Management of Traumatic Bone Defects

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24.1 Introduction

Traumatic bone loss has long been a challenging clinical problem. Contemporary techniques in the management of acute bone stabilization, revascularization, and soft tissue reconstruction have lead to an increase in limb salvage. [1] The reconstruction of bone defects has numerous options. Generally the management of bone defects can be divided into two approaches. The first approach involves reconstitution of a bone defect that has been stabilized in situ by autologous bone grafting or one of its variations. The second approach involves distraction osteogenesis. The two approaches are not mutually exclusive but have their relative indications and difficulties. Distraction osteogenesis therapy is generally more protracted, technically very challenging, and accompanied by high complication rates [2]. However, distraction osteogenesis can be spectacularly successful in the simultaneous management of soft tissue coverage, bone defect, and spatial deformity. Because of the complexity of frame construction, pin site management, patient compliance, and duration of treatment, distraction osteogenesis procedures are perhaps best reserved for specialty clinics. Management of bone defects by skeletal stabilization, early soft tissue coverage and by autologous reconstruction utilizes implants, techniques, and resources that are widely available. This paper will present a summary of contemporary techniques that will

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allow for the primary therapy of complex traumatic bone loss.

24.2 Initial Management of Traumatic Bone Defects

Bone defects caused by direct trauma usually are the result of a high energy injury and are therefore associated with mortality and morbidity of visceral or traumatic brain injury. Assessment of the long bone injury will determine whether the limb is viable and should be amputated versus limb salvage. Considerations for limb salvage are obviously complex and efforts to quantitate the injury in regards to amputation such as the Mangled Extremity Severity Scale (MESS) or the Orthopaedic Trauma Association Limb Evaluation and Assessment Protocol (LEAP) are often helpful but not definitive [3, 4]. Limb salvage requires a limb in which vascularity can be reestablished, adequate neurologic function in terms of sensation and motor, viable muscle – tendon groups, and soft tissues – bone injury in which sepsis can be ultimately ablated. The actual extent of bone loss that limits limb salvage has yet to be defined regardless of reconstruction technique. In addition to the biological factors, the patient's psychosocial systems need to be evaluated as reconstruction and limb salvage is a relatively long process possibly requiring multiple surgical interventions, medical therapies, rehabilitation, and patient compliance.

The initial management of a limb deemed suitable for limb salvage will consist of emergent resuscitation of the patient. Priority for reestablishing hemodynamic stability and managing the closed head injury component will frequently preclude definitive skeletal stabilization. The concept of "damage control orthopaedics" has recently emerged in which spanning external fixation or unreamed intramedullary nailing is expediently performed to limit the anesthetic time and reduce pulmonary exposure to medullary canal contents in severely injured patients [5]. When performed under these circumstances, pin sites and implants should be chosen to allow for subsequent definitive fixation and stabilization of the bone defect. Conversion to definitive fixation should be performed as soon as feasible to minimize potential septic seeding from external fixation pin sites – generally less than 10 days. Stabilization of open fractures with intramedullary nails has been validated to be acceptable in terms of infection risk [6]. In general, locked intramedullary stabilization of a diaphyseal and some metaphyseal defects is preferred as length, rotation, and axial alignment can be reestablished and maintained in a single procedure. The IM nail allows for immediate rehabilitation of the limb in near anatomic position. In addition, the IM nail has the biomechanical advantages of strength and symmetric load sharing in comparison to plates. The locked plate is a relatively recent development which allows for improved mechanical stability in situations of poor bone quality, bone defect or comminution, and articular fracture patterns associated with metaphyseal or diaphyseal extension. Plate fixation can be performed with minimal exposure to provide stable bridging constructs for the management of bone defects. If a limb requires vascular repair, plate or IM nail fixation needs to be coordinated with the vascular reconstruction to provide a stable environment for the repair as well as utilize the surgical exposure if indicated. An essential early step in the management of a bone defect is the initial debridements of bone and soft tissue. The initial debridements are likely to reduce the septic burden and re-establish soft tissue viability in the shortest time. The principles of debridement are well established and consist of excision and removal of nonviable osseous and soft tissues. Serial debridements are frequently required to discern borderline tissues on a clinical basis. The decision of implant and technique is therefore dictated by patient hemodynamic and neurologic status, concomitant vascular repair, tissue and bone debridement, and soft tissue coverage Initial management of the bone defect is

directed at managing the dead space of the defect in preparation for soft tissue coverage and bone reconstitution. During debridements, the defect can be provisionally managed with commercially available PMMA-antibiotic beads or surgeon fabricated PMMA-antibiotic spacers. The PMMA-antibiotic beads or PMMA-spacers can be serially exchanged during debridements to aide in reducing deep sepsis and has been well described [7].

In summary, the initial phase consists of patient resuscitation with provisional or possibly definitive fixation of the skeletal defect. This is combined with establishment of a sterile bone defect and clean wound by surgical debridement and soft tissue wound care. The time line would be days 1–3.

24.3 Skeletal Fixation and Soft Tissue Coverage

If the limb has been treated with spanning external fixation, conversion to IM nail or plate implant can be performed – ideally within 7 days. Soft tissue coverage should be obtained either by wound closure, wound V.A.C therapy, or local/free flap coverage. Early soft tissue reconstitution aids in the prevention of deep sepsis as well as preparing an environment advantageous for bone grafting. The bone defect can be managed either primarily with early bone grafting or vascularized bone transfer. However, the cultivation of an "induced membrane" has clinical and basic science advantages for delaying definitive autologous bone transfer into segmental defects for a period of 4–6 weeks [8, 9].

Conversion from spanning external fixation or provisional stabilization to definitive implant fixation should restore the limb to near anatomic length, axial alignment, and rotation. The definitive implant should have sufficient mechanical properties to function during the duration of bone reconstitution. With early restoration and maintenance of the limb in anatomic position, patient comfort, rehabilitation, and function is greatly enhanced – a distinct advantage over distraction osteogenesis.

The keystone step during the Interim Management Phase is perhaps the reestablishment of an environment amenable to successful bone grafting. Animal studies and clinical studies indicate that a biologically active membrane that facilitates bone regeneration can be induced by the temporary implantation of a PMMA cement spacer. Histological, immunohistochemical, and biochemical assay in animal models demonstrate that by 4–6 weeks, a fibrous, highly vascularized, growth factor rich encapsulating membrane has encapsulated about the PMMA spacer. At 4–6 weeks postimplantation, vascular endothelial growth factor (VEGF), transforming growth factor (TGF-beta), and bone morphogenetic protein-2 (BMP-2) are at peaking levels within the membrane [10]. Autologous bone techniques may therefore optimally performed at 4–6 weeks post-PMMA spacer implantation. The technique is easily performed. PMMA cement is prepared and a tubular or appropriately shaped spacer is fabricated to span the defect and overlap the native bone ends. Antibiotic cement can be utilized as an adjunct to around the bone defect to prevent deep sepsis. Commercial antibiotic-PMMA mixtures that are available for primary total joint arthroplasty can be utilized (Biomet, Warsaw IN, Zimmer, Warsaw, IN, and Stryker, Mahwah, NJ). The surgeon, however, can prepare PMMA with higher amounts of added heat stable antibiotic to produce a bactericidal spacer [11].

In summary, the interim phase consists of obtaining: (1) early definitive internal fixation to stabilize the bone defect and limb in near anatomic alignment, and (2) preparation of a sterile osteogenic defect for osseous regeneration. A stable soft tissue environment is reestablished by wound closure or flap coverage if needed. In many cases, an induced membrane is formed by the temporary implantation of bulk PMMA with planned autologous grafting at approximately 4 weeks.

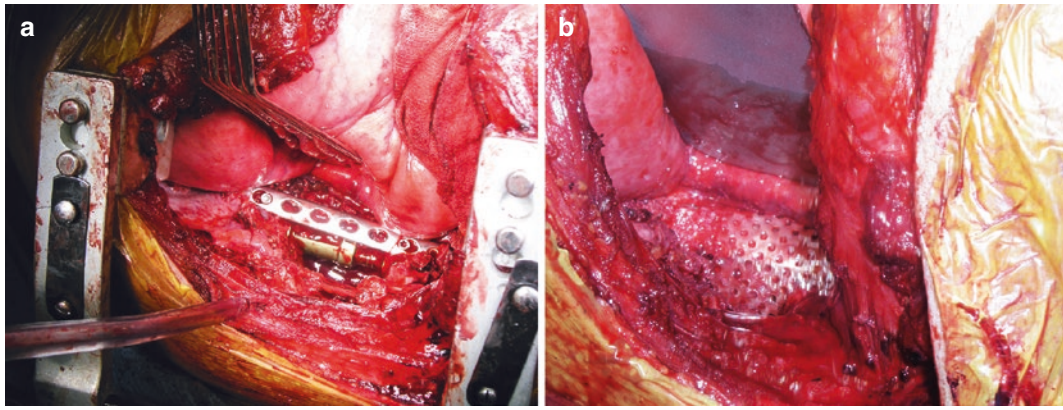

Fig. 24.1 (**a**) Thoracic spine burst fracture of T6 with corpectomy and stabilization of body with titanium mesh gauge and small fragment plate. Spinal cord is exposed. (**b**) PLA membrane is fabricated to form posterior wall following corpectomy of T6. Mixture of autologous bone from vertebral body fracture and DBM putty is grafted in cage as well as anterior to the membrane which protects cord from bone graft spillage into spinal canal

24.4 Bone Defect Reconstitution

Autologous bone grafting remains the gold standard in the reconstitution of bone defects. Autograft is the only material that provides osteogenic cells (osteocytes, osteoblasts, marrow stem cells), osteoconductive matrix (inorganic mineral), and osteoinductive molecules (BMPs, transforming growth factor-beta, vascular endothelial growth factor, and others) [12]. There are many techniques described for bone graft harvest including iliac graft harvest, local cancellous bone harvest, bone marrow aspirations and concentration, vascularized fibula, and most recently intramedullary canal harvest (Reamer Irrigator Aspirator-Synthes, Inc., West Chester, PA) [13–17]. In addition to autologous bone harvest, there are commercially available sources for recombinant osteoinductive bone morphogenetic proteins (BMP-7/OP01 and BMP-2). Alternatively, a spacer can be used in special indications, e.g., spine fractures (Fig. 24.1).

The primary limiting factor in autologous bone transplant has been reported morbidity and complications associated with the harvest site as well as adequate volume for large defects. With defects of 2 cm or less, traditional anterior iliac crest bone graft is usually sufficient as 5–72 ml can be harvested [13]. Larger defects can still be grafted with iliac crest by multiple harvest sites such as the contra lateral site or use of the posterior iliac crests with amounts of 25–90 ml be obtained [13]. In addition, the use of a small acetabular reamer may result in less donor site pain and larger volume of graft [14].

The most recent development in autologous harvest techniques is the intramedullary canal harvest. A recent review confirms that the use of the Reamer Irrigator Aspirator (RIA) in a single pass reaming of the femur produces significant amounts of bone graft (25–90 ml) with low rates of complications and postoperative pain [13]. While the rate of complication is lower than that described in conventional iliac harvest, iatrogenic femur fracture has occurred. In addition, studies of RIA harvest material suggest that it is rich in growth factors, viable cells, and morselized trabecular bone [15]. The RIA harvest can thus be considered biologically equivalent to iliac graft. The bone marrow harvest, however, lacks any structural properties that can be achieved with tricortical iliac harvest.

In addition to autologous bone graft, bone graft substitutes can be utilized to augment the

autograft harvest. Bone graft substitutes include osteoconductive materials such as synthetic tricalcium phosphates, calcium sulfates, and coral. These materials are fabricated as granules, blocks, strips, putties, and pastes. However, the efficacy of these materials as stand-alone graft in segmental defects is unknown [18]. Similarly, there are currently at least 40 commercial preparations of Demineralized Bone Matrix (DBM). DBM is an acid extract of human cadaveric bone consisting largely of type I collagen and other acid stable proteins including bone morphogenetic proteins. The osteoinductive content of the DBM is low and subject to the variables of donor biological activity, processing, and carrier [16]. The osteoconductive properties of the various commercial DBMs relate to carrier chemistry, adjunctive inorganic additives such as cadaveric cancellous bone or synthetic mineral. At present there are no prospective studies proving the benefits of DBM for the reconstruction of segmental bone defect. The primary use of DBM may be as an extender for autologous bone harvests such as intramedullary reaming harvest, cancellous bone, or marrow aspirates and concentrates [16]. The role of recombinant bone morphogenetic proteins in bone defect reconstruction continues to evolve [19]. The high cost, carrier characteristics, biological activity and mechanical qualities of available commercial BMP preparations limit its use at present mainly to small cortical defects and acute open tibia fractures.

There are numerous options for the application of the autologous bone graft. Defects up to 29 cm have been successfully grafted using the induced membrane technique as described recently by Masquelet [9]. At 4–6 weeks post-PMMA block implantation, the block is removed by longitudinally incising the encapsulating membrane. Autologous bone in the form of iliac graft or RIA bone marrow harvest, or autologous bone-bone substitute or autologous bone-allograft mixture is then used to fill the resulting cavity. A defect stabilized with an intramedullary nail will require less bone graft volume than defects stabilized with external fixation or plate constructs. A resorbable polylactide membrane can also be used to shape and contain the graft for applications such as the distal tibia and femur. In addition, resorbable membranes can be used to contain the graft in applications near the spinal cord, interosseous membrane of the forearm, or other applications where the reconstruction needs to be precisely configured [20]. The polymeric membrane may be used where bone grafting is done primarily such as the reconstruction of an unstable thoracic burst fracture where cancellous bone graft is combined with a titanium vertebral reconstructions cage and a posterior vertebral body wall is fabricated by molding a polymer membrane (Fig. 24.1). Another technique for applying autograft is the use of cylindrical titanium cages to form a weight bearing diaphysis. In this technique, titanium mesh cages that are typically used in spinal vertebral reconstructions are fashioned to bridge the defect which has been stabilized with an intramedullary nail. The cage is packed with cancellous bone and the cage–host bone margins are autografted to create a construct which has considerable immediate mechanical stability [21].

In summary, Phase III consists of bone reconstitution of the defect with an autologous bone graft. The autologous bone graft can consist of harvested iliac crest, intramedullary reaming harvests, or combinations of autogenous materials with synthetic bone substitutes or allograft materials. The stabilized defect can be prepared with the formation of an induced membrane, or bridged with a resorbable polylactide membrane or titanium mesh cage. Alternatively, Ilizarov distraction osteogenesis can be used, as shown in the case example (Fig. 24.2).

Because of adequate mechanical stability from the internal fixation construct, functional rehabilitation can be instituted very early in the clinical course of limb salvage and bone defect reconstruction. The three phase algorithm incorporates surgical techniques and implants that are widely available.

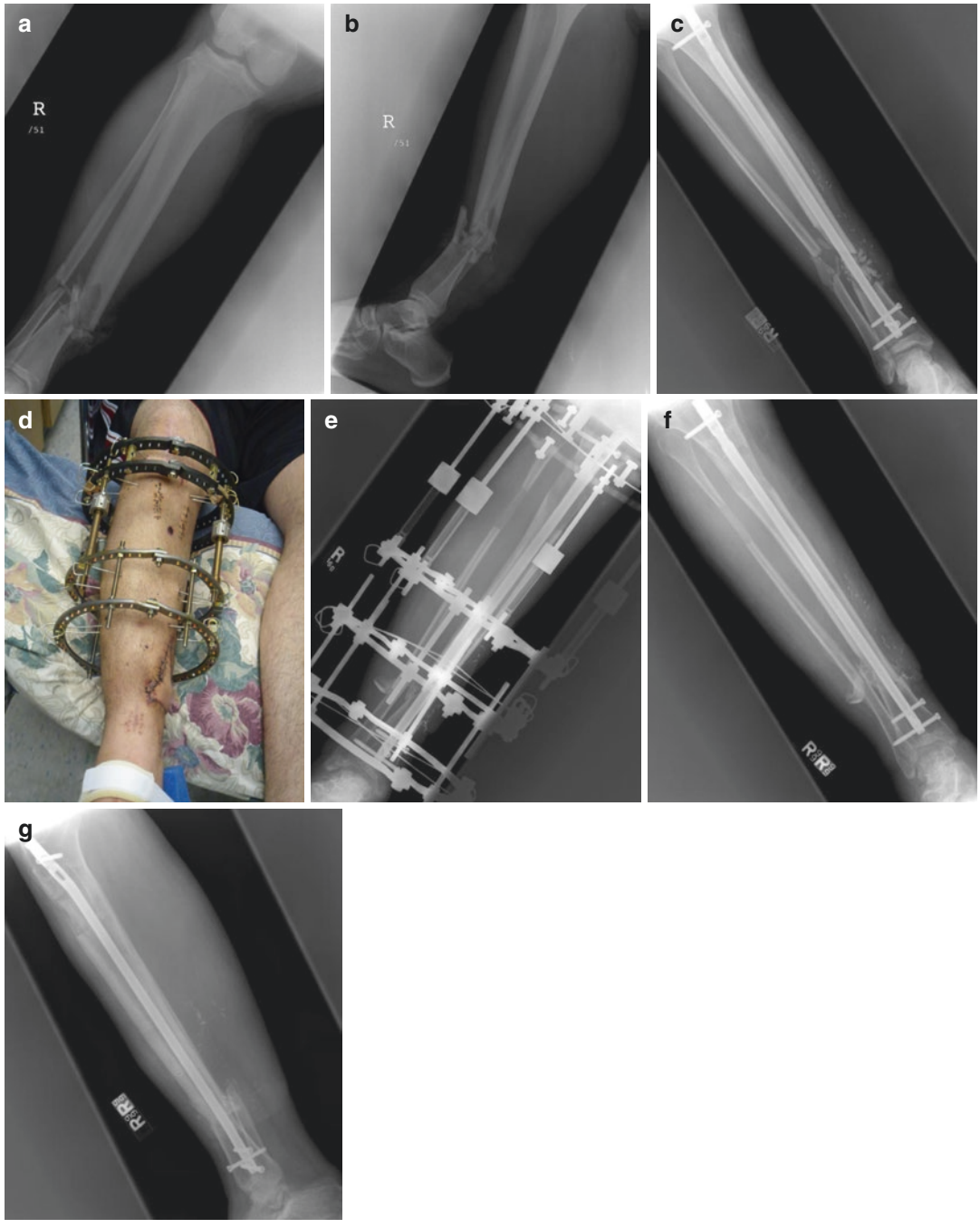

Fig. 24.2 (**a**, **b**) Injury film of open grade IIIb tibia and fibula fracture. (**c**) AP radiograph post op following debridement of diaphyseal bone segment, IM nailing, and wound closure by local flap. (**d**) Soft tissue status after placement of the Ilizarov distraction device. (**e**) Radiographic evidence of regeneration following Ilizarov transport. (**f**, **g**) Radiograph at 4 months after bone transport

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