Congenital Pseudarthrosis of the Tibia

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Abstract

Congenital pseudarthrosis of the tibia is characterized by anterolateral deformity of the tibia and shortening of the limb. Its etiology remains unclear. Although several classification systems have been proposed, none provides specific guidelines for management. Treatment remains challenging. The goal is to obtain and maintain union while minimizing deformity. The basic biologic considerations with surgical intervention include resection of the pseudarthrosis and bridging of the defect with stable fixation. Intramedullary stabilization, free vascularized fibula, and Ilizarov external fixation are among the most frequently used methods of treatment. In addition, bone morphogenetic protein recently has shown promise. Nevertheless, despite improvements in healing rates with congenital pseudarthrosis of the tibia, the potential for amputation in failed cases persists.

Although rare, congenital pseudarthrosis of the tibia (CPT) poses one of the most challenging management problems in pediatric orthopaedics. Its treatment compounds the difficulty of achieving and then maintaining union while simultaneously providing a functional extremity. Management of pseudarthrosis and the associated deformity of the tibia and fibula are on a continuum. Boyd[1] suggested in 1982 that success in treating CPT in a growing child can be known only by following the patient to maturity.

The etiology of CPT remains unclear. Several theories have been proposed, including intrauterine trauma, birth fracture, generalized metabolic disease, and vascular malformation. Based on the sporadic reports in the literature of familial and bilateral involvement, some investigators have proposed that CPT is hereditary.[2] The fibula is affected in approximately one third of patients.[2]

The relationship between anterolateral bowing and neurofibromatosis (NF) is well known. Approximately 6% of patients with NF type 1 develop deformity of the tibia, while up to 55% of cases of anterolateral bowing and pseudarthrosis are associated with NF.[3] Because anterolateral bowing of the tibia frequently presents in the first year of life, it may be the first recognized manifestation of NF. The presence of NF does not appear to affect the incidence of union or the ultimate outcome of the tibial pseudarthrosis. A relationship between tibial pseudarthrosis and fibrous dysplasia also has been suggested.[4] Despite the suggested association of CPT and fibrous dysplasia, however, microscopic evidence to confirm this is lacking.

Pathology

Ippolito et al[5] reviewed the pathologic material of 24 patients with CPT

and correlated the findings with clinical and radiographic data. At the site of pseudarthrosis, the authors found thickened periosteum and a cuff of fibrous tissue. The main histopathologic change was the growth of an abnormal, highly cellular fibrovascular tissue. Histologic comparison of patients with and without NF revealed no differences. This highly cellular fibrovascular tissue was accompanied by a paucity of vascular ingrowth. Whether this tissue is the primary lesion or is caused by the pseudarthrosis is not known. Some investigators have suggested that the primary pathologic lesion is in the periosteal tissue around the tibia rather than in the bone itself.[6]

Classification

Numerous classification systems of CPT have been suggested, including those of Boyd,[1] Andersen,[7] and Crawford.[8] These systems generally describe the radiographic appearance of the untreated bone at the pseudarthrosis site, the presence of fracture at birth, and involvement of the fibula. However, none of the classification systems provides specific guidance for management or is predictive of outcome. An example of the inadequacy of these classification systems is the fact that, once fracture has occurred, the radiographic type of tibial lesion is irrelevant. Additionally, because resection of the pseudarthrosis is commonly undertaken as part of initial surgical treatment, virtually all tibial dysplasias that come to surgery are, by virtue of this resection, converted to the same entity, that is, a tibia with a bony gap that must be united (Figure 1).

Consequently, the classification system that may be most relevant to treatment is a simple two-part system that identifies whether the tibia is fractured. Johnston[9] suggested that two criteria be considered to initially classify anterolateral bowing of the tibia: (1) presence or absence of fracture and (2) the age at which the first fracture occurs (early onset before age 4 years, delayed onset after age 4 years). Tibias that fracture and go on to pseudarthrosis are treated surgically; intact tibias are observed, with perhaps some orthotic protection.

Clinical Features

CPT is characterized by anterolateral angulation of the tibia. This bowing, combined with an overall decrease in distal tibia growth, results in shortening of the limb.

Anterolateral bowing may be noted at birth. The deformity is an apical prominence in the leg laterally, with the foot inverted or medially displaced in relation to the lower leg. If fracture has occurred, motion at the site of pseudarthrosis is evident. When signs of NF are present, the diagnosis is more straightforward. Much later, mild deformity may be noted when a limp develops because of shortening or impending fracture. The foot on the involved extremity may be normal or just slightly smaller than the contralateral foot. Roach et al[10] described a late form of CPT presenting as a fracture in an older child without any prodromal symptoms.

Treatment

Treatment of CPT is challenging. The primary goal is to obtain and maintain union while minimizing angular deformity. The use of a brace before fracture occurs is the mainstay of early treatment. Its use is recommended at all times when weight bearing and is continued through skeletal maturity. The anatomic alignment of the limb should be controlled to avoid fracture. After surgery, a brace also may play a complementary role in treatment.

The highest rates of union have been reported after surgical intervention although no single method of surgery has proved to be ideal. The basic biologic considerations with surgery include resection of the pseudarthrosis, biologic bone bridging of the defect with stable fixation, and correction of any angular deformity.

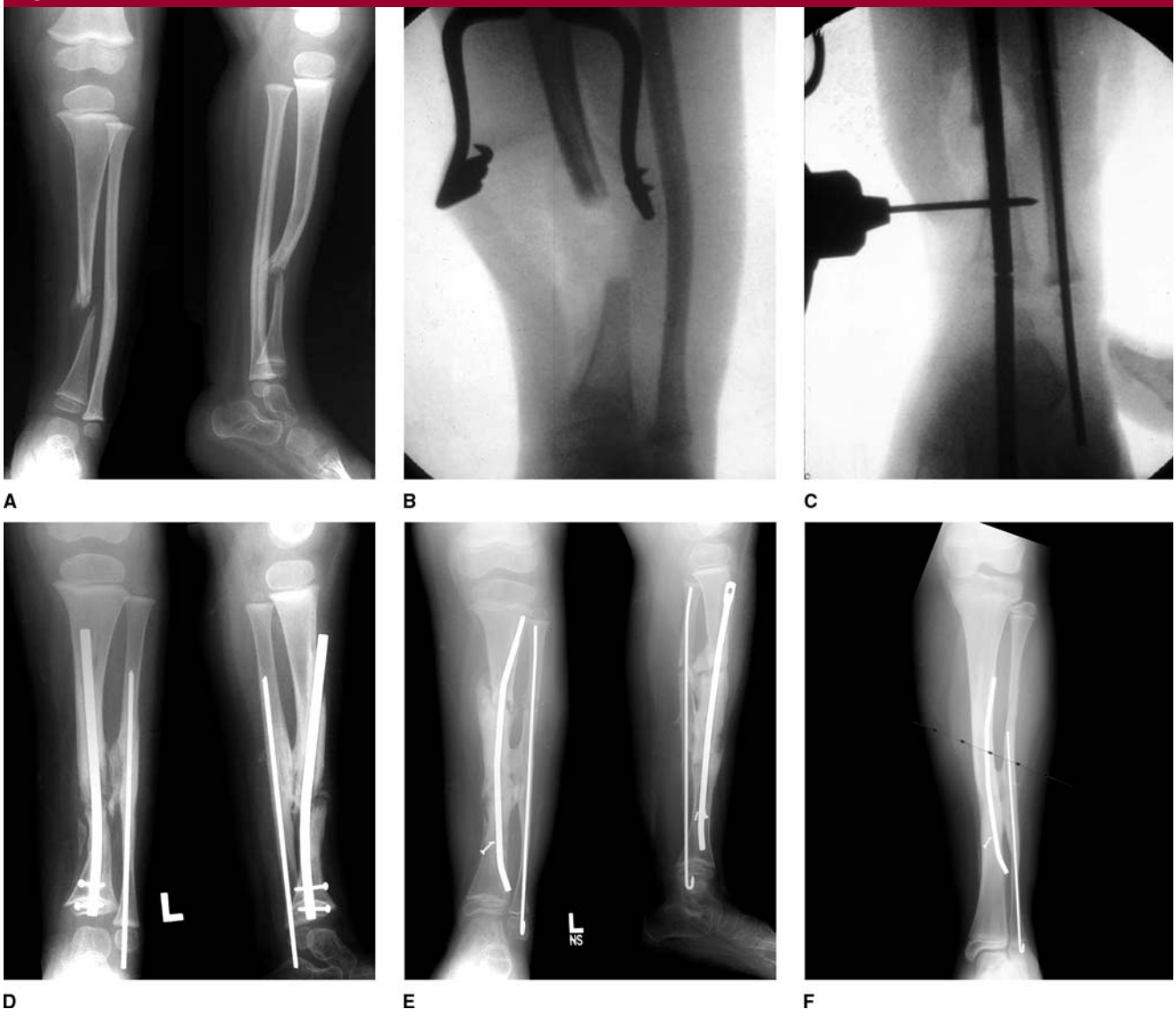
Intramedullary Stabilization

Intramedullary (IM) stabilization of CPT was introduced by Charnley.[11] This method has been recommended as first-line surgical treatment of CPT with acceptable healing.[12-17] Conceptually, the IM nail provides stability to allow healing of the pseudarthrosis and helps prevent refracture.[12,13] One reported advantage is that IM stabilization is relatively easy to perform. Also, the postoperative course is less difficult for the patient compared with other treatment methods (eg, free vascularized fibula grafting, Ilizarov fixation).[16]

Several IM nail designs have been used to treat CPT. Telescoping nails, which are affixed at both ends in the epiphyses, lengthen as the child grows.[18] Fixed-length solid nails can be inserted through the heel or, less commonly, through the knee, but may require replacement as the child grows. The Williams nail, a two-part nail (inner rod and insertion rod), is inserted antegrade through the pseudarthrosis site and out the heel, then is driven retrograde across the pseudarthrosis, and finally is detached, leaving the end of the indwelling nail in the desired distal position.[19] No single IM device is uniformly successful, and no evidence suggests that use of one is superior to that of others.

Although some technical points are controversial, several steps are common to successful IM treatment of CPT.[2,14-17] First, abnormal tibial bone and associated abnormal periosteum must be resected. If present, a fibular pseudarthrosis also must be resected.[13,15] Next, the "normal" tibial ends are apposed and stabilized with the IM nail, and bone graft is placed. IM stabilization should remain in place after healing to help prevent refracture.[12,13]

Figure 1



A, Anteroposterior (*left*) and lateral (*right*) radiographic views of a 3-year-old boy with neurofibromatosis type 1. **B,** Anteroposterior radiograph demonstrating treatment with resection of the pseudarthrosis lesion, back to "normal" bone, before shortening, rodding, and bone grafting **(C)**. **D,** Anteroposterior (*left*) and lateral (*right*) postoperative radiographic views demonstrating custom interlocked intramedullary nailing. **E,** Anteroposterior (*left*) and lateral (*right*) radiographic views of the patient at age 6 years. Revision surgery consisted of a single flexible rod with realignment osteotomy proximal to the original pseudarthrosis site. **F,** Anteroposterior radiograph 10 years after revision surgery demonstrating solid union. The patient had normal function.

The results of IM fixation of CPT have been reported in both short- and long-term retrospective studies. Anderson et al[12] reported on the use of the Williams nail for IM fixation of CPT in 10 patients; at a mean of 6 years, 9 patients had healed. However, five of nine patients went on to refracture. There were no amputations in the short term. This group was followed long term, and other patients were added to the series and reported on at an average of 14.2 years. The authors reported that 16 of 21 patients had achieved a satisfactory result and that 5 had undergone amputation.[13] Johnston[15] reported that 11 of 23 patients had a good outcome with IM fixation at an average follow-up of 9 years. He stressed the importance of addressing the fibula at the same time.

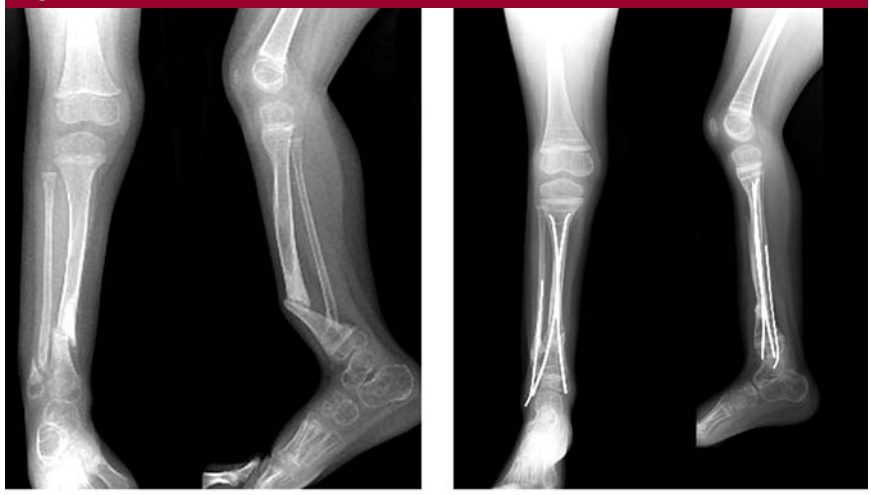
Placement of an IM rod across the ankle and subtalar joint in an effort to obtain better stabilization of the distal fragment is an established technique[12,19,20] for pseudarthrosis treatment; however, the cost to ankle motion and leg function is significant.[21] Damage to articular surfaces

by transfixation of the ankle, combined with fibrosis and atrophy of the periarticular tissues resulting from lack of ankle motion and long-term bracing to "protect" the transarticular implant, uniformly produces a calcaneus gait and a stiff ankle. Recognizing the detrimental effects of the rod across the ankle, especially in patients who appear to have gained union of the pseudarthrosis, some authors recommend surgically pushing the rod up, out of the ankle and into the tibial medullary canal, as soon as possible following apparent union and after sufficient longitudinal growth has occurred to make this feasible.[13]

The decision to go across the ankle remains controversial. Efforts to avoid transankle fixation may be justified on functional grounds if suitable fixation in the tibia alone can be accomplished. The union rate does not appear to differ based solely on whether the ankle is crossed or not, although this observation has not been studied prospectively.[9] Union has been successfully achieved without crossing the ankle in select patients in whom the distal tibial fragment initially did not seem to be of sufficient size to attempt this (Figures 1 and 2). However, there are no guidelines in the literature regarding how old a patient must be for such a procedure or how long the distal tibial segment must be to accomplish union while avoiding transankle fixation.

If initial IM fixation that does not cross the ankle fails, either by locking screw fracture or rod migration (Figure 1, D), the fixation can be revised with a rod of greater diameter and length once some tibial growth has occurred; often this is successful in the larger bone (Figure 1, E). Even if union is not achieved at the first surgery, effective internal splinting of the tibia without immobilizing the ankle may provide the patient with a functional leg while growth and hypertrophy of the tissues proceed. Such growth and hypertrophy set the stage for a repeat attempt at a later date, when the likelihood of achieving union may be more favorable (Figure 1, F).

Figure 2



A B

A, Anteroposterior (*left*) and lateral (*right*) radiographic views of a 2-year-old girl with congenital pseudarthrosis of the tibia. **B,** Anteroposterior (*left*) and lateral (*right*) radiographic views at 2-year follow-up after treatement with flexible intramedullary titanium nails.

Figure 3

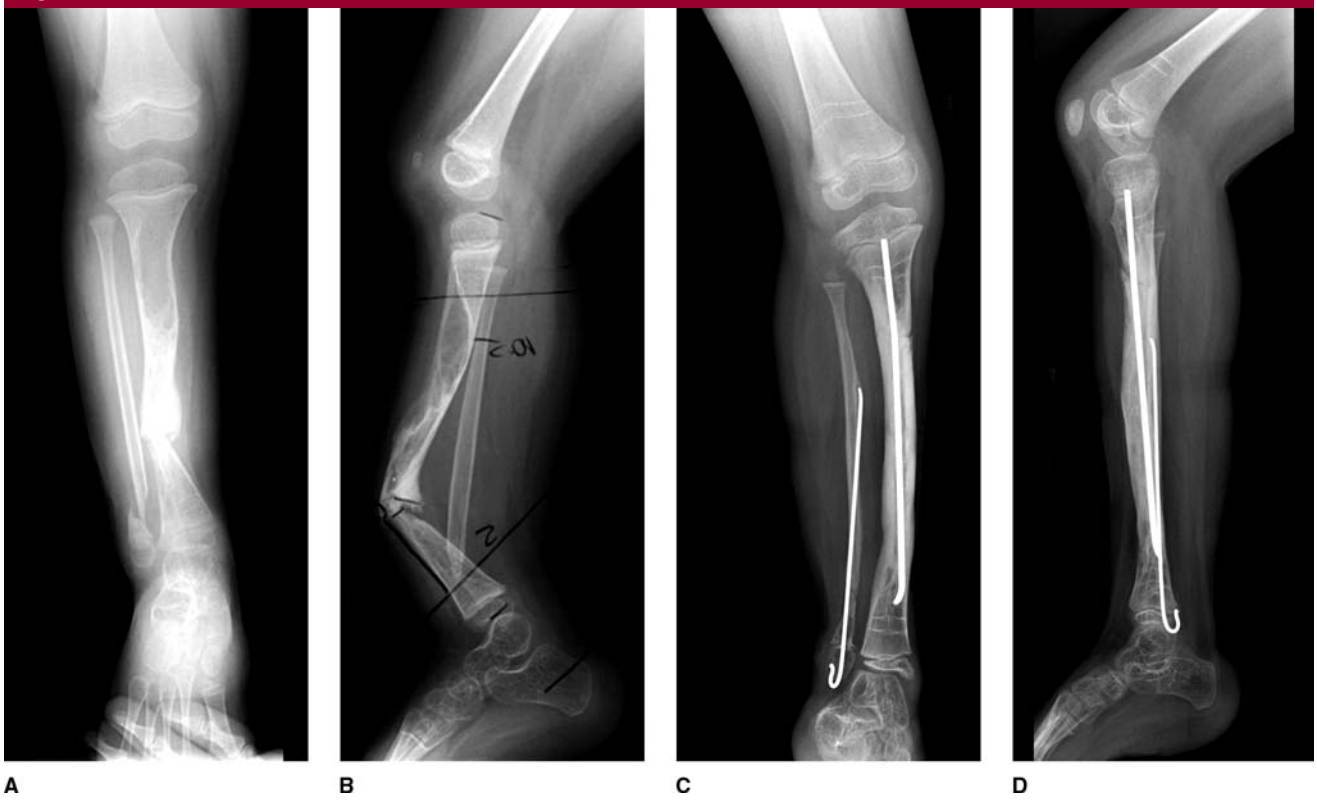
A B

A, Intraoperative photograph demonstrating a collagen sponge impregnated with rhBMP-2 encircling the pseudarthrosis site. Autogenous bone graft is added inside the sponge. **B,** The sponge is wrapped completely around the site, encasing the bone graft.

Bone Morphogenetic Protein

Following the introduction of recombinant human bone morphogenetic protein (rhBMP-2) for clinical use in fracture healing and spinal fusion applications, the phenomenon of osteoinduction has now been applied to the treatment of CPT.[22,23] Using doses of 4.2 to 12 mg of rhBMP-2–soaked collagen sponges wrapped around bone graft at the pseudarthrosis site (Figure 3), Richards et al[24] reported radiographic union in six of seven patients at a

Figure 4



Anteroposterior **(A)** and lateral **(B)** radiographic views of a 4-year-old girl with neurofibromatosis type 1, neglected pseudarthrosis, and a large nonossifying fibroma in the proximal tibia. Anteroposterior **(C)** and lateral **(D)** radiographic views 18 months after surgery, demonstrating healing with valgus alignment, with recombinant human bone morphogenetic protein placed in the fibrous defect and around the pseudarthrosis site.

mean of 33 weeks postoperatively, with five of seven healing after the index procedure (all IM rodding). Moreover, union remained intact at a mean of 3.6 years. No adverse reactions were seen in the six healed patients.

The robust callus observed at the pseudarthrosis site following rhBMP-2 application (Figure 4) and the favorable preliminary results reported, combined with the persistent healing deficiencies seen in the typical patient with CPT, may support the use of adjunctive osteoinductive biologic material such as rhBMP-2, regardless of the method of treatment. Although the use of rhBMP-2 has been questioned in conditions that may have malignant potential (eg, NF), this remains theoretic, with no reported adverse outcomes.

Free Vascularized Fibula Graft

Soon after free vascularized fibula grafts were described in the mid 1970s, the technique was applied to CPT.[25] The technique involves two teams. The first team removes the abnormal bone in the tibia proximal and distal to the pseudarthrosis site. The second team of surgeons harvests a 10-to-12-cm length of contralateral fibula with its vascular pedicle. The fibula is then placed in the gap and fixed by a variety of techniques. Initially these techniques included plating or simply screws; more recently, IM nailing has been used.[26] The vascular pedicle typically is attached to the anterior or posterior tibial artery and any associated vein. Postoperative immobilization varies, from a long leg cast to the traditional spica cast. Delayed unions are aggressively treated with repeat bone grafting and an IM device.

The reported series are retrospective (level IV) and consist of 1 to 29 patients each.[25,27-31] Recent reports have been on multicenter studies.[26,32] Follow-up varies from 2 to 12 years. Union rates, initially reported at 95%,[24,30] have been more recently adjusted to 60% to 88%,[26,28-30,32] with an average of 2.4 operations required to achieve union. Fifty percent to 80% of patients have needed additional procedures to achieve union; amputations were rare.[26,28-32] Union

rates increased with patient age at the time of the procedure.[26] Problems encountered included nonunion, predominantly distal.[31] Moderate to severe angular deformities were reported as well as notable limb-length discrepancies. Postoperative bone scans confirmed blood flow to the transplanted fibula.[25] The donor site morbidity reportedly has been low[25,26,31] but may be underestimated. These studies do not report data on ankle valgus, toe and ankle dorsiflexion weakness, or the need for additional procedures on the contralateral "good leg."

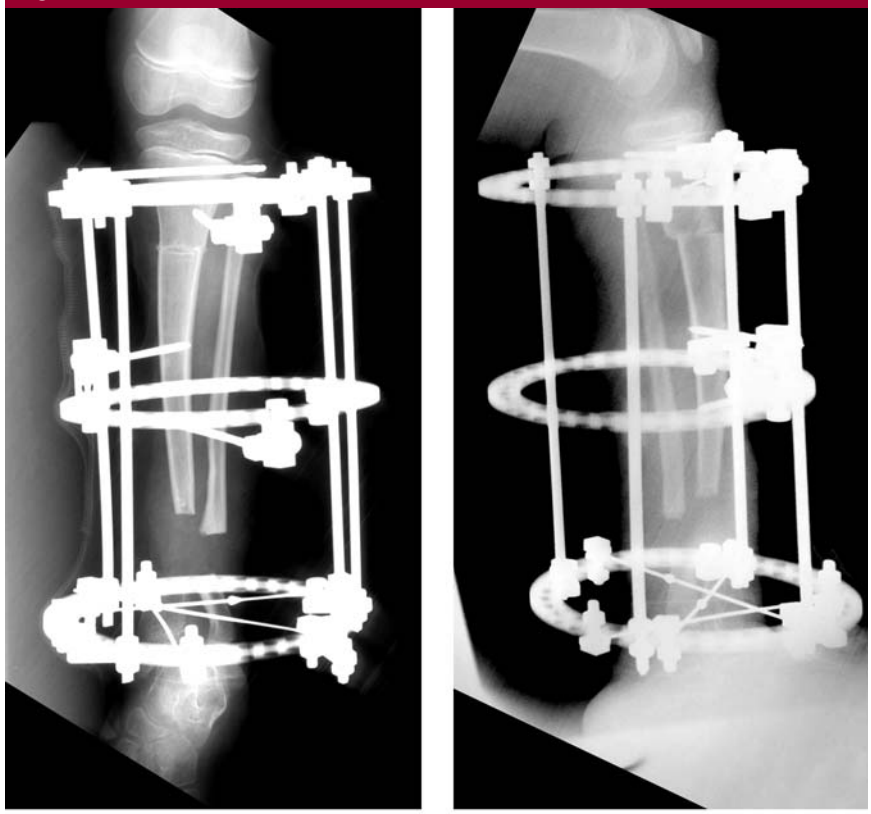
Coleman and Don[33] and Safoury[34] reported on treatment with a vascularized ipsilateral fibula transfer. This technique requires resecting the nonunion site, mobilizing the peroneal artery and vein, and then transferring the fibula and pedicle into the defect. Results show high union rates at 2-to-5-year follow-up.[33] This procedure has the advantage of avoiding morbidity in the unaffected leg; however, ipsilateral fibular transfer may not be feasible in situations in which the fibula is dysplastic or fractured.

Although union can be achieved in >90% of cases,[25,28,31,32,35] problems with refracture and valgus deformity occur essentially in every patient, most likely because of lack of IM fixation and fibular continuity (both principles of successful long-term outcomes).[25,32] Significant morbidity to the donor leg is underestimated, including muscle weakness secondary to removal of fibular muscle origin) and ankle valgus. Ankle valgus, when present, routinely requires additional surgery (hemiepiphysiodesis or supramalleolar osteotomy).[29]

Ilizarov Technique

The Ilizarov external fixator, introduced in the United States in the late 1980s, was soon applied to the treatment of CPT.[36] A number of techniques have been reported,[36-43] and several different frame configurations and strategies have been used.[41] Most commonly, an Ilizarov frame is applied with two rings, one above and one below the pseudarthrosis (Figure 5). When the pseudarthrosis is distal, the foot is included in the frame. The pseudarthrosis is resected, and the gap is compressed. When there is a limb-length discrepancy, a proximal corticotomy is done for distraction.[40,41] Alternatively, the area proximal and distal to the pseudarthrosis is resected, the four-ring frame is applied, a corticotomy is done proximal, and the bone is transported into the gap.[44] If the pseudarthrosis gap addressed with bone transport fills with fibrous tissue while the transport is being accomplished, it may need to be resected and the bone edges "freshened" to get the bone to unite.

Figure 5



A **B**

Anteroposterior **(A)** and lateral **(B)** radiographic views demonstrating the use of Ilizarov fixation in a 9-year-old boy with neurofibromatosis type 1 and persistent congenital pseudarthrosis despite two previous surgical attempts at treatment.

The largest series published to date describe resecting the pseudarthrosis and compressing the gap.[37,41] Based on retrospective case series (level IV), the union rate was 60% to 100% overall.[37-42] The average number of procedures was 1.4.[37] Residual limb-length discrepancy and valgus deformity were commonly reported, with a complication rate of 30% to 100%.[37,44] One study had a significant refracture rate but a low malalignment rate.[41] As was found with free vascularized fibula grafts, older patients had higher union rates.[37]

Two recent reports describe combining free vascularized fibula graft with the Ilizarov technique, thereby offering the advantage of addressing both bone loss and leg length inequality.[45,46] The refracture rate was

high.[46] Although there are no large series reporting the use of alternative ringed fixators, these are now being used interchangeably with the Ilizarov.

Treatment of the Fibula

The need for fibular surgery remains controversial. Joseph and Mathew[16] and Fern et al[47] reported union rates of 83% and 100%, respectively, without fibular surgery, but they did not report on the prevalence of valgus deformity. Fern et al[47] reported a 40% refracture rate after 4.5 years and Joseph and Mathew,[16] a 25% refracture rate at 3 years' follow-up. Johnston[15] concluded that, when the fibula is intact, a fibular osteotomy is necessary to achieve optimal limb alignment and union. He also recommended that a hypoplastic or bowed fibula suggests pseudarthrosis and should be resected. Similarly, Dobbs et al[13] found that the prevalence of tibial refracture was higher in patients in whom the fibular pseudarthrosis was not resected. In contrast, these authors found no difference in union rates or alignment when the fibula was osteotomized compared with the intact fibula left alone. The fibula typically is stabilized with an IM device, such as a Kirschner wire or Steinmann pin, to accommodate the small diameter of the canal.

Amputation

Amputation is seldom a consideration in the early management of the child with CPT. Technical ability to achieve healing of the CPT has improved greatly over the years. With recent advances in treatment, including the use of rhBMP-2, the number of children who undergo amputation may decrease.

However, the potential for amputation always must be included in the early discussion with the parents because a significant number of children still require the procedure.[48,49] Often it is difficult for surgeons, parents, and children to accept that CPT is not going to heal.[50] In the past, many children have had repeated surgical interventions without success, resulting in late amputation.[50] It some cases, therefore, it is better to amputate early and definitively so the child can get on with his or her life.[49,51] Guille et al[52] suggested that the final evaluation should not be based on obtaining a bony union but on the level of function of the extremity.

McCarthy[53] summarized the indications for amputation as follows: (1) failure to satisfactorily achieve bony union after three surgical attempts; (2) significant limb length discrepancy (ie, >5 cm), which necessitates the use of a cosmetically unacceptable orthotic shoe to equalize the leg lengths; (3) a permanently deformed foot with resultant poor function; and (4) functional loss resulting from prolonged medical care and hospitalization.

The typical child who requires an amputation has a persistent nonunion despite three or more surgeries.[48,50,54,55] Most will have dysplastic nonunion with severe shortening of the limb.[50,54,56] Children with NF are at greater risk for amputation.[55] Morrissy et al[50] reported that amputation occurred in all patients who required more than two bone grafts, whose pseudarthrosis took more than 32 months to unite, or who did not achieve union by age 6 years. Occasionally, a patient who has achieved bony union will request an amputation because of poor function due to a weak, short, and deformed limb.[50]

The best functional amputation in a child is a modification of the Syme amputation, which retains the distal tibial epiphysis and results in a longer stump.[56] Although it is tempting to amputate through the site of the pseudarthrosis, doing so has several disadvantages:[53,57] (1) bone at the level of the pseudarthrosis is usually thin and abnormally shaped, which results in a poor end-bearing stump; (2) bony overgrowth is common in young children with acquired amputations and is a continuing concern until growth is completed;[50,58-60] (3) scarring of the skin, subcutaneous tissue, and vasculature at the level of the pseudarthrosis from the previous surgery provides poor coverage of the stump; and (4) amputations proximal to the pseudarthrosis may leave a short stump, which decreases the length of the lever arm and may lead to problems with function and prosthetic fitting.[50]

When it is doubtful that the pseudarthrosis will heal, the goals are a vertically aligned limb and a stump with adequate length for strength as well as for a good fit with a total-contact prosthesis.[53] When amputation at the pseudarthrosis site is necessary, it should be done proximally in an area of relatively normal bone. Usually, there is an associated pseudarthrosis of the fibula; the fibula should be removed proximal to the site of the pseudarthrosis.

Karol et al[21] studied gait and function in patients who had undergone multiple surgeries to gain union; they compared these patients to patients with CPT who had had amputations for failed surgical treatment. At an average of 4 years after healing, persistent weakness was present in the gastrocnemius-soleus complex and the anterior tibialis and quadriceps muscles in the patients who had not had an amputation. These findings of more weakness were exaggerated in children who developed CPT before the age of 4 years. Children with healed early-onset CPT walked no more efficiently than did those with amputations. Preservation of ankle joint mobility correlated with better functional outcome.[21]

Complications

The treatment of CPT is fraught with complications, and failure is common. Complications both of treat-

ment and of the disease have been recognized. Even when union of the pseudarthrosis is achieved, patients may have compromised function. Inan et al[61] reviewed residual deformities in 16 patients treated for CPT. Ten had diaphyseal malalignment; half of these experienced refracture. Residual limb length discrepancy is common. Discrepancies of <5 cm may be treated with contralateral epiphysiodesis when sufficient growth remains. Larger discrepancies can be treated by lengthening of the shorter (ie, pseudarthrosis) leg; however, the risk of nonunion at the site of lengthening is high.[60] Persistent pseudarthrosis of the fibula contributes to valgus deformity at the ankle.[61] Dobbs et al[13] also found that most ankle valgus deformities occurred in patients with concomitant fibular pseudarthrosis, even when the fibular lesion had been treated. Additional procedures may be required to restore alignment, including medial hemiepiphysiodesis or tibial osteotomy.

Some prognostic factors for CPT have been proposed, but these are strongly debated. The correlation between age at surgery and final outcome remains controversial. Initially, surgical treatment after the age of 4 years was advised.[37,40] Others have emphasized the advantages of early surgery.[19] Morrissy et al[50] reported that a good result was unlikely in patients who did not have union by age 6 years.

Tudisco et al[62] reported the functional results at the end of skeletal growth in 30 patients with CPT. They concluded that the prognosis of CPT was very much related to radiologic findings. Patients with severe limb length discrepancy, poor ankle function, and fibular pseudarthrosis had the worst functional results.

Summary

The aim of treatment in CPT is to obtain a straight, healed tibia in a child unencumbered by frequent surgeries. Treatment before fracture is conservative. After fracture, resection of the pseudarthrosis site and IM rodding is recommended. The addition of rhBMP-2 has shown promising early results. Free vascularized fibula graft and Ilizarov external fixation may be reserved for more recalcitrant cases. Amputation should be discussed early and is an option in cases that have failed to unite despite multiple surgical efforts.

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Evidence-based Medicine: Most references cited are level III, with some review articles and basic science/descriptive studies.

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