the child with bilateral deformity, as is understandable. It is also less effective in obese patients. Bracing should not be initiated after 3 years of age, nor should brace treatment be continued if Langenskiöld stage III changes develop (75–77).

We have successfully treated unilateral Blount disease with a modified knee–ankle–foot orthosis (KAFO). The knee is held in extension with a single medial upright KAFO. Thigh and calf cuffs and a varus-correcting lateral knee pad provide three-point fixation. It is worn for 23 of 24 hours (50, 51, 75–77) (Fig. 27.23). The locked KAFO counteracts the pathologic medial compressive forces, allowing resumption of more normal growth and correction of the genu varum. In those patients who are compliant, the clinical appearance of bowing typically improves over the ensuing months; however, the pathologic radiographic changes at the proximal medial tibial metaphysis, physis, and epiphysis are slower to remodel. Brace treatment is continued until the bony changes in the proximal medial tibia resolve; typically, this takes 1½ to 2 years of brace treatment (75–77). Brace treatment will be successful if by 4 years of age the mechanical axis of the lower extremity passes through the center of the knee and the depression of the medial epiphysis resolves. The radiographic appearance of the medial epiphysis and metaphysis should normalize by 5 years of age. If satisfactory correction does not occur, surgical correction should be recommended.

Operative Treatment. Children older than 2½ to 3 years with worsening stage II or evolving stage III Blount disease, who are either noncompliant or not good candidates for brace treatment because of obesity or bilateral involvement, should be treated surgically with proximal tibia and fibular varus-correcting osteotomy. Alternatively, surgical treatment with growth modulation has been shown to be effective in selected cases. Early surgery to realign the leg by 4 to 5 years of age is necessary to prevent progression to stage IV disease, when the early formation of a physeal bar can occur. Surgical treatment unloads the medial compartment of the knee and facilitates the growth of the proximal medial physis. Restoration of normal growth in the medial tibial physis is less likely to occur if surgery is delayed such as until 5 years of age (78).

Young patients and/or those with less than stage IV Langenskiold changes may be considered for growth modulation treatment (79). Growth modulation is best accomplished in this age patient with the placement of a small-fragment (typically two-hole) plate extraperiosteally across the proximal lateral tibial physis. The plate is secured by cortical screws. This construct impedes lateral physeal growth. Over time, correction will occur. Frequent follow-up visits are essential to monitor correction. This is assessed by measuring the mechanical axis of the involved lower extremity. With correction of the varus deformity, the mechanical axis will shift from its previous location medial to the center of the knee to a more lateral position. A mechanical axis slightly lateral to the center of the knee joint is desirable. The medial growth plate often

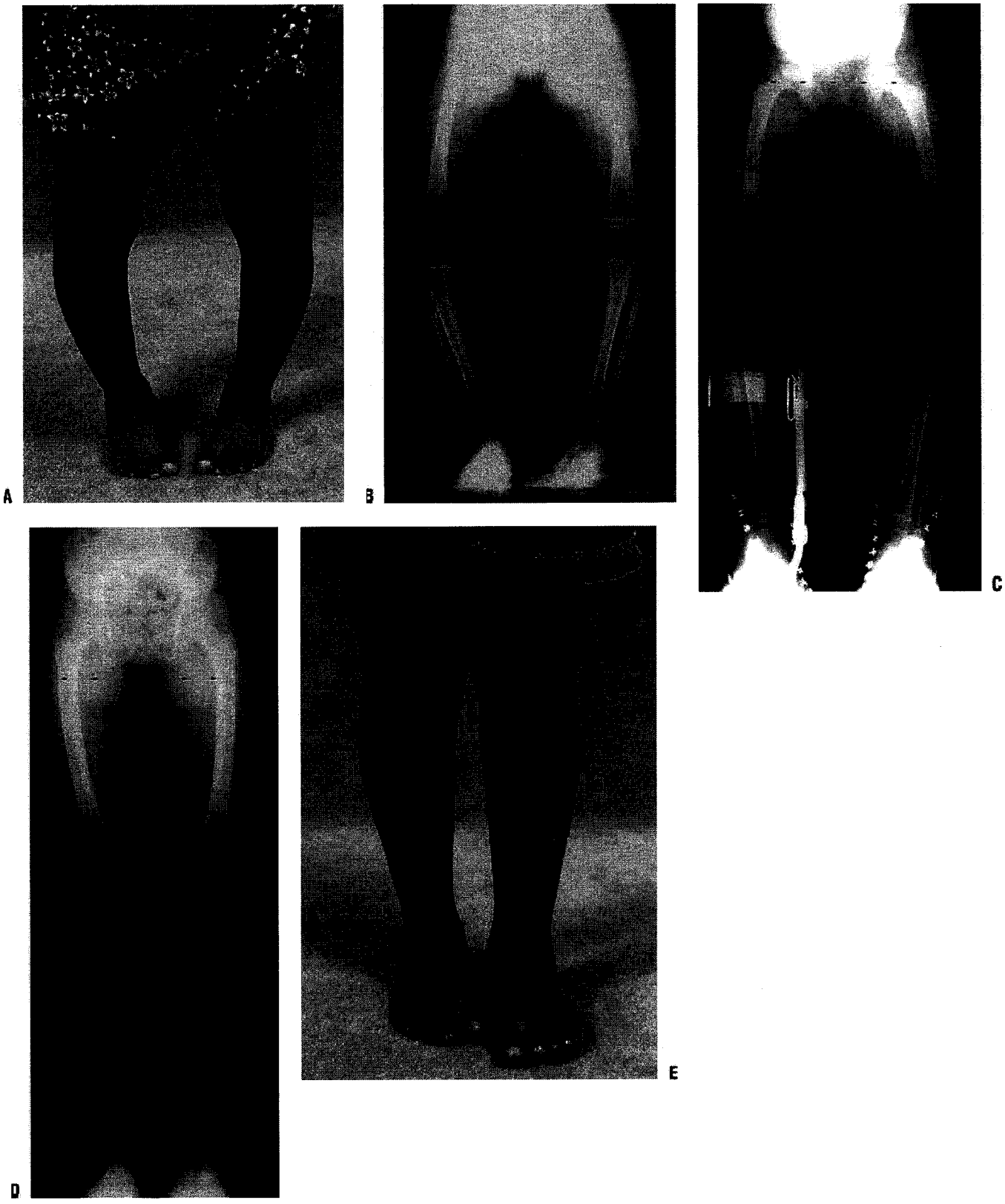

FIGURE 27-23. Orthotic treatment of Blount disease. **A:** This 2-year-old girl presented with asymmetric bowing. **B:** Lower limb radiographs show an increased MD angle with changes of stage II Blount disease. **C:** A locked KAFO was worn full time. **D:** Radiographic appearance improved following 18 months of orthotic use. **E:** Clinical appearance at 4 years of age.

continues to grow more slowly than the lateral growth plate. Slight overcorrection is desirable to compensate for the often occurring and variable differential growth of the proximal tibial physis. Continued follow-up is mandatory to assure that correction of varus is maintained and/or to address recurrent deformity. Repeat application of the plate may be needed to correct mild recurrent deformity.

Osteotomy is preferred for more severe deformity or if close, reliable follow up cannot be assured (Figs. 27-24, 27-25 to 27-32). The proximal tibial osteotomy is performed with attention to both the known inherent risks and the need for obtaining adequate correction of the deformity (78, 80, 81). The fibula is osteotomized through a separate lateral incision, taking care to avoid injury to the deep motor branches of the peroneal nerve (38, 82). The tibial osteotomy can be accomplished in a variety of methods (48, 51, 68, 78, 82–86). A straight transverse osteotomy allows for necessary correction of frontal, sagittal, and rotational deformity. The fragments are stabilized with smooth K-wires (Fig. 27-24C,D). Alternatively, Price et al. have effectively utilized monolateral external fixation to stabilize the tibial osteotomy (86). A slight "overcorrection" into valgus with or without translation of the distal fragment laterally is desirable (48, 50, 51, 82). This places the mechanical axis of the leg within the lateral compartment of the knee, unloading the medial proximal tibia. The mechanical axis of the leg can be assessed intraoperatively using the bovie cord. The cord is stretched from the center of the hip and across the center of the ankle with the leg resting on a radiolucent table. The leg should not be held, but simply allowed to rest on the table. The wire within the bovie cord, which is visible on the C-arm, is used to verify the position of the mechanical axis (Fig. 27-24E,F). This simple technique provides a reproducible method to verify that the mechanical axis has actually been transferred lateral to the center of the knee joint (82). Alternatively, an intraoperative AP x-ray film of the entire lower extremity can be taken to assess the correction obtained. If a unilateral deformity is present, clinical comparison to the normal extremity is helpful in determining whether adequate correction has been obtained. A subcutaneous fasciotomy of the anterior compartment is performed prior to wound closure. Suction drains are routinely used.

Postoperatively, the extremity is immobilized in a non–weight-bearing, long-leg, bent-knee cast. Alternatively, a spica cast is used for the child with relatively short, fat extremities. On occasion, a KAFO is used following cast removal if the preoperative deformity was severe and associated with ligamentous laxity. Following corrective osteotomy, the pathologic changes in the proximal medial tibia must be carefully monitored. These bony changes are not always reversible, and further progression in their development may be associated with a recurrence of deformity (44, 67, 69, 70). It is essential to document that valgus alignment has been obtained and maintained by the use of long cassette radiographs (hip to floor) and comparison of serial examinations until skeletal maturity (Fig. 27-24G).

Complications. Neurovascular complications are the principle risks associated with a proximal tibial osteotomy (38, 80, 87–89). A careful subperiosteal exposure minimizes direct nerve and vessel trauma. Prophylactic limited fasciotomy and the use of drains help avoid increased compartment pressure (38, 82, 89). If a compartment syndrome is suspected postoperatively, immediate fasciotomy should be performed. Based on our past clinical experience, an acute traction or impingement injury to the peroneal nerve may also occur (38). Prompt surgical release of any peroneal nerve compression has typically resulted in a satisfactory outcome.

Worsening Varus Deformity and Physeal Bar Formation. Recurrent or worsening varus deformity with persistent pathologic changes can occur despite restorative osteotomy at a young age (44, 50, 51). The risk for recurrent deformity is present in some children as early as Langenskiöld stage III and is much more common in those with stage IV disease, marked obesity (>95th percentile weight), or ligamentous laxity (48, 50, 51) (Fig. 27-33). If patients present with advanced pathologic changes or with recurrent deformity following brace or surgical treatment, an MRI or CT scan should be utilized to search for the presence of a physeal bar within the distorted proximal medial tibia. Identification of a bar may be difficult because of the serpentine course of this abnormal physis, which takes on a vertical slope as the deformity worsens. Early bridging across the physis typically occurs at the inferior aspect of the vertical limb of the distorted medial physis (Fig. 27-33B).

Progressive varus deformity may occur without an identifiable bony bar (Langenskiöld III or early IV) (48). This occurs rather subtly because of a decreased growth rate of the proximal medial tibial physis relative to the lateral physis and can occur any time prior to skeletal maturity. As the physis transitions from a normal horizontal orientation to a more vertical position, this differential growth becomes more evident. Careful observation is needed to detect this change early in the course of treatment. Premature closure of the medial tibial physis frequently occurs because of persistent deficient proximal medial physeal growth. If this occurs, the varus deformity can often be controlled with growth modulation, using an eight-plate or hemiepiphyseal staples (48, 79, 90, 91). If additional tibial physeal growth is anticipated, the internal fixation is removed after a slight overcorrection is obtained. Careful follow-up including radiographic assessment of recurrent varus deformity and/or leg-length inequality are mandatory until skeletal maturity is reached.

Operative Treatment. If an osseous bar is identified, restorative surgery is indicated. Left untreated, progressive bar formation will result in complete arrest of the medial physis (Langenskiöld stage VI). Physeal bar resection in conjunction with a varus-correcting osteotomy is most effective if the patient is young (under 10 years), the bar is relatively small, and the patient is not excessively overweight (48, 51, 70, 92, 93) (see Figs. 27-37 to 27-39). The proximal tibia is approached through an anteromedial longitudinal incision and the physeal bar is resected first. Often the bar is not discrete, but is a collection of several small punctate foci of bone that coalesce and function as a tether. The medial edge of the normal physis is often difficult to locate. Excision of the bony bridge is done cautiously, preserving as much normal physeal

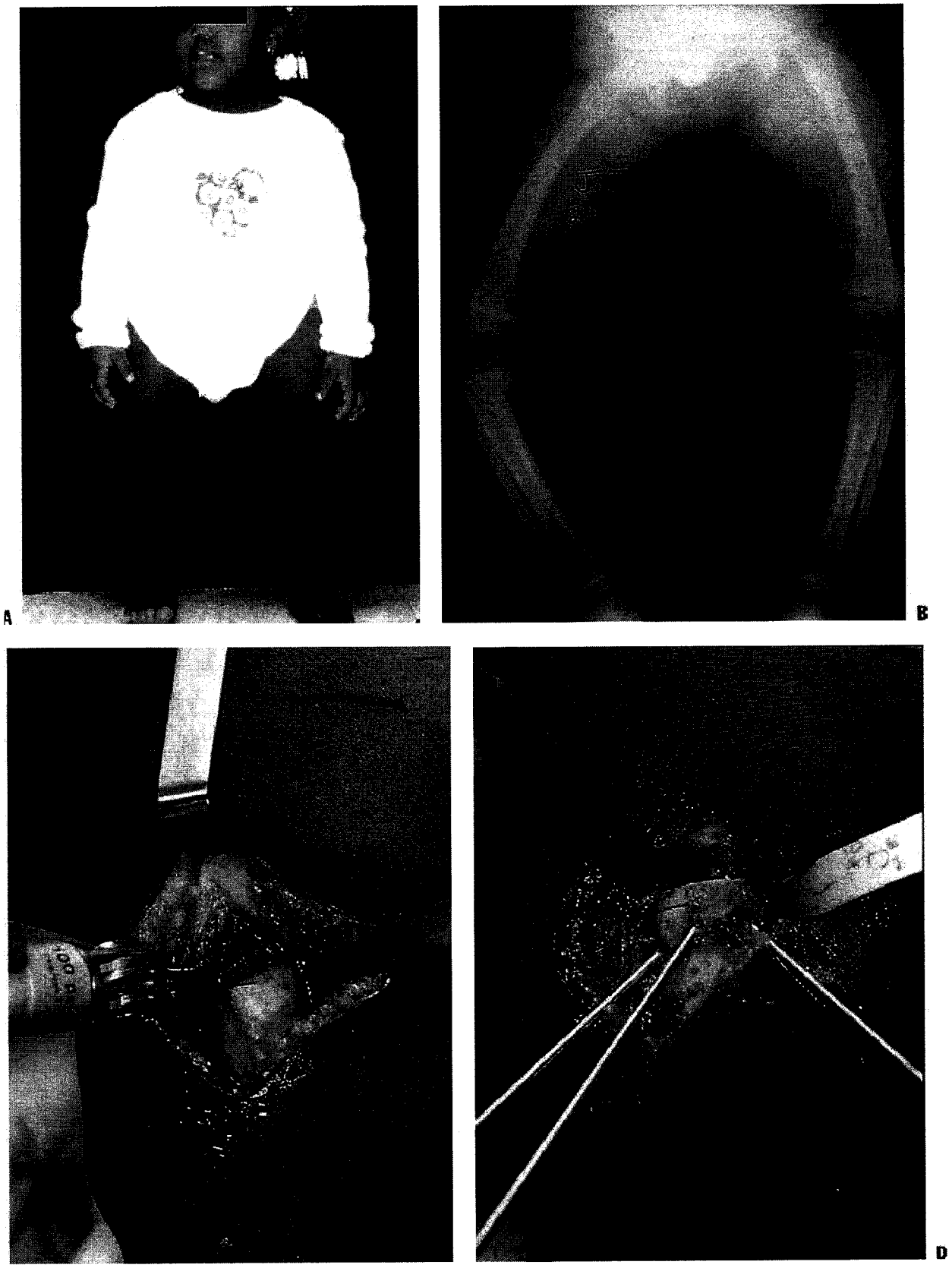

FIGURE 27-24. **A:** This 30-month-old girl shows clinically asymmetric bowing. She is large for her age (>95% weight). **B:** The MD angle on the right is 20 degrees, compared to 10 degrees on the left. This is consistent with stage II changes of Blount disease on the right and physiologic bowing on the left. **C:** A transverse osteotomy is performed distal to the tibial apophysis. An appropriately sized wedge is removed to allow slight overcorrection. **D:** Smooth Kirschner (K) wires are used for fixation, supplemented with cast immobilization.

FIGURE 27.24 (*continued*) **E:** Clinical alignment can be assessed using a bovie cord, which is visualized radiographically. The leg should be allowed to rest in its neutral position. **F:** Intraoperative films of a right proximal tibial osteotomy show slight overcorrection to valgus. A bovie cord centered over the hip and ankle is an easy method to assess mechanical axis intraoperatively. **G:** A clinical photo taken 2 years later shows maintenance of correction on the right. Spontaneous correction of physiologic bowing has occurred on the left.

tissue as possible. However, resection must be complete so that an intact physeal line coursing 180 degrees from the posteromedial to the anteromedial cortical edge of the tibia is visible. The C-arm can be helpful in monitoring the procedure. Methylmethacrylate (Cranioplast) is used to fill the void to inhibit the formation of a recurrent osseous tether. Additionally, the existing varus deformity should be surgically corrected, typically with varus-correcting osteotomies of the tibia and fibula (Fig. 27-33C). Alternatively, milder varus deformity can be corrected with growth modulation utilizing either a temporary lateral hemiepiphyseal staple or eight-plate in conjunction with the medial epiphysiolysis.

Patients experience resumption of medial physeal growth with variable success (93–95). Subsequent growth in the medial physis generally does not equal the growth of the lateral physis. There is a risk of retethering and/or premature medial physeal closure. A second bar resection and varus-corrective osteotomy can be performed for small recurrent bars in younger patients (Fig. 27-33D). If lateral hemiepiphyseal stapling or eight-plating has been done, the patient requires close follow-up for the appropriate timing of staple removal (Fig. 27-33E,F).

For larger osseous bars, or recurrent deformity in obese or older patients, a permanent lateral epiphysiodesis of the tibia

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Osteotomy of the Proximal Tibia and Fibula for Angular Deformity (Figs. 27-25 to 27-32)

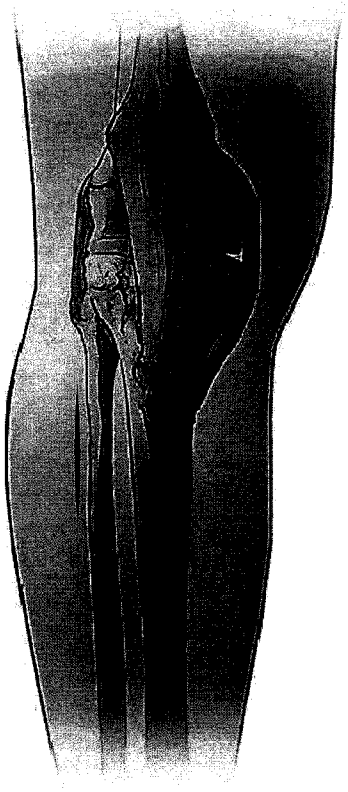


FIGURE 27-25. Osteotomy of the Proximal Tibia and Fibula for Angular Deformity. The patient is positioned supine. A radiolucent table can be used if using an image intensifier. Osteotomy of the fibula is completed using a 3-cm longitudinal incision along the posterior edge of the fibula approximately 5cm distal to the fibular head.

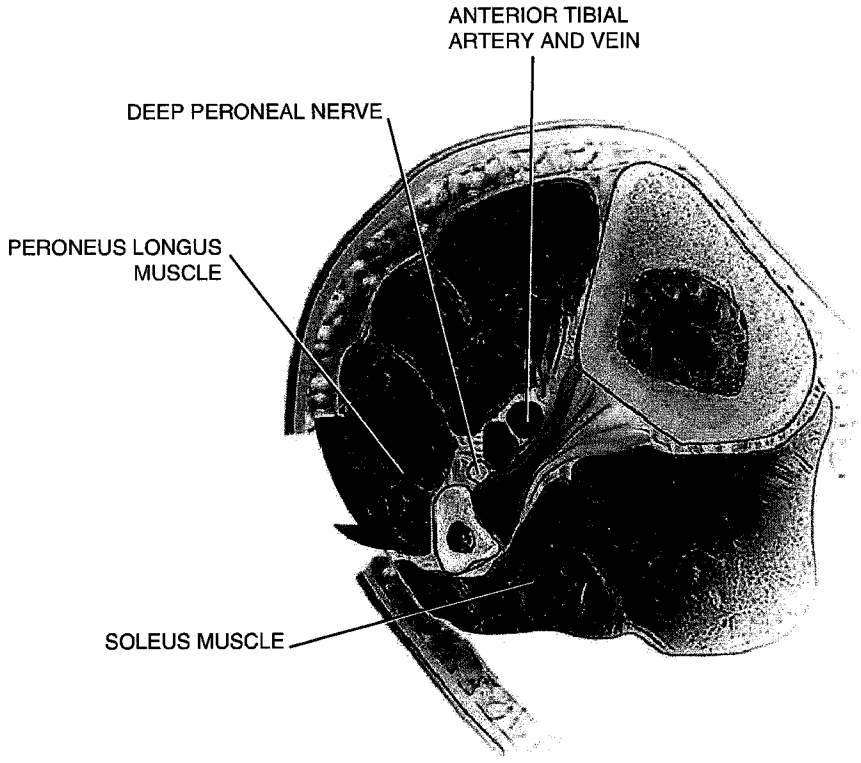


FIGURE 27-26. The posterior edge of the peroneus longus is identified and a periosteal elevator used to sweep the muscle anteriorly to expose the fibula. Metacarpal retractors are placed subperiosteally. A power saw is used to cut the fibula. For severe deformities (stage IV or greater), a 1-cm section of fibula is removed to decrease the risk of stretch on the peroneal nerve as the fibula angulates with correction of the tibia.

FIGURE 27-27. The tibia is approached using a straight longitudinal incision just lateral to the tibial crest. Oblique or serpentine incisions may complicate later reconstructive procedures as an adult.

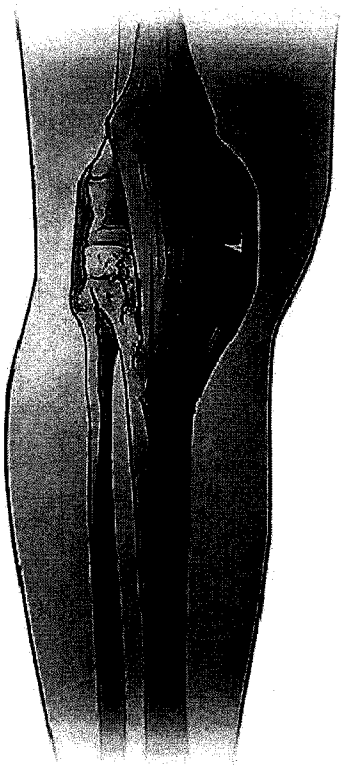
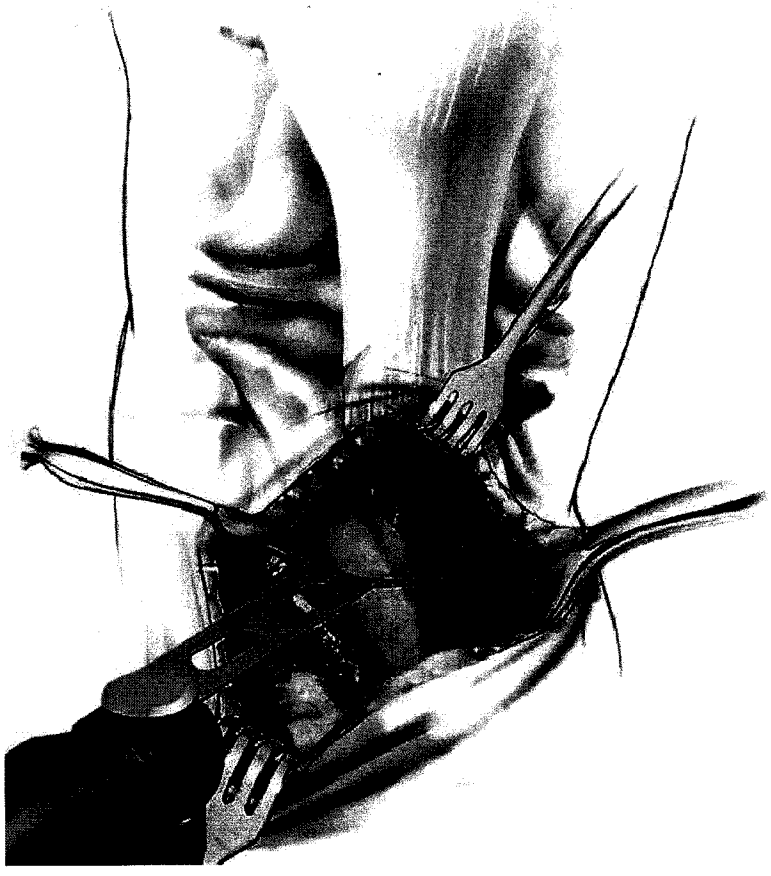


FIGURE 27-28. The tibia is exposed subperiosteally, below the tibial tubercle. Crego retractors are placed medially and laterally to protect the neurovascular structures. A transverse osteotomy is completed using a power saw, parallel to the joint line, perpendicular to the axis of the tibia and at the level of the distal aspect of the tubercle.



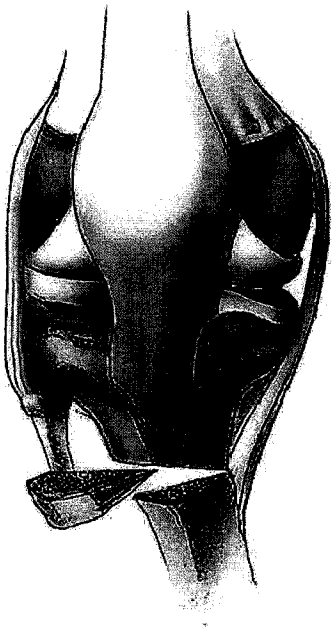


FIGURE 27-29. If significant internal tibial torsion is present, the distal fragment is externally rotated prior to removal of the laterally based wedge. The thickness of the wedge is determined using a template drawn from the preoperative radiograph.

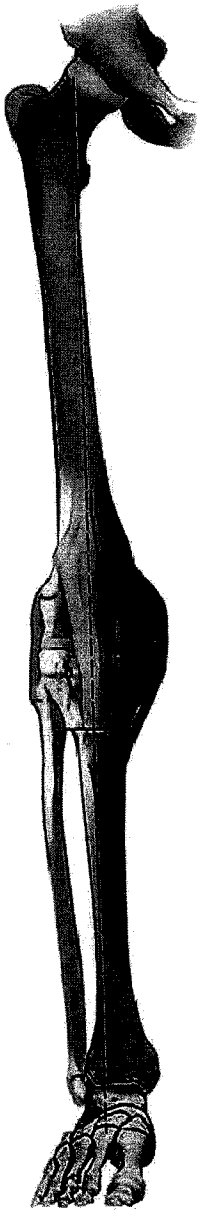


FIGURE 27-30. The tibial fragments are reduced and the alignment checked using a bovie cord. Slight overcorrection is desireable as the diseased medial physis may continue to demonstrate abnormal growth for a time, resulting in loss of correction. It may also be necessary to translate the shaft of the tibia to optimize bone contact and distortion of the tibial anatomic axis.

FIGURE 27-31. The tibial osteotomy is stabilized using two crossed Kirschner wires.

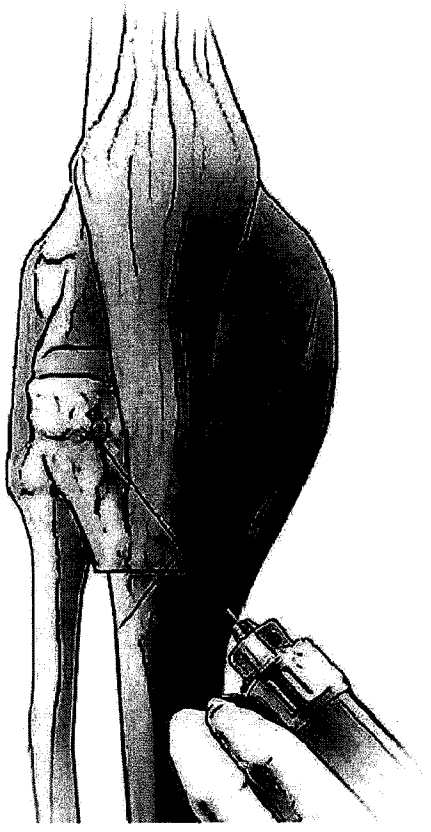
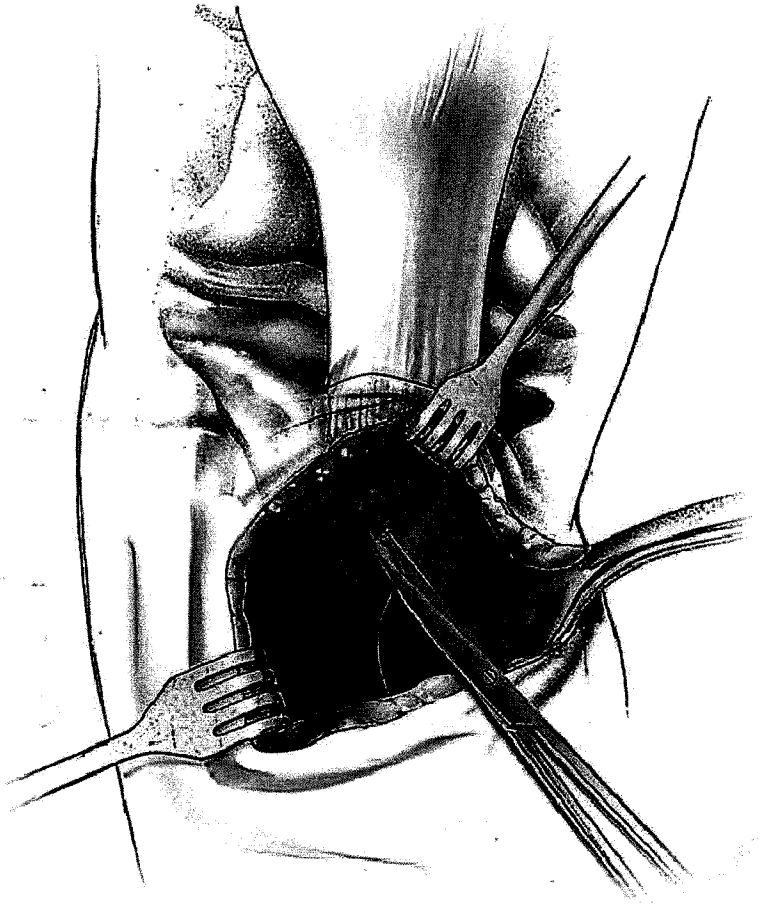


FIGURE 27-32. Prior to wound closure, a fasciotomy of the anterior compartment is completed using a Metzenbaum scissors. The wound is closed over suction drains and a bent knee cast applied. Alternatively a T- or buttress plate can be placed along the medial aspect of the tibia. This requires a longer incision and greater dissection proximally and medially. It is useful in larger children, adolescents or in combination with elevation of the tibial plateau.



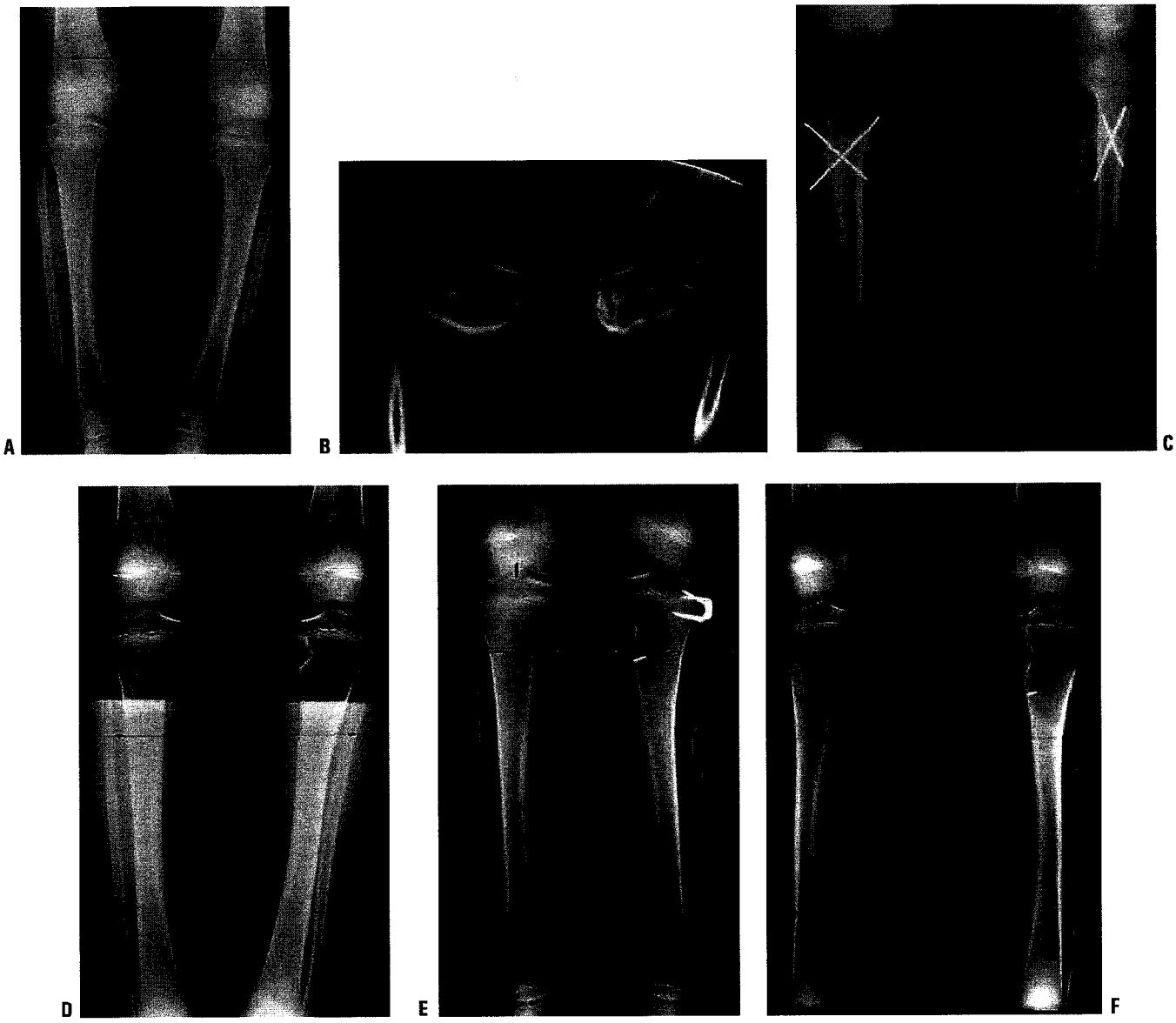


FIGURE 27-33. **A:** These AP radiographs show focal changes of unilateral stage IV Blount disease. The medial tibial physis is indistinct. These changes are suggestive of physeal bar formation. **B:** A CT scan shows the deformity in the medial physis. The growth plate has a vertical rather than horizontal orientation. A bridge of bone is clearly evident here. Varus will rapidly recur following osteotomy if the physeal bar is not recognized and treated. **C:** These postoperative films show correction of the varus and resection of the bar. The defect created by excision is filled with radiolucent methylmethacrylate (Cranioplast). **D:** Subsequent films show recurrent bar formation with gradual loss of correction over 2 years. **E:** A second excision of the physeal bar along with lateral physeal stapling has resulted in improved alignment. **F:** Following removal of the staples, varus has gradually recurred. The abnormal medial physis tends to close prematurely.

and fibula is indicated and is performed in conjunction with osteotomies to correct depression of the medial plateau and any residual varus as described in the next section (48, 51, 70). A potential for leg-length inequality exists with any of the above approaches. This discrepancy can often be corrected with an appropriately timed contralateral epiphysiodesis or with lengthening of the short tibia.

Severe Varus Deformity with Medial Joint Depression. Patients with Langenskiöld stage V and VI deformity have irreversible changes in the medial tibial physis. The architecture of the proximal tibia is distorted, including the medial tibial condylar surface (Fig. 27-34). Typically, these changes are seen in children older than 10 years, yet they may be seen as in patients as young as 6 years of age. The proximal

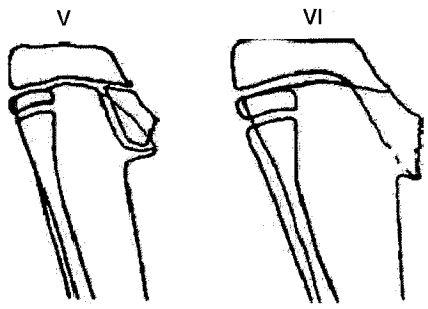


FIGURE 27-34. Stage V and stage VI Blount disease are complicated by depression of the medial tibial condyle. The physis has a vertical orientation. This marked growth disturbance is the result of physeal bar formation seen at the junction of the normal horizontal physis and the depressed medial plateau. Insufficient normal physis remains for growth of the medial physis to be restored by resection of these large physeal bars.

tibial varus deformity is characterized by severe depression of the medial tibial plateau, often with ligamentous laxity. Compensatory distal femoral valgus deformity may develop (66, 82, 88). In severe cases, the tibia will be subluxed laterally on the femur. Left untreated, degenerative arthritis is likely to occur early in life (94, 95). This deformity occurs because the medial physis has closed prematurely or is so extensively involved that epiphysiolysis will not restore proximal tibial growth. A lasting satisfactory outcome requires correction of both the abnormal limb alignment and the pathologic depression of the medial tibial plateau (96–99) (Fig. 27-35).

Operative Treatment. The preferred approach to correct this complex deformity is a combination of varus-correcting proximal medial tibial plateau osteotomy and realignment osteotomy of the proximal tibia (Figs. 27-36, and 27-40 to 27-45). If significant distal femoral valgus is present, osteotomy of the distal femur is performed as well (66, 82). The proximal medial tibia should not be approached subperiosteally. Rather, soft-tissue attachments to the proximal medial tibia need to be preserved to minimize devascularization of the medial tibial condyle following the medial plateau-elevating osteotomy. A medial parapatellar arthrotomy (optional) allows visualization of the articular surface of the tibia. The posterior neurovascular structures are at risk of injury and are protected by placing a curved retractor between the neurovascular structures and the tibia. The intended plane of this arcuate osteotomy as monitored with a C-arm is outlined with drill holes and then carefully completed with a curved osteotome. The osteotomy is begun distal to the insertion of the medial collateral ligament, starting at the apex of angulation in the proximal medial metaphysis and curving proximally toward the tibial eminence. Careful monitoring with the C-arm is essential to assure that the plane of the osteotomy is directed superolaterally in order to bisect the tibial intercondylar eminence. The osteotomy hinges on the subchondral bone. A lamina spreader is inserted into the osteotomy and gradually opened, which corrects much

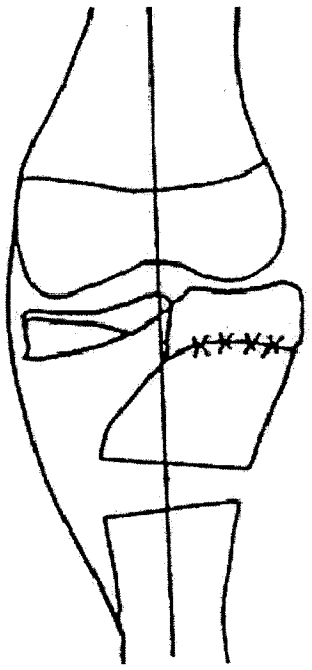


FIGURE 27-35. Restoration of normal limb alignment requires complex reconstruction. A curved osteotomy is performed correcting much of the proximal medial tibial varus deformity and also restoring the medial tibial condyle to a more normal position in relationship to the lateral condyle. A proximal lateral hemiepiphysiodesis is performed to prevent recurrent deformity because the medial physis is no longer functional. A second varus-correcting osteotomy of the proximal tibia may be necessary to completely restore a normal mechanical axis and orientation of the proximal tibia.

of the severe proximal tibia varus deformity. Knee joint stability is restored. Excessive force should not be used in opening the lamina spreader as it is possible to produce a displaced intra-articular fracture of the medial condyle. When satisfactorily corrected, the articular surfaces of the two condyles form a 25- to 30-degree angle on the AP C-arm view. Internal fixation is obtained with cannulated screws placed medial to lateral; 6.5 mm screws are used in older children and 4.5 or 5 mm screws in smaller patients. A contoured plate is then applied, medially, to securely fix the elevated fragment. A bone graft is placed into the gap created as the severe proximal varus deformity is corrected. A segment of adjacent tibia or tricortical iliac crest autograft may be used. Alternatively, allograft (iliac crest supplemented with a bone putty) can be used. If the lateral proximal tibial physis is open, a concomitant epiphysiodesis of the lateral proximal tibia and fibula is completed to prevent further unbalanced proximal tibial growth and recurrence of deformity. Contralateral proximal tibial and fibular epiphysiodesis may be performed at this time to avert limb-length inequality, particularly in patients close to skeletal maturity.

To fully restore normal extremity alignment, it may be necessary to perform a second (varus-correcting) proximal tibia/fibula osteotomy (96–98). Usually this is done as a separate procedure following satisfactory healing of the more

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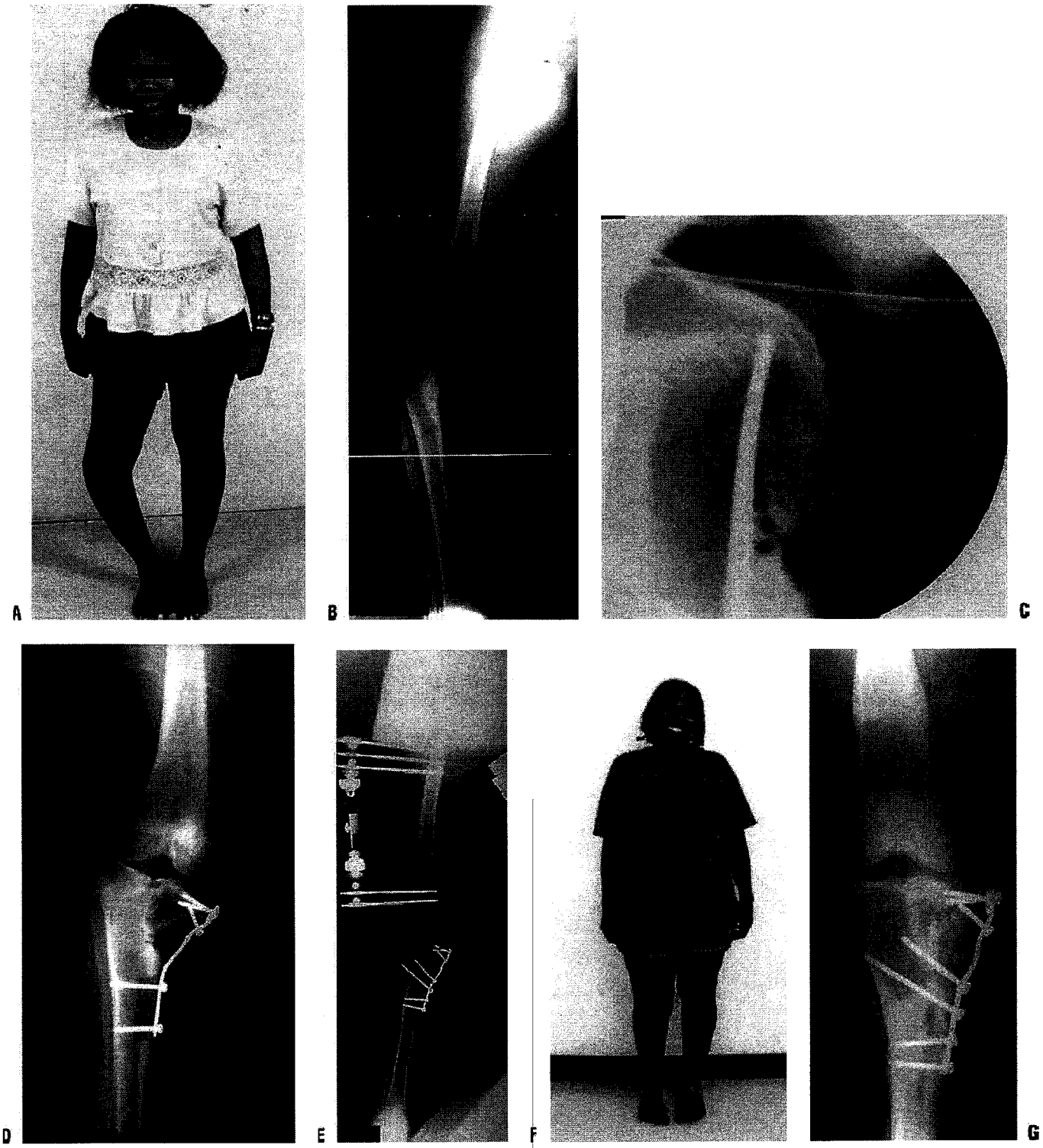


FIGURE 27-36. Treatment of stage V Blount disease. **A:** Severe deformity and a lateral thrust are noted clinically. **B:** Blount disease that progresses to physeal bar formation results in severe depression of the medial metaphysis. Valgus may develop in the distal femur because of overgrowth of the medial femoral condyle. Restoration of medial physeal growth is not possible. **C:** Image intensification is useful to control the direction of the medial tibial plateau osteotomy. The cut begins at the apex of deformity in the medial cortex and is completed between the tibial spines. **D:** A cortical strut is used to support the elevated plateau. **E:** Osteotomy of the tibia or femur, or both, is performed to correct residual tibial varus or femoral valgus. **F:** Normal anatomic and mechanical alignment can be achieved with this approach. Residual limb-length inequality can be managed by contralateral epiphysiodesis if needed. **G:** Radiographic appearance after healing of the osteotomies shows restoration of joint orientation and mechanical alignment.

Resection of Medial Tibial Physeal Bar in Blount Disease (Figs. 27-37 to 27-39)

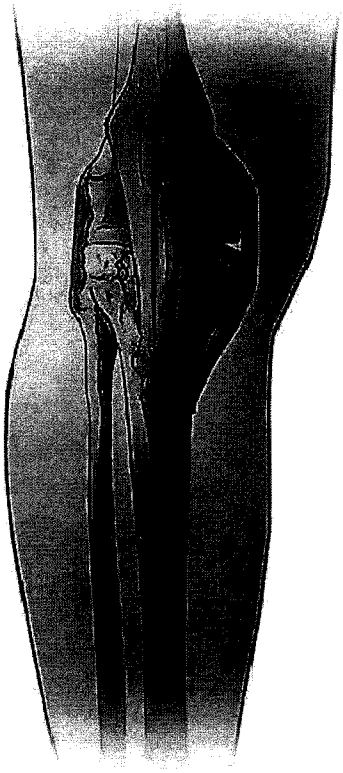


FIGURE 27-37. Resection of Medial Tibial Physeal Bar in Blount Disease. The patient is placed supine. An 8 to 10 cm midline longitudinal incision is made from the midpoint of the patella as for a proximal tibial osteotomy.

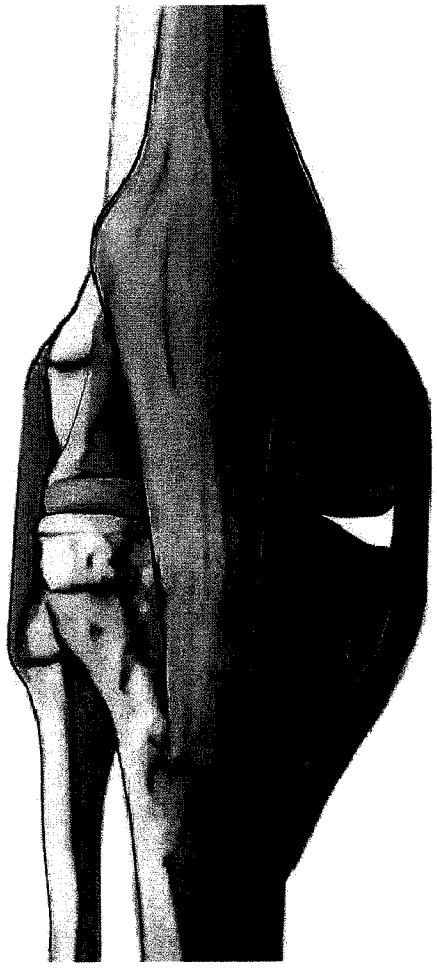


FIGURE 27-38. The proximal medial tibia is exposed subperiosteally. Image intensification may be helpful to follow the progress of resection and identify the medial edge of the normal physis. A burr can be used to remove the bone bridge. These physeal bars are typically at the apex of the deformity where the physis has changed from a horizontal to a vertical orientation. It is important to visualize normal horizontal physis to assure adequate resection yet preserve as much of the medial physis as possible.

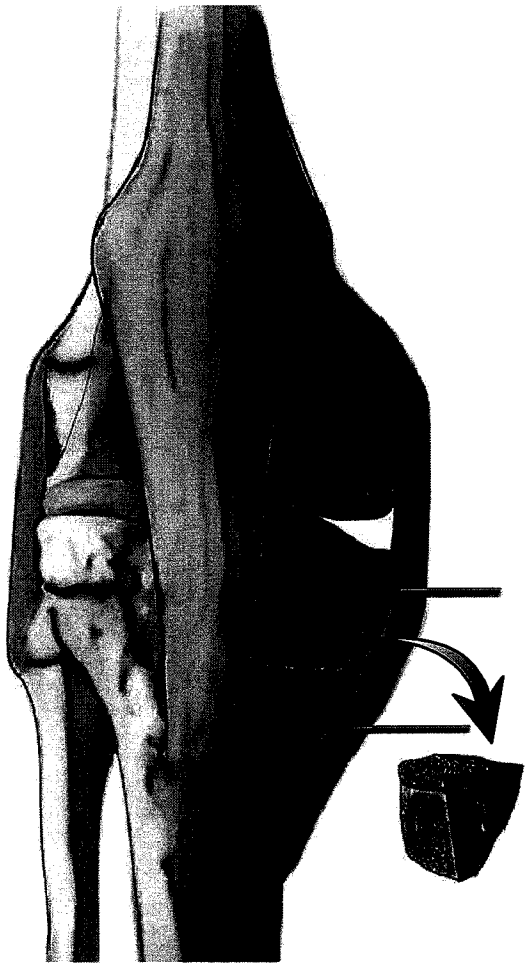


FIGURE 27-39. A small amount of methylmethacrylate without barium (Cranioplast) is prepared and placed within the defect to prevent re-formation of a bar. Smooth Kirschner wires are inserted 1 to 2 cm into the medial epiphysis and metaphysis. These will act as markers of physeal growth. As medial physeal growth resumes, the distance between the wires will increase. A proximal tibial osteotomy as previously described is completed to re-align the extremity and unload the medial tibial physis.

Double Osteotomy with Elevation of the Tibial Plateau for Blount Disease (Figs. 27-40 to 27-45)

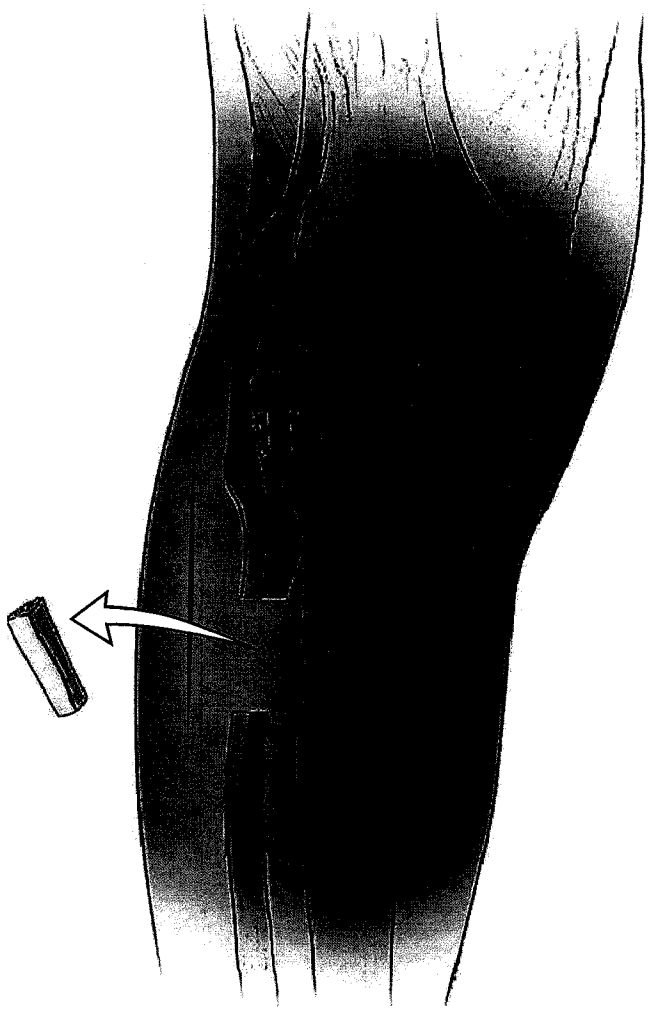


FIGURE 27-40. Double Osteotomy with Elevation of the Tibial Plateau for Blount Disease. The patient is placed supine on a radiolucent table. Hemiepiphyseodesis of the proximal lateral tibia is completed using staples placed subperiosteally as no further growth will occur from the medial tibial physis. A 2-cm section of fibula is resected for use as bone graft for the plateau elevation.

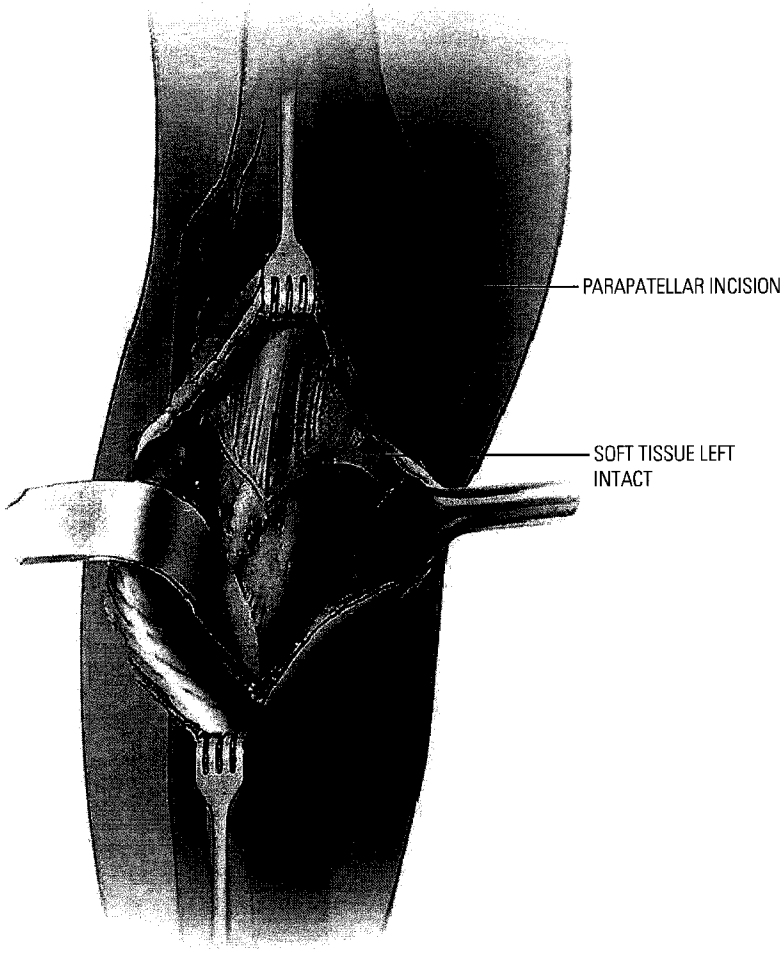


FIGURE 27-41. A midline, longitudinal incision as described for physeal bar resection is used. The soft tissue attachments to the proximal medial tibia are preserved to protect the blood supply to the medial plateau fragment. The tibial shaft is exposed subperisteally on its medial side. Curved retractors are placed around the tibia to protect neurovascular structures. A parapatellar incision facilitates visualization of the correction.

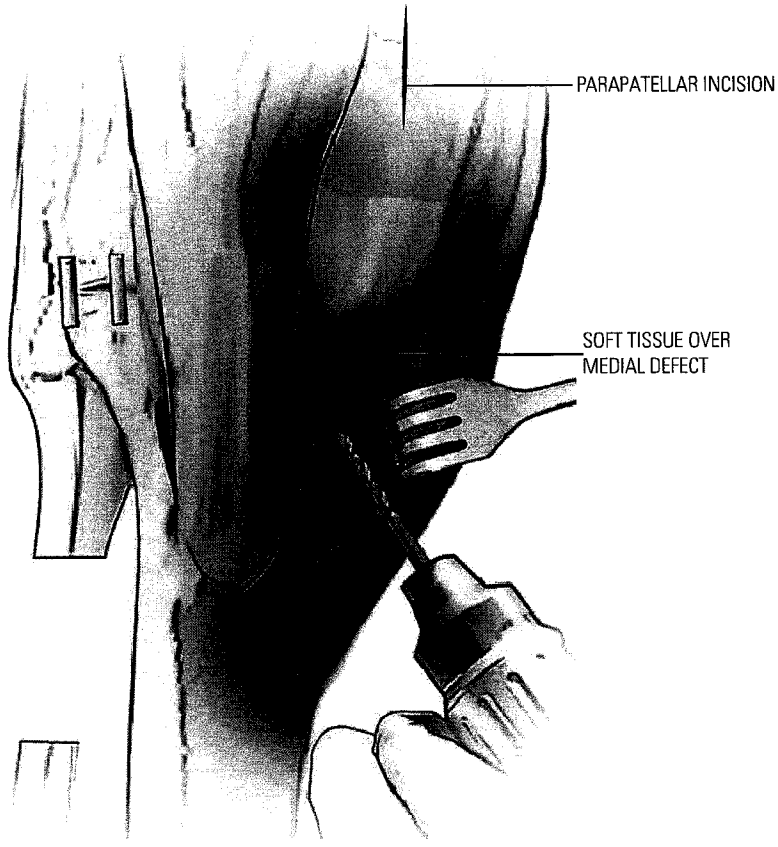


FIGURE 27-42. Under guidance of the image intensifier, multiple drill holes are made from anterior to posterior, to create an arcuate osteotomy. This curved line begins at the notch created by the junction of the metaphysis and the depressed epiphysis. It continues proximally, and ends in the subchondral bone between the tibial spines.

FIGURE 27-43. The osteotomy is completed using a curved osteotome to connect the drill holes. As the osteotomy is completed, the osteotome can be used to separate the medial epiphyseal fragment from the metaphysis.

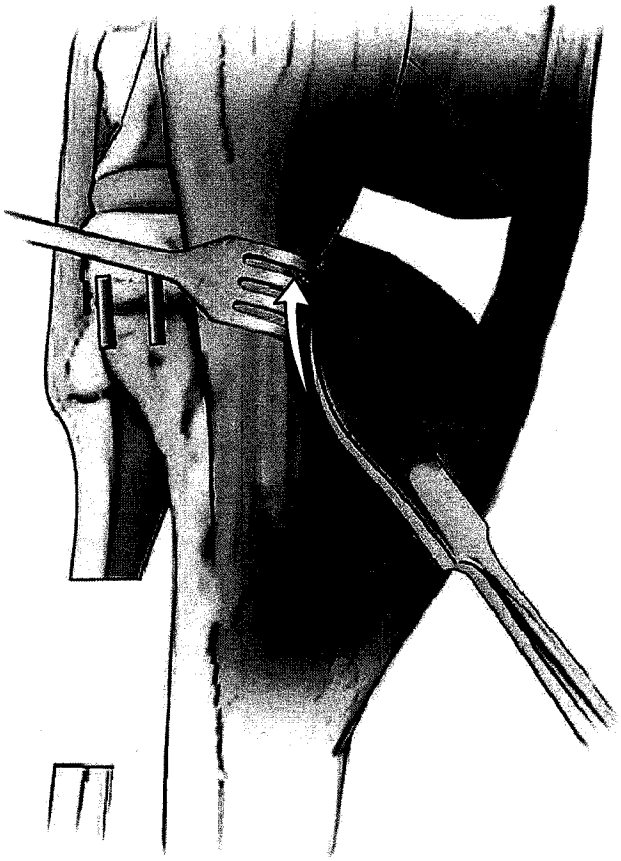
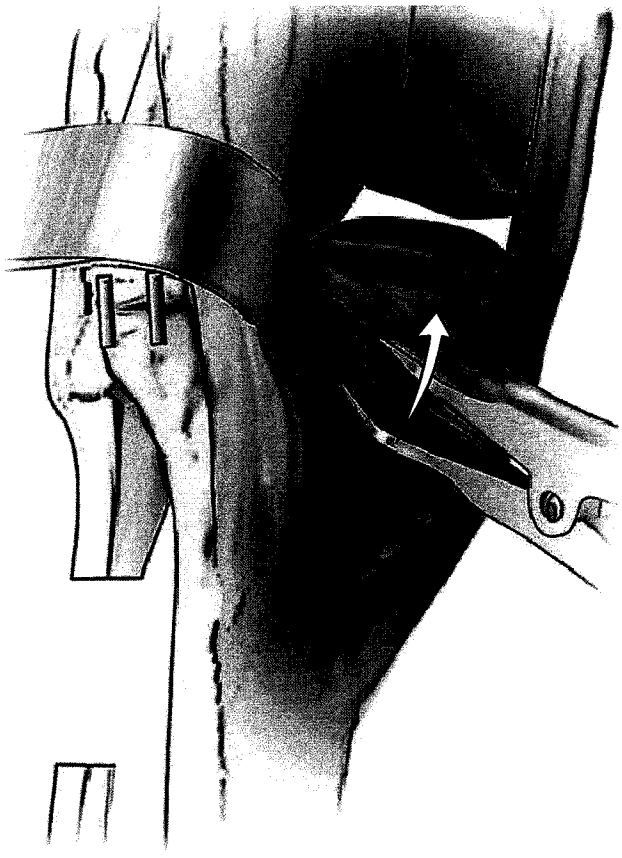


FIGURE 27-44. A smooth laminar spreader is then inserted into the gap and gently opened, reducing the depression in the medial plateau. Image intensification is used to assess the progress of correction and minimize risk of inadvertent displacement of the articular surface.



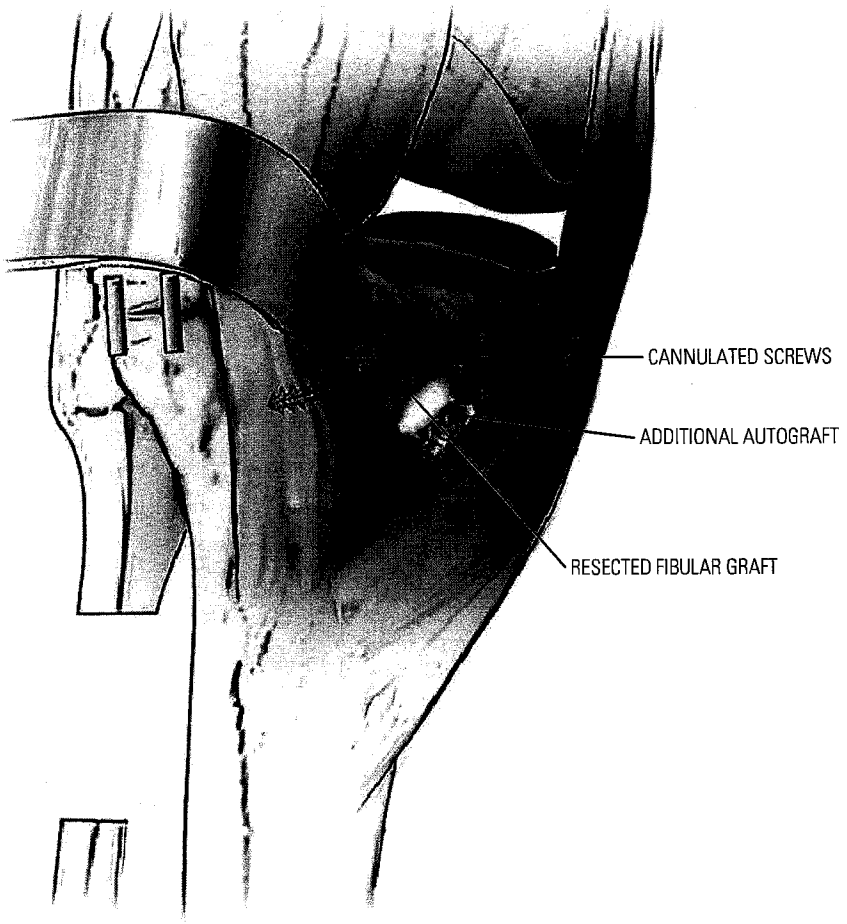


FIGURE 27-45. The arcuate osteotomy is fixed using two 4.5- or 6-mm cannulated screws, depending on the size of the fragment. The resected fibula or, alternatively, tricortical iliac crest graft is placed to support the medial epiphysis. Additional autograft or allograft is added as needed. A contoured plate is applied to the medial tibia to complete the construct. Remaining deformity can be corrected with a second osteotomy in the proximal tibial metaphysis, either at this time, or as a staged procedure (preferable). Prophylactic anterior compartment fasciotomy is performed prior to wound closure over suction drain. In some cases with severe deformity, the elevated plateau segment protrudes medially, compromising wound closure. Resection of a portion of the metaphyseal bone may facilitate wound closure.

proximal tibial metaphyseal/epiphyseal osteotomy. The second proximal tibial osteotomy can be fixed with plate and screws or alternatively with an external fixator, which is beneficial if limb lengthening is desired. Occasionally, a distal femoral osteotomy or growth modulation may be indicated to correct secondary distal femoral valgus. The goal of this comprehensive approach is correction of all components of the deformity, including the medial tibial plateau depression, joint laxity, asymmetric proximal tibial growth, varus of the tibia, and valgus of the distal femur. With this accomplished, both normal joint orientation (relationship of the knee and the ankle) and alignment of the extremity (mechanical axis of the limb will bisect the center of the knee joint) will be achieved.

After correction of the angular deformity, significant limb-length inequality may remain. This may be managed by epiphysiodesis of the contralateral limb, or in the case of a more severe discrepancy, a combination of lengthening and shortening may be used to equalize limb length. Davidson (99) has utilized a circular external fixator to stabilize the elevated plateau fragment and perform a gradual correcting osteotomy of the proximal tibia. Use of the external fixator provides the potential option of lengthening, in addition to deformity correction of the proximal tibia.

Complications. Extensive soft-tissue and bony dissection is necessary to concomitantly elevate the medial tibial plateau and perform a varus-correcting proximal tibial osteotomy. The medial proximal tibia is more prominent and elongated following the plateau elevation. Wound closure may be compromised and may need to be performed as a delayed closure. In a series by Schoenecker et al. (96), 3 of the initial 22 patients treated by this comprehensive approach experienced wound healing complications. In two patients, eventual wound healing occurred with local care, and one required operative repair with subsequent satisfactory secondary wound healing. The extensive soft-tissue and bony dissection necessary to perform a tibial plateau elevation also increases the risk of avascular necrosis of the medial tibial condyle. This occurred in 1 of 22 of the above tibial plateau elevations. Satisfactory revascularization and reossification occurred in this morbidly obese 8-year-old child following a 1-year period of non–weight bearing. To date, the authors have performed a proximal medial tibial plateau osteotomy in the treatment of severe tibial plateau depression secondary to infantile Blount disease on 35 patients. There have been no additional wound healing problems or radiographic evidence of avascular necrosis of the medial tibial plateau. There have been no operative neurologic or vascular injuries in any of the 35 procedures.

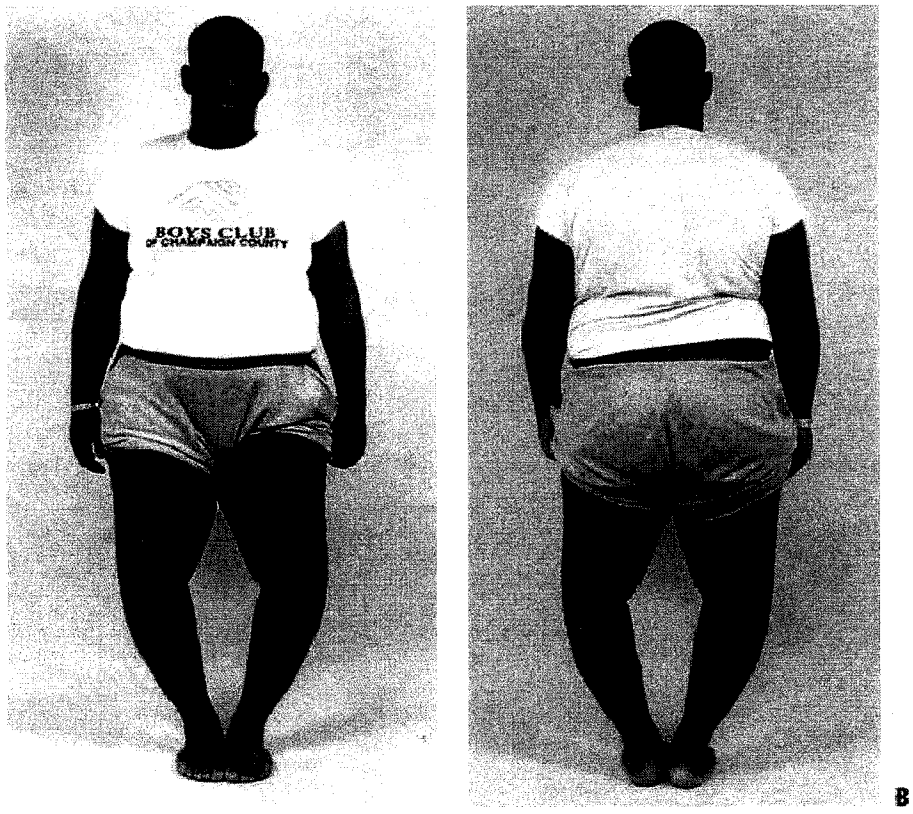


FIGURE 27-46. A, B: A 13-year-old boy with adolescent Blount disease. As is often seen in this group of patients, he is morbidly obese. The large thigh circumference in such patients contributes to the deformity and increased load across the medial distal femur and proximal tibia.

Late-onset Juvenile and Adolescent Blount Disease

Definition. Blount (65) identified a second group of patients who developed varus deformity of the tibia in later childhood or early adolescence. He described this deformity as adolescent tibia vara (Fig. 27-46). Typically, these children present for evaluation of bowing deformity that develops later in childhood. They are usually overweight, sometimes morbidly so (100–102). The varus deformity in this group of patients with late-onset or adolescent Blount disease typically involves the medial proximal tibia as well as the medial distal femur. In contrast, children with deformity from persistent early-onset or infantile Blount disease typically have varus of the medial proximal tibia only. There should be no confusion in differentiating patients who present as adolescents with changes of Blount disease from those who have had varus deformity since infancy. Children with infantile Blount disease develop advanced pathologic changes in the proximal medial tibia, as described by Langenskiöld, whereas those with juvenile or adolescent Blount disease develop varus without medial joint depression. Distal femoral varus is a typical component of the pathologic deformity in these older children (66).

Etiology. Classically, adolescent Blount disease occurs in obese patients with characteristically wide thighs; however, there are exceptions (100–102). Obesity potentiates the occurrence of adolescent Blount disease because of the increased load across the medial compartment of the knee (103–107). The varus develops after 9 to 10 years of age and often involves both the proximal tibia and the distal femur. Increased thigh circumference makes it difficult for these children to keep their center of mass over the weight-bearing foot during the single stance phase of gait. Their extreme weight adds to an already increased load on the medial knee joint and promotes the development of the varus deformity.

Davids et al. (100) examined the gait deviations that compensate for the increased thigh girth associated with obesity. During ambulation, individuals tend to minimize the horizontal displacement of their center of mass by positioning the foot during single-leg stance as centrally as possible along the line of progression. This optimizes energy expenditure during normal gait. An obese individual, with large thighs, has difficulty adducting the hip adequately in order to allow placement of the foot along the line of progression. Davids speculated that this "fat thigh syndrome" produces a varus moment on the knee that leads to increased pressure on the medial proximal tibial physis and inhibits growth in accordance with the Hueter-Volkmann principle (101–103). This work supports the observation that preexisting varus of the knee is not necessary to initiate the pathologic mechanical changes that result in adolescent tibia vara. The incidence of adolescent Blount disease has markedly increased in the past 20 years corresponding to the development of earlier and more severe adolescent obesity (107). For some of these patients, adolescent tibia vara and SCFE occur in association with each other (108, 109). A second, smaller group of patients present with genu varum in late childhood or early adolescence. They are older than those with infantile Blount disease and typically

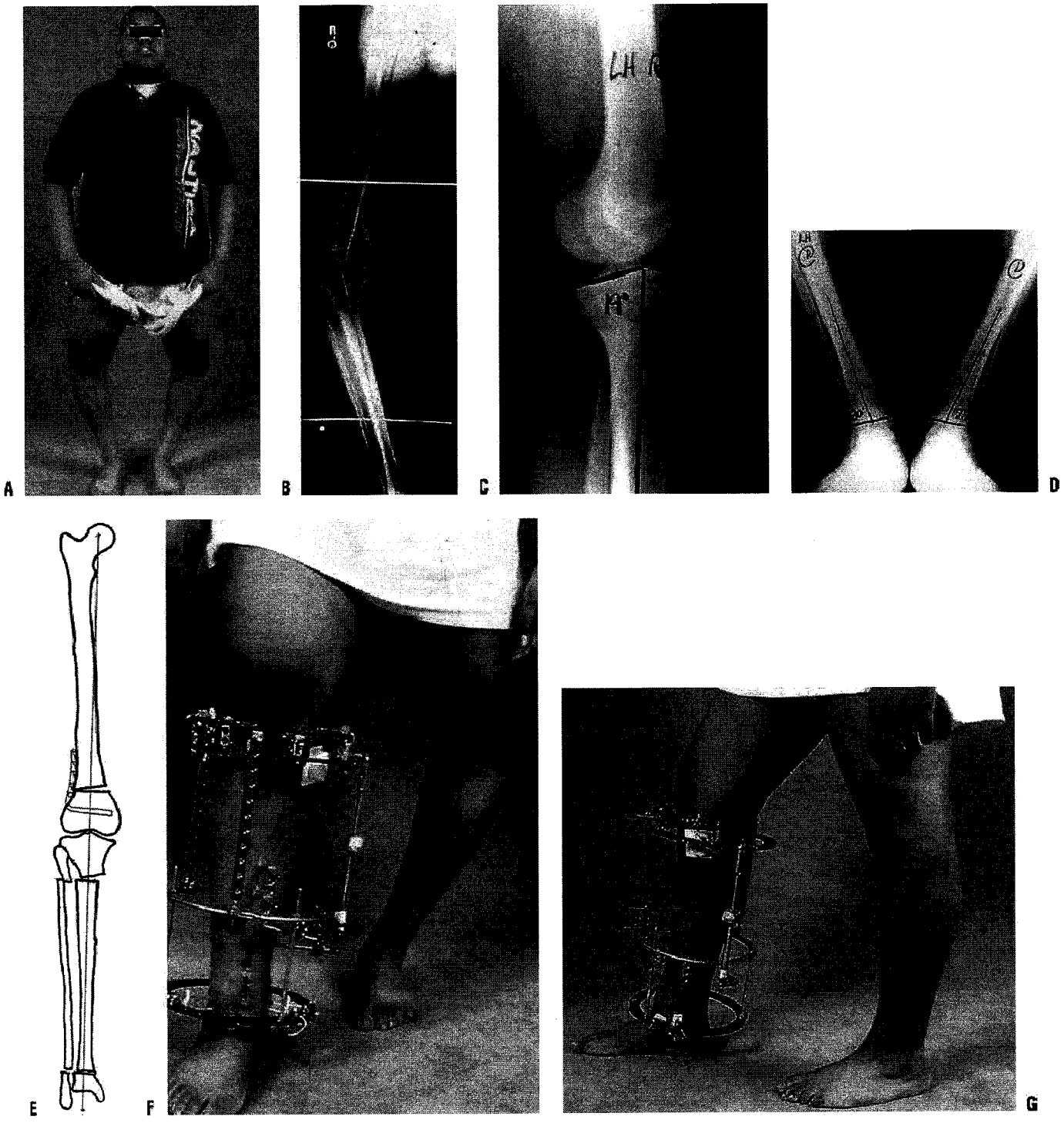


FIGURE 27-47. **A:** Adolescent Blount disease frequently occurs in very large teenagers. The deformity is often bilateral. **B:** Long cassette images are used to assess mechanical alignment as well as the anatomic axes of the femur and tibia. Distal femoral deformity is often present as well as proximal tibial varus. **C:** Procurvatum of the proximal tibia develops, with increased posterior slope of the proximal tibia. **D:** Distal tibial valgus develops to allow the foot to have flat contact with the floor. **E:** Restoration of normal alignment may include multilevel osteotomies. Preoperative templates are useful for planning operative strategies. **F:** In this example, the plan included immediate correction of distal femoral varus using a blade plate and gradual correction of proximal tibial varus and distal tibial valgus using a circular small wire frame. **G:** Multiplane correction is facilitated with this technique. Adjustments can also be made to correct the procurvatum that may be present.

FIGURE 27-47. (*continued*) **H:** The circular frame provides flexibility. It also allows lengthening as needed in cases of unilateral or asymmetric deformity. **I:** Radiographs confirm the restoration of alignment. Correction is generally well maintained. **J:** Clinical photo after bilateral treatment shows satisfactory clinical correction compared to the preoperative photo. **K:** Correction of procurvatum restores normal orientation of the knee.

are not morbidly obese. In retrospect, these are children with mild (physiologic type) bowing that never resolved. They do not develop the pathologic changes seen in infantile Blount disease. The varus deformity in these children becomes more apparent during the rapid growth of early adolescence (104).

Pathoanatomy. An affected growth plate will have histologic aberrations throughout the entire physis; however, the medial physis is more affected than the lateral physis (103, 109). The histologic changes are very similar to those found in infantile Blount disease and SCFE. In adolescent Blount disease, the radiographic changes in the epiphysis and metaphysis are less apparent compared to infantile Blount disease, because the secondary ossification center is larger and better established in these older patients.

The growth inhibition present in the proximal tibia affects the posteromedial physis and initially produces varus, followed by progressive procurvation of the proximal tibia (48, 82, 110, 111). Although the name adolescent tibia vara would suggest that varus of the proximal tibia is the only deformity present, distal femoral varus deformity is common, because this physis is also subjected to excessive loading (82, 100, 110) (Fig. 27-47A–C). This is in contradistinction to infantile tibia vara in which the distal femur is typically either normal or occasionally in valgus. The in-toeing noted in adolescent Blount disease is generally less severe than it is in infantile tibia vara. The combination of varus, procurvatum, and internal rotation results in a complex three-dimensional deformity of the proximal tibia. As the proximal tibial and distal femoral varus deformities increase, there is a significant strain placed on the lateral collateral ligament of the knee, which leads to laxity and varus deformity within the knee joint. In some very severe cases, compensatory distal tibial valgus develops to allow the patient to place the foot flat on the floor (Fig. 27-47D). Although the natural progression of advanced infantile Blount disease is the formation of a medial proximal tibial physeal bar, discrete physeal bar formation does not occur in adolescent Blount disease. However, early closure of all lower extremity physes can occur, perhaps because of overload related to obesity.

Clinical Features. The typical patient with adolescent tibia vara is an obese male who presents with complaints of bowing, often with knee pain and occasionally instability (102, 104, 107). The patient should be assessed while walking both toward and away from the examiner, who should note gait mechanics and, specifically, the presence of a limp or lateral thrust to one or both knees. Although unilateral complaints are more common, attention should be paid to both limbs because the patient's obesity

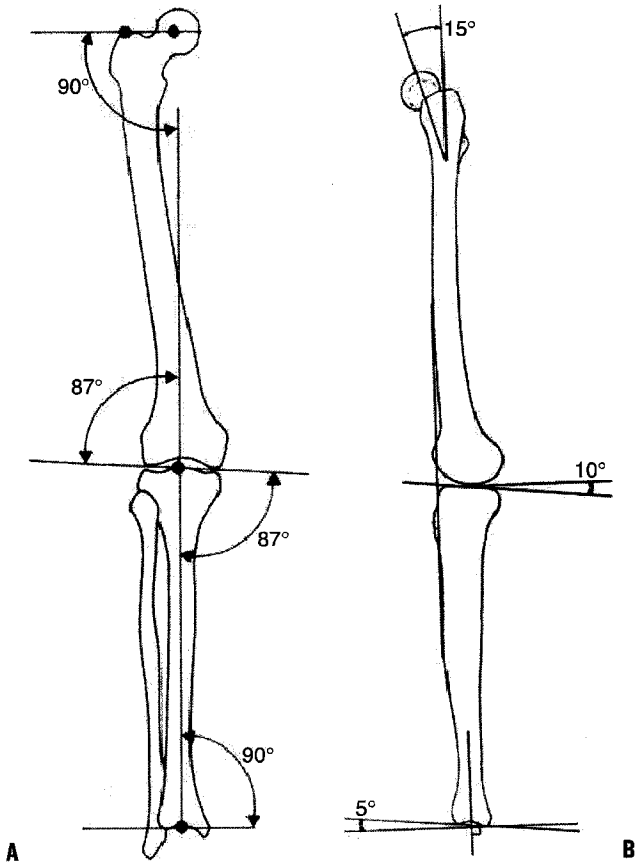


FIGURE 27-48. A: Frontal plane mechanical axis of the lower extremity consists of two components: colinear centers of the femoral head, knee joint, and ankle joint; and an almost perpendicular relation of the hip, knee, and ankle joints' orientation lines to the mechanical axis. **B:** Normal sagittal plane mechanical axis and joint orientation lines.

can mask mild bowing on the contralateral limb. Knee stability is assessed because lateral collateral ligament laxity can occur. Proximal tibial procurvatum deformity may occur, producing a relative knee flexion deformity. The patient may have anterior knee pain secondary to holding the knee in a flexed position during gait. Patients complain of medial knee pain secondary to medial knee joint stress. The hips should also be examined for evidence of SCFE (108, 109). Morbidly obese patients presenting with adolescent Blount disease may have varying amounts of respiratory distress. The walk from the waiting room to the examination area can be quite taxing to these patients. Sleep disorders related to apnea are also common (112).

Radiographic Features. A standing radiograph of both lower extremities is essential for evaluating the patient with adolescent tibia vara (Fig. 27-47B-D). For most adolescent patients, the image should include both lower extremities, including pelvis and ankles on one image. Simultaneous satisfactory visualization of the hips through an abundance of soft tissue as well as the ankles through a relative paucity of soft tissue can be difficult. Care should be taken when positioning the patient to ensure that the knees are straight ahead with the patellae centered. This is particularly difficult in large patients in whom the palpation of bony landmarks is uncertain. Radiology technicians who are not experienced in obtaining these radiographs frequently compensate for the inability to identify the patellae by simply turning the feet straight ahead. Because of the internal tibial torsion, this produces external rotation of the knees and an inadequate radiograph for accurate assessment of bony deformity. Occasionally, because of the width of the patient or the patient's inability to sufficiently rotate the hip internally, it may be necessary to obtain separate standing radiographs of each lower extremity. A true lateral supine radiograph of the proximal tibia is obtained to evaluate the magnitude of the procurvatum deformity. The radiograph should be centered on the knee and the film positioned so that a significant portion of the tibial diaphysis can be visualized. Finally, with the feet positioned straight ahead, a standing AP radiograph of both ankles is obtained.

The radiographs should be assessed according to the method described by Paley and Tetsworth (110, 111). Initially, the mechanical axis deviation should be measured using a line drawn from the center of the femoral head to the center of the ankle (Fig. 27-48). The surgeon should also look for a limb-length discrepancy at this point. Both the lateral distal femoral and the medial proximal tibial angles (MPTAs) should be measured to evaluate the frontal plane deformity of both the distal femur and the proximal tibia. It is incorrect to assume that the distal femur is normal because the knee joint appears to be parallel to the floor (82, 110, 111). The genu varum produces relative abduction at the hip and can mask a significant femoral deformity. The radiograph of the knee in the weight-bearing position must be examined to assess the presence of significant lateral collateral laxity and an increased joint line congruency angle (the angle formed by an intersect of two lines, one drawn parallel to the distal articular surface of the femur and one parallel to the proximal articular surface of the tibia). Likewise, the lateral view of the knee should be evaluated to assess the size and location of the procurvatum deformity (Fig. 27-47C). The presence of compensatory distal tibial valgus is assessed on the AP ankle film (82, 110) (Fig. 27-47D).

Operative Treatment Goals. The problems that must be addressed are varus deformity of the proximal tibia and distal femur, procurvatum of the proximal tibia, internal tibial torsion, and, occasionally, a secondary valgus deformity of the distal tibia. The goal of surgery is to restore normal anatomical orientation of the knee and ankle joint and a normal mechanical axis of the lower extremity (82, 110–114). For a unilateral deformity, limb-length inequality also needs to be addressed. Osteotomy is the definitive treatment of adolescent Blount disease. However, depending on the patient's age, satisfactory limb realignment can be attained on occasion by hemiepiphysiodesis either by plate and screw combination or by staple growth modulation (79, 90, 91, 113, 115).

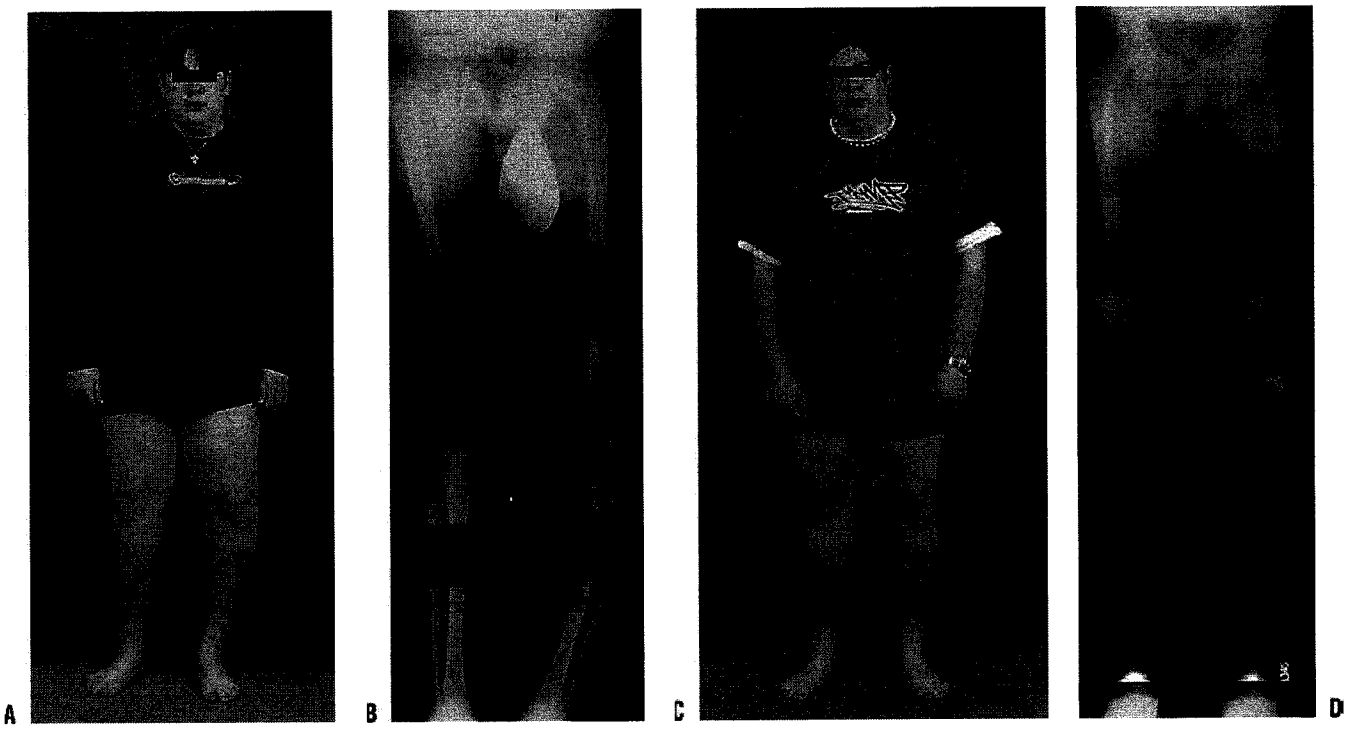


FIGURE 27-49. **A:** Clinical photo of a teenager with unilateral adolescent Blount disease. **B:** Long cassette radiograph demonstrates varus deformity in the distal femur and proximal tibia in a skeletally immature individual. **C:** Clinical appearance following correction. **D:** Hemiepiphyseal stapling was used. Correction is noted 1 year after staple insertion in the lateral distal femur and proximal tibia. This technique is optimal in mild-to-moderate deformities where 1 to 2 years of growth remain.

Preoperative Evaluation. Prior to proceeding with operative intervention, an appropriate, detailed, preoperative plan is essential to the goal of obtaining a well-aligned limb (Fig. 27-47E). The magnitude and location of the various bony deformities, the presence of soft-tissue laxity at the lateral collateral ligament, and the presence of joint contractures and leg-length discrepancy should all be assessed and incorporated into an overall plan for addressing the deformity. Because these patients are often obese or morbidly obese, a thorough evaluation of their cardiopulmonary system is essential prior to any consideration of operative treatment. The extreme size of these patients can lead to nocturnal hypoxia with significant decreases in sleeping O_2 levels and accompanying hypercarbia (112, 116). If these changes are prolonged, significant pulmonary hypertension can result, leading to right-heart hypertrophy. If symptoms such as marked snoring or irregular breathing patterns at night are present, sleep studies with pulmonary and cardiology evaluations may be indicated prior to general anesthesia.

Hemiepiphysiodesis. Hemiepiphysiodesis is indicated if the growth plates are still open and the varus deformity is not too severe (79, 90, 91, 113, 115, 117) (Fig. 27-49A,B) (see Figs. 27-54 to 27-56). Traditionally, staple hemiepiphysiodesis has been performed. Two to three "Blount staples" (Zimmer, Inc., Warsaw, IN) with reinforced corners are placed extraperiosteally at the lateral distal femoral physis, the lateral proximal tibial physis, or the medial distal tibial physis depending on the site of deformity. Once hemiepiphyseal stapling is performed, it is critical to follow up the patient closely with clinical and radiographic examinations to monitor the correction obtained and possible staple displacement and/or breakage. If complete deformity correction is obtained, staple removal may be necessary to prevent overcorrection. Relative rebound varus growth is unpredictable in this clinical setting (90). Complete epiphysiodesis may be preferred at the time of staple removal to avoid loss of correction by rebound. Hemiepiphyseal stapling has resulted in reduction of deformity or arrest of progression of the proximal tibial or distal femoral deformities in some of the patients who had at least 15 to 18 months of growth remaining. This simple technique may obviate the need for subsequent femoral and sometimes tibial varus-correcting osteotomy (Fig. 27-49C,D). The adolescent who may not be a good candidate for staple hemiepiphysiodesis is one with a history of progressive varus deformity and knee joint pain. A dynamic lateral thrust is usually present in the patients who have knee joint laxity. Hemiepiphyseal growth modulation may not provide rapid enough resolution of the bony deformity or correction of the ligamentous laxity that is present. More recently, Stevens has reported a similar hemiepiphysiodesis (modulating growth) effect following the placement of a construct utilizing a short plate or eight-plate and screws (Orthofix) much like a staple bridging across a growth plate (79) (see Figs. 27-51 to 27-53). Preliminary outcome indicates that, as with staples, correction of varus deformity will predictably occur with eight-plate insertion

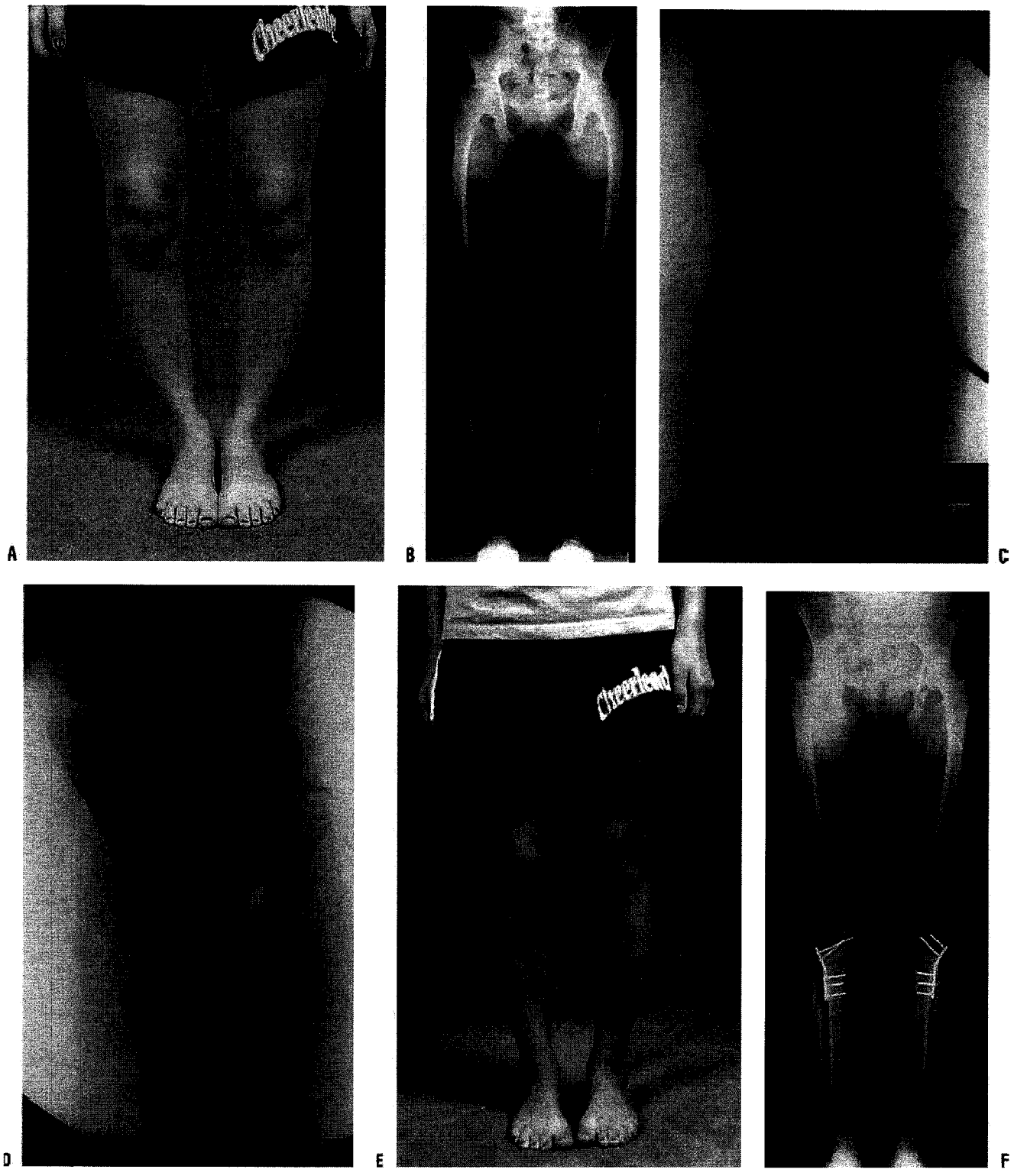


FIGURE 27-50. **A:** There is a subgroup of patients with adolescent Blount disease who are not obese. Deformity is typically bilateral and mild to moderate. **B:** Radiographs in this nearly skeletally mature girl demonstrate deformity only in the proximal tibia. **C:** The oblique osteotomy directed toward the physeal scar. **D:** A laterally based wedge is removed, and the osteotomy fixed with a "tension band" plate. **E:** Clinical photo after bilateral correction. **F:** Bilateral lower extremity radiographs following osteotomy.