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CME review article

Limb reconstruction after traumatic bone loss

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ABSTRACT

A variety of options exist to reconstruct limbs following traumatic bone loss. The management of these injuries is challenging and often requires prolonged and potentially painful treatment. The Ilizarov technique of bone transport using circular external fixators is widely used for limb reconstruction of large bone defects. Other techniques include vascularised fibular grafting, the use of induced pseudosynovial membranes combined with cancellous autologous bone grafts and the use of autologous, allogeneic or synthetic bone grafts on their own for smaller defects. Future directions include further research on bone tissue engineering using stem cell therapy and growth factors such as bone morphogenetic proteins. The purpose of this Continuing Medical Education article is to describe the key limb reconstructive techniques that may be employed to treat traumatic bone loss. In particular, this article is intended to serve as a revision tool for those preparing for postgraduate examinations.

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Introduction

The reconstruction of limbs following significant traumatic bone loss is challenging and often technically difficult. The decision as to whether an injured limb is salvageable is based on the extent of muscle, bone and joint damage as well as the potential for neurological and vascular recovery [1]. Historically, primary amputation was frequently used to manage fractures with significant bone loss [2,3]. In modern times, a variety of bone reconstruction treatment strategies to regenerate bone loss and restore function exist. These treatment strategies include autologous bone grafting (for defects less than 5 cm in size) [4], bone transport using Ilizarov frames and monolateral external fixators and the Masquelet

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technique which combines induced membranes and cancellous autologous bone grafts [4,5].

The tibia is the site most frequently associated with traumatic bone loss as a result of its subcutaneous position [3]. Significant traumatic bone loss is often caused by high-energy injuries and is most commonly seen in males [3]. These injuries may be associated with severe soft tissue injuries and polytrauma [3,6].

There is no widely employed specific classification to describe traumatic bone loss [6]. Salai et al. classified bone loss according to whether the injury was open or closed, the size of the bone defect and the type of bone defect (articular or non-articular) [7]. Gustilo and Anderson's classification is commonly employed to describe open fractures. This classification is based on the degree of soft tissue injury and contamination which are indicators of the risk of infection [8]. Robinson et al. classified tibial fractures with bone loss as trivial, minor, moderate and severe according to whether the defect was a wedge or circumferential and the maximal length of bone loss. This classification could potentially be applied to other long bone fractures [6,9].

Initial assessment and management

The initial assessment and management of patients with severe limb injuries should follow Advanced Trauma Life Support principles [10]. Debridement of soft tissue and bone is the first step in the treatment of limbs deemed to be salvageable [6]. A plastic surgeon should be consulted early in cases where there is significant soft tissue loss. The joint British Association of Plastic Reconstructive and Aesthetic Surgeons/British Orthopaedic Association (BAPRAS/BOA) standards for the management of open fractures of the lower limb, recommend that a multidisciplinary team including both orthopaedic and plastic surgeons in a specialist centre is required for the treatment of complex open fractures [10]. Initial skeletal stabilisation may be undertaken with a temporary external fixator [6].

Internal fixation

If bone loss is limited, immediate definitive internal fixation may be an option depending on the condition of the soft tissues. Plate fixation with bridging of bone defects combined with bone grafting may be performed [6]. Minimally invasive plate osteosynthesis (MIPO) is an alternative technique to standard plate fixation which aims to reduce iatrogenic soft tissue damage, avoid disruption of the vascular supply and fracture haematoma, hence reducing infection rates and providing improved biological healing [11–13]. Endo et al. reported successful outcomes in a series of three cases (five limbs) where once sufficient callus formation had been detected, external fixation was converted to the MIPO technique using a locking compression plate to shorten the external fixation wearing period in femoral lengthening [14]. Intramedullary nailing of long bone fractures is an option that can provide good skeletal stability and limb alignment and may allow early joint movement [6]. Acute shortening may be considered and the limb may be subsequently re-lengthened [6,15]. It has been recommended that tibial fractures with more than 3 cm bone loss should be closed gradually to avoid neurovascular compromise [15,16].

External fixation and bone transport

Bone transport is widely used in limb reconstructive surgery. Bone transport using external fixators as described by Gavrill Ilizarov has revolutionised the management of long bone defects [17,18]. This technique allows simultaneous treatment of large bone defects, soft tissue loss, infection and leg-length discrepancy [17,19,20]. The Ilizarov technique uses circular external fixators which consist of rings and connecting rods. Partial rings and arches are useful when working near joints and they allow access to traumatic wounds. Rings of a smaller diameter are more stable than larger rings. 2 cm of space should be left circumferentially between the ring and the skin to allow for possible limb swelling. The stability is also increased by having a smaller distance between rings, using two rings instead of one for each bone segment and increasing the wire diameter. At least four connecting rods between the rings and at least two wires per ring are necessary [20].

The use of a ring external fixator and tensioned wires allows early weight bearing as it provides greater support than a monolateral frame [21]. The top rings allow force to be transferred through the external frame and to bypass the bone defect [21]. Although this technique uses the ring fixator, the use of a monolateral half-pin frame may produce successful bone transport [22].

Ilizarov described the use of a corticotomy, which is a low-energy osteotomy of the cortex, with preservation of the local blood supply to both the periosteum and the medullary canal. Ilizarov believed that this enhanced bone formation. The ends of the corticotomy are gradually brought together while distraction occurs at the defect site. A period of latency ranging from three to 10 days is instituted before distraction is commenced and following corticotomy. This latency period is generally considered to enhance bone formation [22]. The shorter periods are sufficient for the classic Ilizarov corticotomy, however the longer periods may be required if a traditional osteotomy that has disrupted the medullary canal is performed [22]. As an adjunct to Ilizarov's technique, some surgeons may chose to use strategies such as insertion of autologous bone marrow grafting and demineralised bone matrix in order to improve healing of the corticotomy/osteotomy [23].

Ilizarov carried out experiments in a canine tibial model in order to gain a better understanding of osteogenesis during limb lengthening as well as to study the changes in soft tissues undergoing elongation [19,24]. These studies concluded that the rate and frequency of distraction are important to osteogenesis under the influence of the 'Tension–Stress' effect. The 'Tension–Stress' effect refers to the phenomenon that when tissues are subjected to gradual, steady traction stresses are created resulting in the tissues becoming metabolically activated. Provided there is adequate blood supply there is stimulation of proliferative and biosynthetic cellular functions and tissue regeneration [19,24]. The most favourable results were achieved with a distraction rate of 1.0 mm per day in four equal increments (0.25 mm every six hours) combined with stable external fixation [19,24]. Clinical studies confirmed that this technique promoted osteogenesis in humans but it was noted that the rate and frequency of distraction may have to be adjusted depending on factors such as the quality of bone formed and the response of the soft tissues [25]. Figs. 1 and 2 are radiographs of patients treated with the Ilizarov technique.

This technique requires long-term placement of external fixators and may be associated with complications [17]. Neurovascular damage is a potential immediate complication but may be avoided with thorough knowledge of the anatomy [20]. Pin site infection is a common complication that occurs in the majority patients undergoing limb lengthening with external fixation [26]. The risk of serious complications such as soft tissue contracture, joint contracture or subluxation may be minimised with good preoperative planning. Late complications such as chronic recurrent pin-site infections, osteomyelitis, premature union, delayed or non-union, hardware failure, reflex sympathetic dystrophy, late bowing and failure may occur [20]. There should be extensive preoperative education of the patient and their family in order to increase compliance as the treatment is lengthy and may be painful [22].

The Taylor spatial frame (TSF) is a modern multiplanar external fixator that may be used for bone transport and is based on the Ilizarov principle. The rings are connected by six telescopic struts