Moderators' Summary: Amputee Care

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In this session, the Armed Forces Amputee Patient Care Program (AFAPCP) is reviewed; the nature of the injuries sustained by the combat amputee is delineated; heterotopic ossification is identified as a difficult sequela in the military amputee; current research efforts that are bringing the skeletally attached, neurally integrated robotic prosthesis closer to reality are outlined; and the outcome of civilian traumatic amputation is explained, with comparisons made to the military patient population.

Gajewski and Granville review the AFAPCP from the time of wounding through advanced rehabilitation. The rationale behind the creation of amputee patient care centers in order to concentrate amputee care and expertise and enable patients and their families to provide mutual support to one another is discussed. The improved survival of the wounded, with resulting increased severity of extremity wounds, is hypothesized as being secondary to several factors, including better ballistic body armor, the increased use of tourniquets and hemostatic dressings, improved medic and corpsman training, far-forward "damage control" surgery, and the capability to evacuate unstable patients to tertiary care facilities in the continental United States (CONUS).

The current unified approach to catastrophic extremity injury is outlined. Resuscitation is begun at the point of injury, with tourniquets applied to prevent exsanguinating hemorrhage. Advanced Trauma Life Support principles are used to identify and treat life-threatening associated injuries. Broad-spectrum antibiotics are administered. Débridement of all contaminated and devitalized tissues is performed through longitudinal, extensile incisions, recognizing that contamination is driven far up fascial planes in blast injuries. Fasciotomies are performed liberally because the patient will have long periods during evacuation when no intervention is possible. All viable soft tissues are retained to maximize the reconstructive options at the definitive treatment facility. Guillotine circular amputations are discouraged because the prolonged skin traction required to achieve closure of these amputations slows rehabilitation and isolates the patient.

The short evacuation times of the current conflict eliminate skin retraction as a clinically significant entity. Fractures are stabilized by splinting or external fixation. The soft-tissue injury, not the bony injury, dictates the level of amputation. All wounds are left open. Negative-pressure dressings are used frequently but current field methods are not air worthy, so they are removed before air evacuation. Initial surgery is limited, with care being taken to avoid hypothermia, acidosis, and coagulopathy. Resuscitation is continued postoperatively, and repeat surgeries are planned with consideration of the physiologic state of the patient. Usually débridements are performed every 48 to 72 hours through the evacuation chain and are continued at the tertiary care facility until a clean wound with viable tissues allows closure.

On arrival in CONUS, each patient is evaluated by a multidisciplinary team. Dressings are changed under adequate anesthesia. Patients with wounds with significant drainage or other wound conditions of

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concern are taken immediately to the operating room; the remainder are scheduled for surgery the following day. Once adequate débridement is achieved, myodesis is performed. Myodesis, as well as skin closure, frequently requires surgical creativity because nonstandard flaps are necessary for length-preserving amputation. Wound closure is achieved by the simplest means compatible with the maximum preservation of length. At times, this may involve rotational flaps or free tissue transfer.

The authors have found that modern prosthetic advances such as anatomic socket design and silicone gel liners allow successful fitting over split-thickness skin graft and insensate flaps. Fracture fixation is performed as soon as the soft-tissue envelope allows. Intramedullary and submuscular methods of fixation are preferred, when possible, to maximize the vascular supply to the bone. Rehabilitation is begun even before the patient's wounds are closed, beginning with core strengthening, preservation of joint motion, transfers, and wheelchair mobilization. Once the wounds are closed, residual limb shaping is initiated with knit shrinkers, followed by silicone gel liners. Protection of the residual limb with rigid dressings or with custom or off-the-shelf polypropylene clam shells is advisable.

Core strengthening, aerobic training, and joint range of motion exercises continue during the preprosthetic rehabilitation. Weight bearing through the residual limb is begun through the rigid dressing or initial test socket using the tilt table. Physical and occupational therapy are provided for all patients for a minimum of two 1-hour sessions per day, with an additional 2 hours spent in the gym without one-on-one therapist supervision. Concurrently throughout hospitalization, patients receive multidisciplinary treatment for associated problems. Important roles in the care of the patient are played by the chaplain and by departments and organizations such as Social Work, Behavioral Health, Anesthesia Pain Service, Amputee Coalition of America Peer Visitors, and Veterans Affairs Benefits advisors, in addition to Orthopaedic and General Surgery, Physical Medicine and Rehabilitation, Physical and Occupational Therapy, Case Management, and Prosthetics.

Gajewski and Granville note that, although patients are provided the most advanced prosthetic components available, it is the intensity of rehabilitation and the discipline and dedication of the military amputee patient population that results in the high level of function achieved by so many of their patients. Prosthetic training begins as soon as adequate core strength is achieved and the residual limb can tolerate prosthetic fitting and, in the case of lower extremity amputees, weight bearing. The availability of computer-aided design and manufacturing (CAD/CAM) equipment allows frequent socket changes to compensate for the rapid volume changes present early in treatment. Often, a patient may go through more than a dozen test socket revisions. From the start of ambulation with the prosthetic, care is taken to engender proper gait patterns for lower extremity patients and to emphasize prosthetic strategies for upper extremity patients. Patients progress from the parallel bars, to a walker or crutches, to a cane, to aid-free ambulation, to ambulation on stairs, ramps, and uneven ground. The last phase of rehabilitation targets the patient's return to an active lifestyle and possible return to duty. It includes advanced skills (sport-specific drills and activities) and vocational evaluation and training. The running program integrates aquatic drills with track work and device-specific training. A weekly community reintegration program exposes the patients to a variety of sporting and non-sporting activities outside the hospital environment. Driving evaluations are done for all patients. Those desiring to continue on active duty work are evaluated on common soldiering tasks, such as weapons proficiency. Nongovernmental organizations, such as Disabled Sports USA and the Wounded Warrior Project, provide many opportunities for week-long trips for intensive sport-specific training; they also offer housing and vocational opportunities for those who choose to leave the military.

Potter and Scoville review the incidence of major limb amputation in US conflicts since the Civil War. They propose that the 2.3% rate of amputation in the current conflict reflects the improved survivability of severe blast injury resulting from improved body armor, far-forward surgery, and rapid evacuation of the unstable patient to tertiary care facilities in CONUS. Amputee patients in the current conflict are treated at two centers, both to concentrate the expertise necessary for optimal care and to garner the benefits of mutual support from their brothers- and sisters-at-arms with similar injuries. The authors note that amputation is not an isolated injury in these patients: 16% undergo multiple amputations; 39% have associated long-bone fractures; 45% have active infections; 41% have significant other soft-tissue injury; and 12% have peripheral nerve injury. These associated injuries have a marked impact on the course and final outcome of the rehabilitative process. The authors also note the social factors affecting recovery and discuss the multidisciplinary support necessary to bring both the patient and his or her family through this challenging period. To this end, the AFAPCP uses a sports medicine model for rehabilitation; additionally, several nongovernmental organizations make important contributions by providing opportunities for recreational and competitive participation in a wide variety of sports.

Potter and coauthors note that heterotopic ossification (HO) in the residual limbs of civilian traumatic amputees, with its attendant problems of pain, skin breakdown, and difficulty with prosthetic fitting and utilization, is rare, with only a few case reports in the literature. In the current conflict, however, the problem is surprisingly common, with an incidence of 62%. The incidence is 80% for those with blast injury and amputation within the zone of injury. The authors review the current understanding of the basic science of HO. The most widely accepted theory is that mesenchymal stem cells present in muscle are stimulated into osteoprogenitor or osteoblastic cells. The role of bone morphogenetic proteins (BMPs) and the BMP antagonist, noggin, in experimental HO models and fibrodysplasia ossificans progressiva is discussed.

The authors also discuss prophylaxis in total hip arthroplasty (THA) and in patients with acetabular fracture by use of nonsteroidal anti-inflammatory drugs (NSAIDs) and low-dose irradiation (XRT), as well as by less common modalities, including calcitonin, vitamin K antagonists, colchicine, corticosteroids, and etidronate. The logistical impediments and medical contraindications for initiation of prophylaxis at the time of wounding are elucidated, and the resultant protocol for HO treatment at the AFAPCP centers is explained. Administration of XRT within the 72-hour window extrapolated from the THA data is logistically impossible, and the effects of XRT on initial healing of these massive wounds have not been studied. The renal, gastrointestinal, and bleeding complications associated with NSAID administration in these multisystem injuries contraindicate this modality. Additionally, these drugs have known deleterious effects on fracture healing.

Treatment of HO begins with a thorough history and physical examination. Orthogonal radiographs typically are adequate, but occasionally computed tomography with three-dimensional reconstruction can aid socket modifications and preoperative planning. The authors do not feel that bone scan is necessary for adequate assessment. Particular attention is paid to identifying other possible causes of residual limb pain and maximizing medical management. Multiple attempts at achieving a pain-free socket fit are made before excision is contemplated. If these attempts fail, surgery is performed, following careful preoperative planning to minimize the possibility of intralesional excision. Intraoperative cultures are taken, and overlying scar and skin graft is removed whenever possible. Postoperatively, most patients are given XRT of 700 to 800 cGy and a 6-week course of NSAIDs. To date, 18 limbs in 17 patients have undergone excision at an average of 8.2 months postoperatively, with only one minor, clinically irrelevant recurrence at an average follow-up of 6 months.

Possible etiologic factors contributing to HO are proposed by the authors. These include increased primary and secondary blast forces from modern weaponry; the increased severity of survivable extremity wounds; more aggressive efforts to retain levels resulting in amputation within the zone of injury; mild or subclinical associated traumatic brain injury; the use of pulsatile lavage and negative-pressure dressings; and subacute or occult infection.

Aaron and coauthors review the research efforts currently underway at their institution, Brown University, directed at the development of osseointegrated and neurointegrated robotic upper and lower extremity prostheses. They note that current prosthetic limitations include difficulty with socket fit, inadequate residual limb length (resulting in loss of strength and balance), and loss of neuromuscular function. They describe a new ankle-foot prosthesis for transtibial amputees that can actively control joint impedance and can provide powered plantar flexion, which should improve the symmetry of gait and reduce energy expenditure. They describe three phases of ankle function during stance: the initial phase, controlled plantar flexion, in which the ankle behaves as a linear spring; a second phase, controlled dorsiflexion, in which the ankle behaves as a nonlinear spring; and a third phase, powered plantar flexion, in which the ankle behaves as a torque source in series with the controlled dorsiflexion spring.

The authors describe their prosthesis—which consists of a motor and transmission, series springs, and a carbon-fiber leaf-spring foot—as a series-elastic actuator. They note that this is a safer mechanism than direct-drive systems because a limiting maximum force can be specified. They further note that a pilot study confirms their hypothesis that the prosthesis allows a more natural gait than do conventional transtibial prostheses.

Aaron and coauthors describe three other current projects that focus on optimizing the human-prosthesis interface. First is a study of different titanium surface treatments developed in an attempt to promote epithelial ingrowth to seal the skin-prosthesis interface; this would minimize the risk of infection leading to loosening of the prosthesis and loss of residual limb length. The authors have developed a novel method that allows them to rapidly create titanium and titanium alloy surfaces with different chemical and physical properties, and a quantitative fluorescent assay to measure cell number, adhesion, and morphology. Concurrently, the authors have begun mechanical testing of whole human skin to determine its viscoelastic and biomechanical properties in order to allow design of an improved cutaneous abutment.

Second, they describe their program to develop neural control interfaces that will allow complex sensory and motor control of robotic prostheses. This will involve not only the development of microscale signal processors, broadband optical telemetry and powering, and miniaturized processors, but also the mathematical algorithms that will allow decoding of motor spike trains into usable signals to drive complex activities. The resulting integrated systems will have to be adaptive and able to compensate for instabilities in either the sensors or the biologic system.

Finally, Aaron and coauthors address the problems inherent with the short residual limb. They note that the increased weight and complexity of prostheses necessary to fit a short residual limb increase the energy cost of prosthetic use and decrease the functional outcome for both the upper and lower extremities. They review 15 reports in the literature of bone lengthening in an amputee to improve the residual limb length and note the problems associated with lengthening; these include long consolidation times, pin infections, inadequate skin coverage, and joint stiffness. They describe the augmentation of distraction osteogenesis with electromagnetic field application and with ultrasound, noting that the former reduced bone loss in the distal segment and that the latter increased bone consolidation and torsional strength of the healing callus with a reduction in treatment time and earlier fixator removal. The authors describe their own studies. In animals treated with low intensity ultrasound, the authors found improved vascularization and consolidation, which allowed progressive weight bearing, accelerated radiographic healing, and increased bone volume.

MacKenzie reviews the Lower Extremity Assessment Project (LEAP), a multicenter, civilian-trauma study of limb-salvage and amputee patients. Based on the Sickness Impact Profile (SIP) and on return to work statistics, the outcome for both groups of patients has been poor (at 2- and 7-year follow-up, respectively). One half of patients had physical subscores on the SIP of 10 or greater, indicating significant disability; only 34% achieved scores typical for their age and sex. Also, just 58% of those who had worked before injury had returned to work at 7 years; in addition, those working were limited 20% to 25% of the time. The study shows that outcome is determined more by a patient's personal, social, and economic resources than by the treatment (salvage versus amputation) selected for the injury.

MacKenzie proposes a conceptual framework for examining these outcomes and for identifying interventions that may improve them. This framework recognizes that medical complications, pain, acute stress disorder (ASD), and posttraumatic stress disorder (PTSD) are common in this patient population and ultimately degrade the patients' quality of life. Characteristics of the individual and his or her environment influence the prevalence of these conditions and their impact on outcome. These characteristics are identified as mutable or immutable; characteristics in the former category are proposed as targets for intervention. Patient factors that have significant association with poor outcome include older age, female sex, nonwhite race, lower level of education, smoking, poor self-reported health status before injury, and legal-related compensation issues. These characteristics are largely immutable. However, the study also identifies anxiety, depression, and pain early in the treatment course as significant predictors of poor outcomes; these are mutable factors that can be targeted for intervention. Self-efficacy, or confidence in being able to perform specific tasks, was identified as a positive predictor of successful outcome; MacKenzie proposes that self-management interventions based on cognitive-behavioral theory show promise in increasing self-efficacy.

The implications of the LEAP findings for the military patient population are explored. The prevalence of associated upper extremity injury is underscored, with the importance of sensation and coordinated motion of individual digits, functions that are not replaced by current prosthetic technology. Favorable characteristics, such as young age, preinjury physical conditioning, and the military patient's strong social support network, are cited as factors suggesting a better outcome. However, the author cautions that long-term follow-up is necessary to ensure that the support continues once the soldier, marine, sailor, or airman is discharged from the service.