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Chronic Osteomyelitis in Children

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Summary: In developing countries, chronic osteomyelitis often results from untreated acute hematogenous osteomyelitis but may also be seen as sequelae of trauma (war injuries). This condition is characterized by areas of devitalized bone/soft tissue (sequestra), which serve as a nidus for recurrent episodes of infection. The periosteal response (involucrum) serves to restore structural integrity, and partial or complete reabsorption of sequestra usually accompany this host response. In addition to providing adequate nutritional support, and treating any coexisting medical or infectious diseases, the treatment of chronic osteomyelitis involves surgical removal of all infected/devitalized tissue with or without antibiotic therapy. Sequestrectomy is usually delayed until a suitable involucrum has formed to preserve stability and minimize the chances of fracture and/or segmental bone loss. The disease and/or its treatment may result in focal or segmental loss of bone, requiring further intervention to restore osseous continuity, alignment, and length. Treatment options for focal bone loss include conventional bone grafting and open cancellous bone grafting (subcutaneous bones), and the limb should be protected (cast or external fixator) until healing is complete. For segmental loss of bone, options include conventional bone grafting (external fixator to maintain length and stability) or bone transport. The latter technique, if technically feasible, allows the simultaneous management of limb malalignment and limb length discrepancy. The choice depends on the local resources, and either technique may result in a suitable outcome for the majority of patients. For segmental defects in the tibia, the ipsilateral fibula may be used as a bypass graft. Creation of a single-bone forearm may represent the best option in cases with significant loss of the radius or ulna, provided that the wrist and elbow are normal. **Key Words:** Osteomyelitis—Chronic—Treatment.

Orthopaedic surgeons planning to work in a developing country will undoubtedly be exposed to chronic osteomyelitis. In children, the disease usually results from untreated acute hematogenous osteomyelitis. Chronic osteomyelitis may also be seen after traumatic injuries, especially in times of civil unrest or war, or as a complication of surgical procedures such as open reduction and internal fixation of fractures. The long bones are affected most commonly, and the femur and tibia account for approximately half of the cases. Predisposing factors include poor hygiene, anemia, malnutrition, and a coexisting infectious disease burden (parasites, mycobacteria, acquired autoimmune deficiency syndrome), or any other factors that decrease immune function. Chronic osteomyelitis is defined by the presence of residual foci of infection (avascular bone and soft tissue debris), which give rise to recurrent episodes of clinical infection.

Eradication of the infection is difficult, and complications associated with both the infection and its treatment are frequent. Our goals are to review the pathophysiology, natural history, and treatment options for children with chronic osteomyelitis within the context of a developing world setting.

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PATHOPHYSIOLOGY

The primary focus of acute hematogenous osteomyelitis in children is in the metaphysis. If untreated, the intramedullary pressure increases and the exudate

FIG. 1. (**A–C**) Sequestra represent fragments of devitalized bone, which may become walled off by the involucrum (**A** and **B**), and large segments of the diaphysis may become sequestrated (**C**).

spreads through the thin metaphyseal cortex resulting in a subperiosteal abscess. A subperiosteal abscess may expand and elevate the periosteum along the diaphysis. Bone necrosis complicates the loss of blood supply from both the increase in intramedullary pressure and the loss of periosteal blood supply. Avascular segments of bone are known as sequestra, and the entire shaft of a long bone may become sequestered (Fig. 1). These fragments harbor microorganisms and give rise to recurrent episodes of clinical infection. The abscess may also break through the skin, forming a sinus. The host response is generated by the periosteum in an attempt to wall off or reabsorb these fragments and reestablish stability and is referred to as the involucrum. The morphology of the involucrum varies considerably (Fig. 2), and an aggressive periosteal reaction may simulate a malignant neoplasm. As such, a formal biopsy should be considered in many of these cases. If the periosteal response is minimal, then focal or segmental loss of bone is inevitable (Fig. 3). Sequestra may be partially or completely reabsorbed as a result of the host response or may be incorporated into the involucrum.[15,32]

There is a risk of coexisting septic arthritis in regions where the metaphysis is intraarticular (proximal femur,

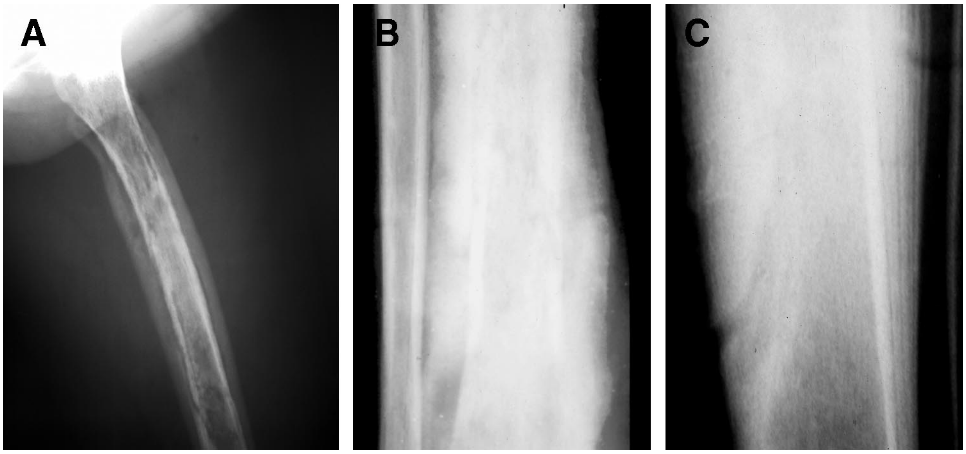

FIG. 2. Variations in the periosteal response (involucrum). A smooth periosteal response (**A**) appears similar to the "hard" periosteal callus seen in fracture healing. In contrast, the involucrum may take on a fluffy, more aggressive appearance (**B**). (**C**) A laminated response (right side) similar to the "onion skinning" seen in Ewing's sarcoma. Note the large cloacae on the lower left side.

proximal radius, proximal humerus, distal fibula). This risk is increased in children less than 2 years of age as a result of the unique aspects of the infant's vasculature.[9] The metaphyseal and epiphyseal vessels communicate until approximately 12 to 18 months of age, after which the physis serves as a mechanical barrier to the spread of infection.

The clinical findings include fever, malaise, bone pain, tenderness, soft tissue swelling, and often a sinus with persistent discharge. On occasion, devitalized bone may be exposed.

FIG. 3. The failure to form an adequate involucrum will result in segmental bone loss.

TREATMENT

Chronic Osteomyelitis

The first step in managing chronic osteomyelitis is to make the diagnosis. Because the radiographic differential diagnosis often includes a neoplasm, a biopsy is often required. Once the diagnosis is made, the treatment of chronic osteomyelitis is surgical. Complete removal of all infected/devascularized tissue provides the only opportunity to eradicate the infection, because antibiotics cannot penetrate devascularized tissue.[7,29,30,31,34] It is also essential to improve the host's physiological state through adequate nutrition, correction of significant anemia if present, and treating any coexisting infectious disease burden.

The timing of surgical intervention is controversial. Although some authors recommend early sequestrectomy to eradicate the infection and provide a better environment for the periosteum to respond,[8,14,17] others recommend waiting until a sufficient involucrum has formed before performing a sequestrectomy to minimize the risk of complications such as fracture, nonunion, deformity, and segmental bone loss.[12,31] In either case, it is critical to preserve the involucrum. The presence of nonunion or segmental bone loss complicates the management considerably, and multiple reconstructive procedures may be required to restore limb stability, alignment, and length. Our preference is to wait at least 3 to 6 months before performing a sequestrectomy.

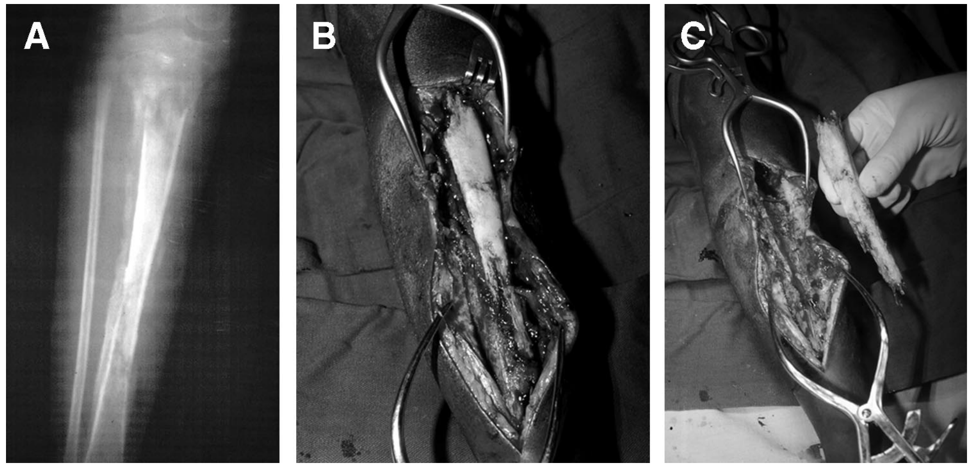

FIG. 4. In this example, the sequestrum is a large segment of the tibial diaphysis, and a suitable involucrum had formed posteriorly and laterally (**A**). At the time of exposure, that segment was avascular in contrast to the surrounding bone and soft tissue (**B**). The segment was easily removed (**C**), and the medullary canal curetted.

Preoperative planning is essential, and both the radiographs and the physical examination are used to plan the most appropriate surgical approach. High-quality radiographs should be studied to identify all sequestra, to define the thickest area of the involucrum, and to locate any cloacae (portals in the bone through which spontaneous drainage has occurred). Ideally, the debridement can be carried out through a window in the weakest area of the involucrum to maximize structural integrity. The skin incision should avoid the subcutaneous surface of a bone and should be centered over any sinuses. Injection of contrast material (sinogram) or methylene blue preoperatively may help to better define the anatomy of a sinus. In addition, the preoperative assessment helps to anticipate any future problems in management such as focal or segmental bone loss.

The technical aspects of debridement are also important.[30] Sinus tracts, and any adjacent scar tissue, are resected during the initial skin exposure. Although the extraperiosteal exposure may be wide, the subperiosteal exposure should be limited to the area of bone to be removed to preserve the local blood supply. A sequestered segment of the shaft may be directly removed provided the involucrum is adequate (Fig. 4A–C). If the sequestrum lies within the involucrum or the medullary canal, a cortical window may be removed by connecting a series of drill holes with an osteotome (Fig. 5A). The window should be oval to minimize risk of fracture postoperatively, and the size depends on the location of sequestra and the extent of involvement. With extensive involvement, the procedure can be better described as a longitudinal partial diaphysectomy (Fig. 5B), and the limb will need protection for an extended period of time. All sequestra should be removed, and any devitalized tissue should be curetted from the medullary canal. The extent of debridement may be defined by the presence of punctate bleeding from the exposed bony surface, referred to as the "paprika sign."[30] If there are concerns regarding the adequacy of the initial debridement, then the patient should be returned to the operating room for additional debridement. Once all abnormal tissue has been removed, the wound should be thoroughly irrigated with sterile saline with or without an antibiotic solution. Boiled or distilled water is also an effective irrigant. The wound should be closed loosely to allow for drainage. There should be no tension on the skin edges. The bone edges may be sculpted to facilitate soft tissue coverage. If possible, muscle may be mobilized to cover any exposed bony surfaces.[3] A drain should be placed. Local rotational flaps may also be beneficial, especially in the tibia.[3,11,26]

Bleeding from a well-vascularized involucrum is a significant concern both intraoperatively and postoperatively, especially when a tourniquet cannot be applied, for example in the femur or humerus. When performing a sequestrectomy at either of these sites, blood should be crossmatched and available for transfusion. The patient may be placed in the Trendelenburg position (femur) or with the head of the bed elevated (humerus). An assistant can elevate the extremity. Postoperatively, the foot of the bed may be elevated with blocks, or the head of the bed may be elevated.

The goal of radical debridement is to eradicate the infection. Depending on the extent of debridement required, the next phase of treatment involves reconstruction of soft tissue and/or bone loss. If greater than 70% of the cortical volume has been retained, then the limb may be protected in a cast until complete reconstitution of the bone has occurred. For greater degrees of bone loss, it may be necessary to use an external fixator until stability has been regained. For focal bone loss, conventional bone grafting may be required, and the open cancellous

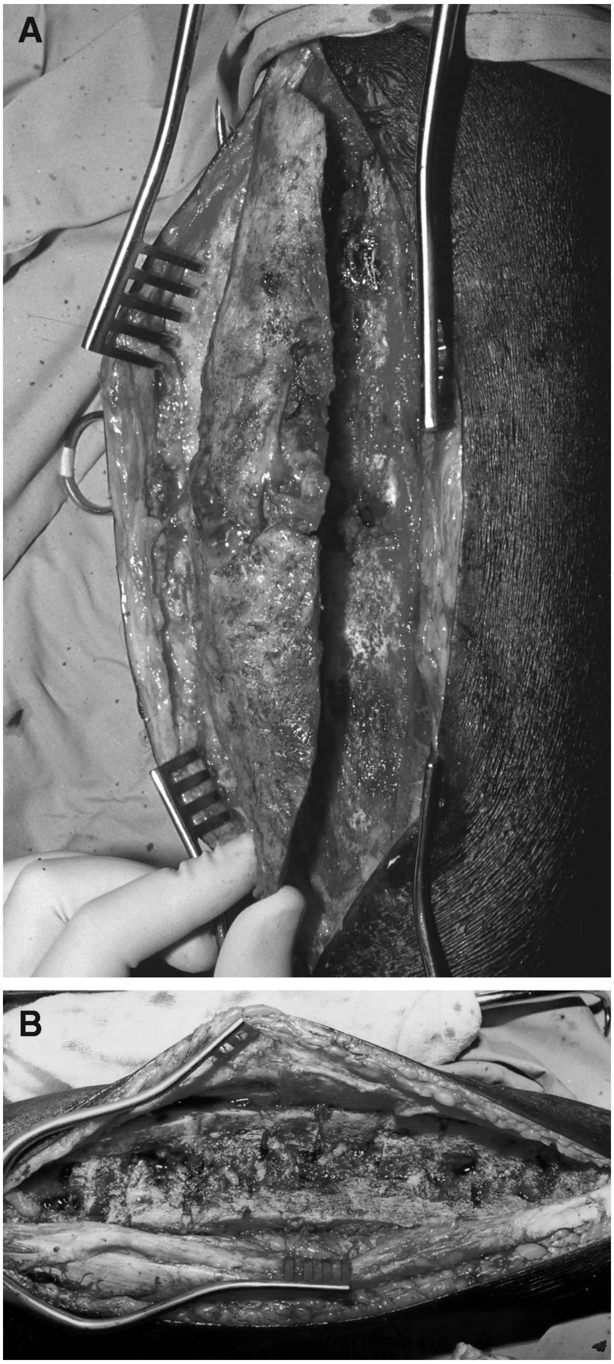

FIG. 5. An oval cortical window is often required to facilitate sequestrectomy and debridement.

FIG. 6. An example of segmental bone loss in the proximal tibia. This patient was managed by open cancellous bone grafting and protected in a cast until healing was complete.

bone grafting technique is appropriate if the bone is subcutaneous or cannot be covered by soft tissue.[7,10,13,24,25,28] For segmental bone loss, alternatives include conventional bone grafting or bone transport (Ilizarov or other devices). Although bone transport is technically more demanding, this method allows for the simultaneous management of bone loss, angular deformity, and limb length inequality.[6,20,23]

Because radical debridement of all infected bone and soft tissue is the essential step in eradicating chronic osteomyelitis, the role of antibiotics remains controversial. Adequate outcomes have been observed after debridement alone in centers where antibiotics were unavailable.[5,22,31] Our approach has been to recommend the same perioperative course of antibiotics (24 hours) as for clean elective surgical cases. In settings where antibiotics are readily available, patients may be given empiric coverage initially, and the type and dosage of antibiotics are then modified based on the culture results and sensitivities. An intravenous route can be used for up to 3 weeks, and then an oral agent may be substituted for several additional weeks. The total treatment time is usually 6 weeks. Variables that impact on the duration of

FIG. 7. Posterolateral bone grafting between the fibula and the tibia was used to treat a small area of segmental bone loss.

treatment include the clinical response and the erythrocyte sedimentation rate. Deep wound cultures (bone, granulation tissue) should be obtained in all patients, because cultures from sinus tracts identify the infective organism in less than 50% of cases.[19] In addition to surgery, the management of coexisting medical problems must be stressed, including the provision of adequate nutrition.

Chronic Osteomyelitis With Focal Bone Loss

The treatment depends on the degree of loss (Fig. 6) and the perceived risk of fracture. Small defects may be managed by protection (cast or external fixator) until the loss has been reconstituted. This is especially appropriate in younger children in whom regeneration of the entire tibial shaft has been documented.[4] Conventional bone grafting represents an excellent option, especially when skin coverage is adequate, and grafting may be performed as a second stage 6 or more weeks after the initial procedure.[8,21]

The open cancellous bone grafting technique is most appropriate for managing focal bone loss within a subcutaneous bone, especially the tibia.[7,8,10,13,24,25,28] The principles of treatment are to remove all devitalized bone, to wait until a suitable bed of granulation tissue has formed, and to place cancellous graft, which is gradually incorporated into the well-vascularized tissue bed. Antibiotics are not an absolute requirement. The original three-stage technique for open cancellous grafting was described by Papineau.[25] The first stage involved one or more debridements, repeated at 5- to 7-day intervals. An antibiotic-soaked dressing was placed in between debridements, and an intramedullary nail or external fixator was placed for bony stability. Stage 2 involves placement of strips of autogenous graft (posterior iliac crest) in layers to fill the cavity, and the adjacent cortical bone is "fish-scaled." An antibiotic-soaked dressing is applied, and the dressing is changed after 3 to 5 days. Daily dressing changes are then completed. The wound may heal by epithelialization, or a split-thickness skin graft may be applied. A local rotational flap or a free flap may also be considered.

Variants of the technique have also been described. Emani et al also used a three-stage technique.[10] After two debridements and placement of an external fixator, daily dressing changes are begun after 5 days. Grafting is performed 8 to 14 days after the second debridement, and more daily dressing changes are begun 5 days after grafting. Sachs et al (three-stage procedure) perform a single debridement, followed by dressing changes every 3 to 5 days.[28] A second debridement is performed after 3 weeks if necessary. Cancellous grafting is performed from 3 to 9 weeks after the initial debridement, and then dressing changes (petroleum gauze) are completed every 2 to 4 days. A split-thickness graft, or local muscle transposition, is performed 5 weeks after cancellous grafting. Green et al perform a single debridement with application of an external fixator, followed by dressing changes (three times per day) until a suitable granulation bed is observed.[13] Cancellous grafting is completed, and the fixator is left in place until the bone has fully incorporated (mean, 7 months). Finally, Panda et al perform a debridement, cleanse the cavity with Dakin's solution (sodium hypochlorite [0.45–0.5%] and boric acid [4%]), and pack it with gauze soaked in 1% framecytine.[24] A dressing change is performed 12 days later, and cancellous graft from the proximal tibia is applied. Daily irrigation is begun 5 days after bone grafting, and a skin graft is sometimes applied after consolidation.

Chronic Osteomyelitis With Segmental Bone Loss

A loss of continuity of either a portion or the entire shaft of a long bone represents a major challenge in treatment (Fig. 3). Once an adequate debridement has

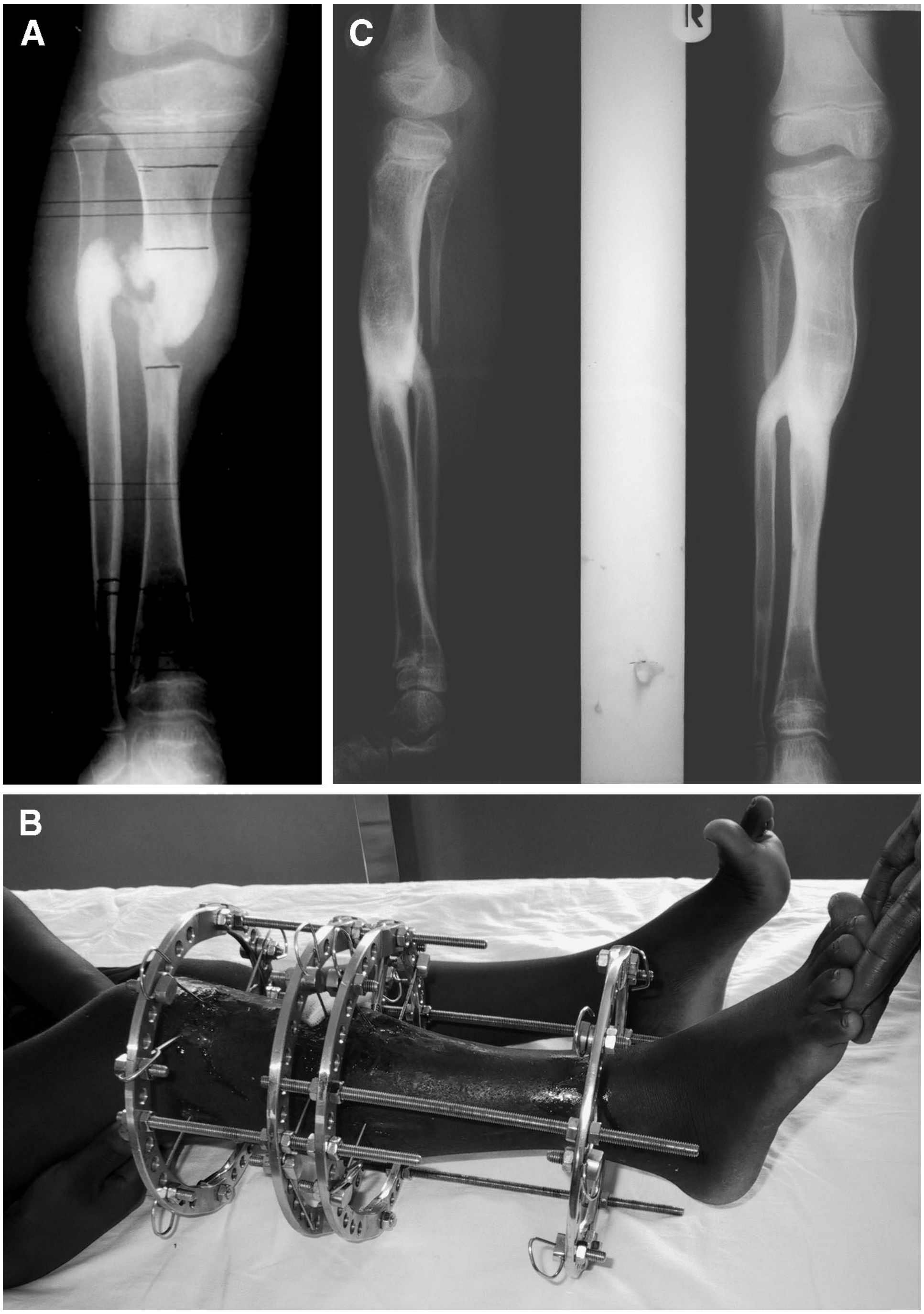

FIG. 8. (**A–C**) Bone transport with a ring fixator serves as an alternative to conventional grafting, or bypass procedures, for segmental bone loss. This boy had a segmental loss of the tibia, associated with an angular deformity, after debridement and failed conventional grafting (**A**). A ring fixator was applied (**B**), and after a proximal corticotomy and bone transport, union has been achieved, and angular deformity was corrected simultaneously (**C**).

been performed, and the infection is under control, reconstructive options include bone grafting or bone transport. For the forearm and the lower leg, bypass procedures may also be used to restore stability.[1,2,5,12,16,18,33,34] Amputation may be reserved for cases in which other methods have failed to either control the infection or restore stability to the limb segment, or when limb reconstruction is not felt to be feasible.

Conventional bone grafting may be helpful in many cases; however, this technique is limited mainly by the amount of autogenous bone graft that can be harvested (Fig. 7).[8,13] In general, segmental defects of greater than 2 cm in length may be difficult to manage using conventional grafting. The most common source of autogenous bone graft is the iliac crest, and the proximal tibia is also a good source of cancellous bone.

FIG. 9. (**A** and **B**) Fibular bypass procedures may successfully reconstruct segmental defects in the tibia. Examples include a one- or two-stage transfer of the fibular ends into a tibial trough (Huntington procedure and variants) (**A**) and posterolateral bone grafting between the tibia and fibula both proximally and distally (**B**).

Bone transport represents an alternative to conventional grafting. Using this method initially described by Ilizarov, a segment of healthy bone is gradually transported longitudinally to fill a segmental defect (Fig. 8A–C).[6,20,23] The initial treatment is radical debridement. A ring fixator is used, and a corticotomy is made at the metaphyseal–diaphyseal junction proximally (unifocal transport), distally (unifocal transport), or at both ends (bifocal transport). Segments are then gradually transported across the gap and "docked" with healthy bone. In addition to treating postseptic nonunion with or without segmental bone loss, the approach allows the simultaneous management of leg length discrepancy and angular deformity. Although the method is labor-intensive, and complications are frequent, complex problems may be solved. Several reports in adults have compared conventional grafting with bone transport and have determined that the overall results are not significantly different, and that both methods may be used successfully in the majority of cases.[6,20] As such, the decision of how to manage segmental bone loss will depend on the resources available locally and the level of expertise of the treating surgeons.

Segmental bone loss within the tibia, or the forearm bones, represents a unique circumstance in which bypass grafting may serve as an alternative to conventional bone grafting or bone transport.[1,2,5,12,16,18,33,34] Numerous techniques for using the ipsilateral fibula as a bypass graft have been reported, either in one or two stages. The goal is to achieve union between the fibula and the tibia both proximal and distal to the site of bone loss (Fig. 9). Stability is restored, and the fibula assumes the loadbearing for the distal limb. Fibular bypass is indicated when a long segment of the shaft is involved, especially if there is a small amount of tibial metaphysis available at one or both ends. Bypass may be performed at the time of debridement or as a separate procedure once the infection has been eradicated. In general, union may be achieved by either posterolateral grafting proximally and distally,[2,12] or by osteotomizing the fibula at both levels and transferring each end into a trough placed at the corresponding level of the tibia.[1,5,16,34] Care must be taken to avoid injury to the peroneal nerve with the proximal exposure. Another potential problem is the late development of ankle valgus after distal fibular transfer, which may be prevented by the Langenskiöld procedure

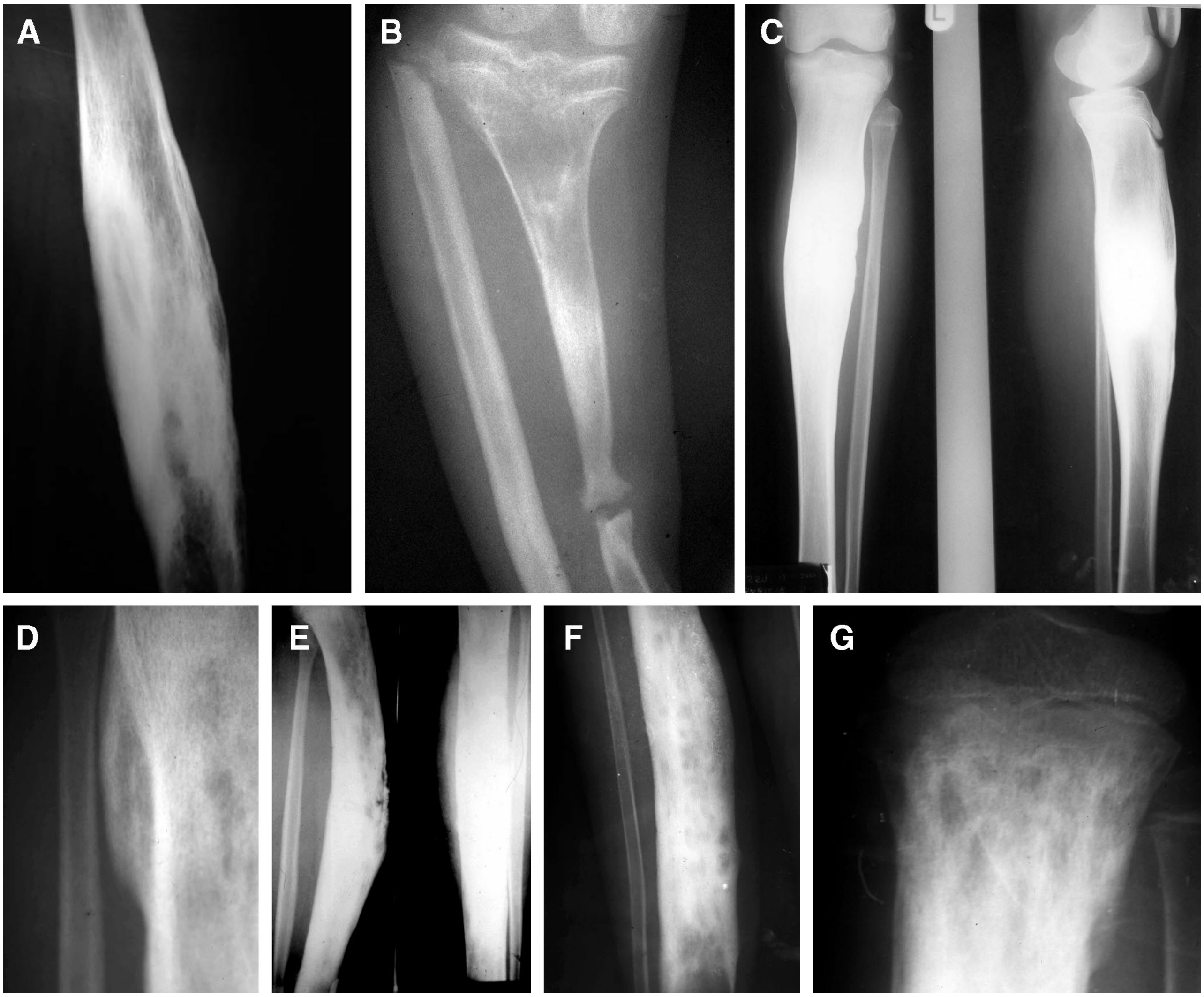

FIG. 10. (**A–G**) The Penny classification[27] of chronic osteomyelitis in children includes both diaphyseal and metaphyseal types. Diaphyseal osteomyelitis may be broken down into the following types: type I (typical, **A**), type II (atrophic, **B**), type III (sclerotic, **C**), type IV (cortical, **D**), type V (multiple walled-off abscesses, **E**), and type VI (multiple microabscesses, **F**). An example of metaphyseal osteomyelitis is shown in **G**.

(synostosis between the distal fibular remnant and the tibia). Nonunion at one of the two transfer sites has also been reported with some frequency. When successful, the fibula will hypertrophy in response to the increased mechanical loads.

Chronic osteomyelitis of the radius or ulna associated with segmental bone loss may be treated by creation of a single bone forearm.[18,33] Prerequisites include a normal wrist and elbow joint.

COMPLICATIONS

A host of complications may be encountered in untreated chronic osteomyelitis or after treatment of the disease. These include pathologic fracture, septic arthritis with joint destruction, physeal damage, nonunion or segmental bone loss, and leg length discrepancy (shortening or overgrowth).

Pathologic fracture results from a loss of structural integrity. The greatest risk occurs during the early stages of infection, before the involucrum has formed, and after sequestrectomy in the presence of an inadequate involucrum. A fracture may be further complicated by a nonunion. Coexisting *septic arthritis* may result in joint destruction, with or without subluxation or dislocation. The infection may directly damage the physis, resulting in partial or complete physeal arrest, leading to a progressive angular deformity, leg length discrepancy, or both. *Bony overgrowth* from physeal stimulation associated with hyperemia may result in leg length discrepancy. If the periosteal response is inadequate, then a *nonunion with or without segmental bone loss* may be observed. Finally, a long-term risk of chronic osteomyelitis is *malignant transformation* ($< 1\%$ of cases) within a sinus that has been present for 20 to 30 years. The most common diagnosis is squamous cell carcinoma. These lesions are typically aggressive, and amputation is often required.

ANATOMIC CLASSIFICATION OF CHRONIC OSTEOMYELITIS IN CHILDREN WITH TREATMENT RECOMMENDATIONS

In a large number of cases seen over 6 years in Kampala, Uganda, an anatomic classification for chronic osteomyelitis in children was developed (J. Norgrove Penny, MD), including diaphyseal osteomyelitis (six subtypes) and metaphyseal osteomyelitis (Fig. 10).[27] For diaphyseal osteomyelitis, type I represents "t*ypical*" osteomyelitis, in which there is a well-defined sequestrum and an involucrum. Treatment involves sequestrectomy/debridement followed by protection of the limb until the bone has been reconstituted. Type II, or *"atrophic,"* involves failure of the involucrum to form, most likely as a result of periosteal cell death. We recommend waiting at least 3 to 6 months to see if the periosteum will respond. If there is no response, then plans can be made for reconstruction, whether by grafting or bone transport. In type III ("*sclerotic*"), there is a fusiform, dense, sclerotic healing reaction generated by the periosteum. This may obliterate the medullary cavity, and small sequestra may remain hidden within this dense shell of bone. Debridement through a cortical window is recommended, and it may be challenging to remove a segment of this dense bone. In type IV, or *"cortical,"* there is a localized sequestrum within the cortex of the involved bone. Sequestrectomy through a localized cortical window is recommended. Type V (*"multiple walled-off abscesses"*) involves one or more well-defined lucencies within the involucrum. These likely represent small collections of debris after reabsorption of sequestra. These can be explored and debrided through a cortical window. Type VI (*"multiple microabscesses"*) is similar to type V based on both appearance and proposed etiology, but involves smaller and more numerous lucencies within the involucrum. It may be difficult to plan saucerization. Options include a longitudinal partial diaphysectomy with debridement, or consideration can be given to long-term antibiotic treatment. Metaphyseal osteomyelitis typically appears as a single, or multiple, walled-off abscesses with or without a sclerotic margin. Sequestra are uncommon, and a limited saucerization and curettage should be sufficient.

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