Moderators' Summary: Management of Segmental Bone Defects

COL Roman A. Hayda, MD
Michael J. Bosse, MD

Dr. Hayda is Director, Residency Program, Director, Orthopaedic Surgery, and Chief, Orthopaedic Trauma, Brooke Army Medical Center, San Antonio, TX, and Assistant Professor of Surgery, Uniformed Services University of the Health Sciences, Bethesda, MD.
Dr. Bosse is Director, Clinical Research, and Orthopaedic Traumatologist, Department of Orthopaedic Surgery, Carolinas Medical Center, Charlotte, NC.

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Modern battlefield injuries are challenging to treat because of their destructive nature with the potential for massive tissue loss. The extent to which the available techniques and technologies have solved the problems seen with these injuries is unknown. Indeed, the simultaneous development of prostheses that allow enhanced function has not resolved the dilemma of reconstruction versus amputation in these complex injuries.

War injuries most commonly involve the extremities and frequently are open because of the mechanism of injury of explosive devices. In comparison with civilian blunt trauma, war injuries are caused by bullets or fragments from blasts and have a propensity for creating open fractures and tissue loss. Current reviews of battlefield conflicts consistently demonstrate that about 70% of all battlefield trauma involves the upper and lower extremities. Although some are simple, many injuries involve multiple tissues: bone, muscle, tendon, nerve, vessels, and skin. There may be a variable loss of bone and other tissues from the initial injury and the required débridement. By virtue of body armor and protective helmets, blast survivors are seen with severe yet viable mutilating injuries of the extremities. Our responsibility to the injured soldier, sailor, marine, and airman is to seek the optimal means of restoring function in a consistent and timely manner with a minimum of complications. The authors represented in this section seek to define the current status of techniques and technologies available to treat injuries with segmental bone defects.

Presently, many strategies exist in the management of segmental defects of bone. These have evolved from the treatment of not only blunt and penetrating trauma but also chronic osteomyelitis, tumors (both benign and malignant), and failed joint arthroplasty. However, there is no consensus on the optimal management of segmental defects during the posttraumatic reconstructive phase in its various forms and locations.

Common to the methods described in this section and stressed by the discussants is the need to establish a clean, healthy, viable bed to allow for successful management of the defect. Severely compromised soft tissues will not allow for healing, nor will inadequate bone stabilization. Once those prerequisites are met, however, these methods may succeed.

The simplest form of treatment may involve simply shortening the bone and allowing for remodeling to address minor amounts of bone loss. One cm in the lower extremity or even 2 to 3 cm in the humerus can be very well tolerated and should be considered for minor amounts of bone loss. However, no precise definitions exist to help ensure an orderly process to union and functional restoration, such as the ability to select fractures that require bone grafting or other adjuncts, in addition to fracture stabilization.

Enhancement of bone healing by external stimulation is an attractive option to hasten union and thus allow for return of function. Aside from electromagnetic and ultrasonic stimulators, which were not specifically discussed at the symposium, Puzas offers an interesting pharmacologic option that may assist in the management of these complex injuries. Early work has demonstrated that parathyroid hormone simulators may be potentiators of the normal bone-healing cascade. However, this preliminary work has not been evaluated in any patient population, particularly the complex trauma patient.

Bioengineered tissues and materials are gaining increased attention as methods of dealing with complex tissue loss. In a methodological approach, Goldstein describes how tissue engineering may involve several solutions, either alone or in combination. Among the most critical is the matrix, which may support the ingrowth of tissues or alternatively provide a scaffold for delivery of cellular elements or bioactive proteins. The matrix may be biodegradable or permanent, depending on the specific needs of the design. Boyan points out, however, that microarchitectural aspects of the matrix may have a powerful effect. For example, bone growth may be promoted by mimicking osteoclastic resorption pits. Furthermore, specific surface chemistry also may promote specific tissue growth. Increased investigation of such issues may be critical in enhancing the success of bioengineering approaches.

These matrices may deliver cellular elements that are either immediately implanted or simply expanded externally, or alternatively are manipulated and expanded as required. Examples of such methods are the delivery of marrow cells on a coralline matrix and cartilage cells for the management of cartilage defects. The delivery of bone morphogenetic proteins on a collagen sponge is an example of the delivery of bioregulatory factors on a matrix. These methods are undergoing a rapid evolution. Many questions remain, not only in regard to the optimal supportive matrix but also the optimal temporal release of biofactors and dosing, in addition to optimal indications in relation to more traditional techniques. Gene therapy techniques offer a tantalizing option to the local or systemic upregulation of the body's own healing mechanisms, involving the whole sequence of factors. At present, only preliminary animal work has been done in this area.

Calcium sulfates and calcium phosphates are examples of just such engineered osteoconductive scaffolds used to manage bone loss, as discussed by McKee. Calcium sulfate is a void filler that rapidly resorbs by hydrolysis. It has been described as a matrix for the local delivery of antibiotics. Because of the production of sterile exudates, the best use of calcium sulfate appears to be in contained metaphyseal defects. Therefore, its use in large diaphyseal defects is limited. Calcium phosphate, by contrast, is degraded by osteoclastic resorption. Its ability to withstand compression has made it an adjunct in the management of periarticular injury. Its use in large posttraumatic segmental bone defects has not been described but is limited by its lack of osteoinductivity. These products may also serve as carriers for antibiotics and bone morphogenetic proteins. Demineralized bone matrix has osteoinductive properties. However, it has not been described as successful in managing segmental defects as a sole agent. At present, its role is best described as that of a graft extender.

A technique for bone distraction, commonly termed the Ilizarov technique, has gained a great deal of popularity since its introduction in the West about 20 years ago. For some, it has become the method of choice in dealing with segmental bone defects. However, the length of treatment and propensity for complications have limited its universal endorsement. The concepts have evolved, as pointed out by Watson, decreasing the incidence of complications and hastening treatment. Small defects can be managed by unifocal or bifocal techniques; for larger defects, trifocal methods of reapproximation of the defect with the simultaneous distraction of two osteotomy sites may lessen total time in the frame. Bone grafting the docking site and using osteoinductive agents and bone stimulators all may serve to decrease total frame time. Hexapod struts allow for the management of complex deformities in both the acute and chronic settings. Coated pins and multiplanar half-pin arrangements also help to simplify constructs. Additionally, external autodistractors and intramedullary devices may simplify the technique. Another alternative is external distraction, followed by the rapid conversion to a standard intramedullary device once the distraction is complete. However, the limited number of reports of these methods makes their universal endorsement difficult.

The use of vascularized fibula is another method available for the management of large segmental defects. This demanding microvascular technique may offer a solution for complex defects. As noted by Levin, this method allows for composite tissue implantation, ranging from bone alone to the inclusion of skin and muscle, depending on need. Provided that microvascular anastomosis can be done, the bone is preferentially stabilized with a ringed fixator and allowed to unite, with the grafted fibula permitted gradually to hypertrophy, as required. Aside from the requirement for microvascular surgical support, its precise indications over other methods have not been defined.

The options available to manage segmental defects of bone have expanded greatly. Nearly all of the techniques described have been successfully used in the management of war casualties. These techniques also will prove to be useful in treating civilian trauma patients. However, despite the advances made, it must be remembered that these are complex injuries that require lengthy and demanding treatment. Complications do occur, even with the most meticulous care, compromising the ultimate result. Delayed union and nonunion, infection, contracture, pain, and functional limitations are ever present, even with utilization of state-of-the-art techniques Additionally, associated segmental articular loss does not have a solution, short of fusion or joint arthroplasty. Similarly, as mentioned, tissue losses involve not only bone and joints but also tendons, nerves, vessels, and muscles. These composite tissue losses further complicate functional return. Optimal strategies for such scenarios must be developed.