Standard Review Article

Tibial bone loss

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Abstract Critical bone loss after open fractures, while relatively uncommon, occurs most frequently in high-energy injuries. Fractures of the tibia account for the majority of open fractures with significant bone loss. A number of different surgical strategies exist for treatment of tibial bone loss, all with different advantages and disadvantages. Care should be taken by the surgeon to review appropriate indications and all relevant evidence before selecting a strategy.

Keywords: bone loss, masquelet, defect, tibia, reconstruction

1. Introduction

Bone loss after fracture, while relatively uncommon overall, occurs more frequently in high-energy injuries. While Keating et al reported that fractures with bone loss accounted for only 0.4% of fractures admitted to the hospital, among patients with open fractures, the number with significant bone loss increases to 11.4%.[1] Fractures of the tibia account for the majority of open fractures with significant bone loss, around 68%, both due to the frequency with which the tibia is fractured relative to other long bones and its subcutaneous nature with limited overlying soft tissue coverage.[1]

There is a point where the tibial defect is deemed a "critical segmental defect," at which the bone loss is significant enough that it will not fill or reossify with just fracture stabilization alone and would require additional interventions. While the exact critical defect threshold may vary from patient-to-patient based on a multitude of individual-specific factors, the generally agreed-upon size criteria for a critical defect include circumferential bone loss of greater than 50% or a segmental defect of greater than 2 cm.[2] A number of different surgical management strategies can be used as adjuncts to standard skeletal fixation when there is a critical defect in the tibia. These strategies offer different advantages and disadvantages, and care should be taken by the surgeon to review appropriate indications and all relevant evidence before selecting a strategy. Most require one or more staged procedures for success.

2. Management

2.1. Initial Management

Tibial shaft fractures with associated bone loss are usually high-energy, open injuries and thus are often associated with other trauma. Initial management should be focused on the treatment of life-threatening injuries, followed by the stabilization of the fracture and prevention of infection. Initial orthopaedic intervention should be focused on timely antibiotic administration, adequate debridement of contaminated and devitalized tissue, and fracture stabilization focused on optimal restoration of length, alignment, and rotation.[3] This can be achieved through intramedullary nailing, plate osteosynthesis, external fixation, or hybrid fixation. Soft tissue injury requiring intervention and vascular injury should be addressed before any delayed bony reconstructive procedure.

Intramedullary nailing is the preferred stabilization method for diaphyseal tibia fractures. It allows for adequate restoration of length, alignment, and rotation, although careful preoperative planning may be required to restore these parameters in the setting of massive bone loss. Intramedullary nail fixation allows for long-lasting relative stability of the fracture, around which a delayed reconstructive procedure for bone loss can be planned. Its indications may be limited in extremely proximal or distal metaphyseal fractures that are not amenable to interlocking constructs; however, metaphyseal fractures or fracture patterns with simple articular extension alone are not a contraindication to nailing.[4] Plating can also be used; however, this requires more extensile exposure.[2] External fixation may be used either for temporizing or, in some cases, definitive fixation. External fixation allows for flexibility in spanning fractures with bone loss, while other concomitant vascular or soft tissue injuries are first addressed.

2.2. Preoperative Considerations

Before committing to a reconstructive strategy for tibial bone loss, patient characteristics must be taken into account carefully and

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corrected when possible. Patient factors including smoking status, glycemic control, nutritional status, and alcohol use are all modifiable risk factors that may contribute to infection and nonunion and, in the setting of bony reconstruction, a failed intervention.[2] Shared decision-making with the patient is also crucial. They should be made aware that most options to reconstruct bony defects in the tibia require extensive procedures, often multiple, which may have significant complications, may prolong discomfort and require a longer rehabilitation period. Careful consideration should be made in patients at significant risk of infection and nonunion as to whether salvage should be attempted or amputation offered, although newer therapeutic surgical advances make limb salvage a better option for more patients than in the past.[5]

3. Techniques

3.1. Autologous Bone Grafting

Autologous bone grafting can be used to effectively manage smaller segmental tibial defects (<5 cm) either acutely or when added to a critical defect in a staged procedure. The most common site of harvest is the iliac crest and less commonly the distal femur or metaphysis of the tibia. Bone autograft is ideal in that it is osteoinductive, osteoconductive, and osteogenic. The size of the defect that can be addressed with autologous bone grafting alone is limited by the amount that can be safely harvested without subjecting the donor site to instability or fracture, historically accepted as a defect <5 cm. Harvesting autologous iliac crest bone graft through a modified anterior approach has been shown to have a low incidence of donor site pain (25%) and infection (0%) and is equally effective in young adult and older patients.[6,7]

More recently, the indications for reamer irrigator aspirator (RIA) (Depuy Synthes, West Chester, PA) have expanded to include larger segmental defects in addition to its current role in the treatment of standard nonunions.[8] Although there is a lack of larger scale studies discussing the efficacy of RIA in large bone defects, some studies have pointed to good outcomes with up to 90% union in segmental bone defects larger than 5 cm.[9] RIA bone graft can be harvested from the femur where graft volume has been reported to be on average 45cc with a maximum of 70cc, making it attractive for large segment defects. RIA, however, carries its own unique complication profile including acute or delayed fracture due to thinning of the cortex, risk of embolism, and increased blood loss, although the rate of complications has been shown to be lower than iliac crest bone harvest with low donor site morbidity.[10,11] Hence, while the use of autologous bone grafting remains the gold standard for smaller segmental defects of the tibia, the emergence of RIA offers promise for higher yields of bone graft that may make this a more popular option for even larger segmental defects.

3.2. Allograft

There are many different bone allograft products that are commercially available and can be used as adjuncts to autograft or by themselves. All allografts are less biologically active than autograft because they do not have all 3 osteoconductive, osteogenic, and osteoinductive properties. However, allograft has the benefit of having no donor site morbidity.

Cancellous bone is osteoconductive only, relying on creeping substitution for incorporation into the host. Cortical strut allograft, often from donor fibula or tibia, offers the structural benefit of mature cortical bone which can be helpful in restoring structure in segmental defects, but is only osteoconductive and limited in its biological capacity to incorporate.

Demineralized bone matrix (DBM) is a preparation of chemically digested bone allograft which forms a malleable paste that maintains its osteoconductive scaffold and osteoinductive growth factors.[12] As an adjunct DBM can play a role, however, it is not effective in isolation in the treatment of segmental defects of long bones such as the tibia.[13]

Nonorganic bone substitutes have also been used in areas of small tibial defects, including calcium phosphate, calcium sulfate, and polymethylmethacrylate. These, however, are used more as void fillers and are not advised as the main component of reconstructing a structural defect.[2] Current research is focused both on developing and finding a therapeutic role for skeletal progenitor cells (SPCs) as well as finding the optimal use, dosage, and timing of bone-promoting growth factors to create biocomposite products that are osteoinductive, osteoconductive, and osteogenic. While the role of SPCs and bone-promoting cytokines in the future remains promising, currently any commercially available products lack substantial evidence of their efficacy or randomized trials for the treatment of tibial segmental defects.

3.3. Distraction Osteogenesis

Distraction osteogenesis makes use of the tension–stress effect to slowly guide the transport of cortical bone and lead to formation of new bone through the use of dynamic fixation constructs.[14] Distraction osteogenesis is most useful in larger tibial defects (>5 cm) and is considered a reliable reconstructive option. Multiple protocols and frame structures have been used, most notably the Ilizarov or Taylor frames, which yield similar results.[15] Major benefits of distraction osteogenesis include its reliability in bone formation, the ability for the patient to weight-bear on the construct, and most notably that there is seemingly no limit to defect size that can be addressed.[2] Outcomes for distraction osteogenesis in tibial defects are generally good. Rohilla et al reported excellent or good bone formation and functional outcomes in over 90% of their patients treated with distraction osteogenesis with a ring fixator.[16] Aktuglu et al[17] reviewed the literature regarding the use of Ilizarov bone transport for tibial defects and also noted good bone quality/bony union in 88.8% of patients and good functional results in 82.6%. Distraction osteogenesis is not without its disadvantages; however, most notably that adequate correction of a segmental defect with distraction osteogenesis can take up to 1 year; there is a high rate of complications associated with external fixator wear for that amount of time including pin infection, stiffness, and refracture through newly formed bone. In addition, the wearing and frequent adjustments of an external fixator for that length of time carry a significant psychological and social burden on patients that should be addressed thoroughly before initiating this method for the treatment of a tibial defect.[2] To bypass much of the issues associated with prolonged external fixation, the use of lengthening nails for distraction osteogenesis has become popular in recent years. Lengthening nails can be used in conjunction with external fixation, plates, or by themselves. In addition, reaming of the nail is thought to deposit bone graft and help stimulate new bone formation in the area of the defect. Several designs including motorized nails and magnetic nails can allow for gradual bone transport.[18]

3.4. Induced Membrane

The induced membrane technique for tibial and other long bone segmental defects was first published by Masquelet, who discovered an inducible membrane during the use of cement spacers to maintain length and alignment in the cases of femoral and tibial bone loss. He described a two-stage procedure whereby in the first stage, a segmental bony defect would be filled with cement on which would form a pseudosynovial membrane. Weeks later, the membrane is carefully opened and maintained and cement would be excised and replaced with bone graft and sealed back within the pocket of the membrane. In his patients Masquelet[19] noted that maintenance of the membrane prevented resorption of the graft and promoted vascularity and corticalization. The induced membrane technique relies on an anti-inflammatory foreign body reaction which causes an organized pseudosynovial membrane to form. This membrane is rich in osteoinductive growth factors and cytokines, and cells within the membrane have similar surface expression markers of mesenchymal stem cells.[20] Second-stage bone grafting with autologous bone graft or allograft is performed 4–6 weeks after the first stage, as presented in Figure 1. This is the ideal window, as studies have demonstrated that osteogenic growth factors including vascular endothelial growth factor, bone morphogenic protein 2, angiopoietin II, and fibroblast growth factor 2 peak within the membrane and the membrane are at its most vascular at approximately 4–6 weeks.[21,22] The results of the induced membrane technique for tibial and other long bone segmental defects are consistently good. Cho et al[23] reported a case series which included 11 tibias with critical defects and achieved 86.7% bony union at an average of 9 months after second stage. Azi et al[24] reported on 19 tibias and 15 femurs and demonstrated 80% bony union of defects at 8.5 months. Furthermore, Qiu et al looked specifically at 40 tibias with traumatic or septic defects and noted upward of 90% union at 7.5 months after second

Figure 1. Radiographs of a patient with traumatic distal tibial and fibular bone loss. Panel (A) shows the initial type IIIb open injury. After extensive debridement, PMMA cement was placed around an intramedullary Steinman pin with external fixation as part of an induced membrane technique (B, C). After 5 weeks, the patient was transitioned to definitive fixation of the tibial shaft fracture with intramedullary nailing along with extension of the construct into a tibio–talo–calcaneal fusion with supplemental fusion with a laterally based plate (D, E). The critical bone defect was successfully bridged by bone formation from the induced membrane.

stage. Konda et al[25] also reported no difference in outcomes between patients with critical diaphyseal bone loss treated with the induced membrane technique and those with fracture nonunions treated in the same manner. Disadvantages of the induced membrane technique include high rates of infection and refracture through grafted area. Overall, however, this remains a reliable method and work horse for deformity surgeons treating posttraumatic large segmental bone loss in the tibia and elsewhere in the axial skeleton.

3.5. Vascularized Bone Grafting

Vascularized bone grafting is another option to bridge tibial diaphyseal defects. Most commonly, a free fibular autograft is used. This technique has become less common with developments in bone transport and induced membrane techniques; however, it remains a viable alternative for large bony defects. Vascularized bone grafting requires a complex harvesting microsurgical procedure, and by maintenance of the flap's blood supply, it can be useful for extremely large defects of bone up to 20 cm.[26] In some cases of large soft tissue or skin defects, this procedure can be combined into the incorporation of an osteocutaneous flap which allows the bone and soft tissue coverage to occur in one step.[27] There are good rates of flap union with fibular vascularized grafting, and the fibular graft, when used in the tibial diaphysis, will hypertrophy in response to load and weight-bearing.[28] Vascular-free flaps are often not the initial treatment of choice for traumatic tibial defects due to their complex nature. There is risk of failure of the vascular anastomosis leading to flap necrosis. Also in the lower extremity, failure of the bone graft to adequately hypertrophy can lead to fracture and necessitate future surgery. Although there are not many direct comparative studies, some have shown similar outcomes when comparing vascularized bone grafting to the induced membrane and distraction osteogenesis techniques.[29,30]

4. Conclusion

Traumatic bone loss after high-energy, open tibial shaft fractures is relatively uncommon; however when a critical defect is present, it requires careful planning and assessment of treatment options. After appropriate stabilization, small defects can be treated with autologous bone graft or one of several biologic or synthetic allograft options. Larger structural defects can be reliably bridged with bone transport through distraction osteogenesis or induced membrane technique with relatively equal outcomes but different sets of advantages and disadvantages. Vascularized autografting remains a viable option, but given its morbidity and advancements in other techniques, it has become less commonly used for traumatic defects. Before any treatment for a critical tibial defect is undertaken, it is important to discuss with the patient their goals and get them to fully understand the nature of these treatment options for bone salvage as opposed to amputation, as all have substantial rates of complications, often require multiple procedures or steps, and have a prolonged rehabilitation period.

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