Advanced Rehabilitation Techniques for the Multi-Limb Amputee

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Advances in combat casualty care have contributed to unprecedented survival rates of battlefield injuries, challenging the field of rehabilitation to help injured service members achieve maximal functional recovery and independence. Nowhere is this better illustrated than in the care of the multiple-limb amputee. Specialized medical, surgical, and rehabilitative interventions are needed to optimize the care of this unique patient population. This article describes lessons learned at Walter Reed National Military Medical Center Bethesda in providing advanced therapy and prosthetics for combat casualties, but provides guidelines for all providers involved in the care of individuals with amputation. (Journal of Surgical Orthopaedic Advances 21(1):50–57, 2012)

Key words: rehabilitation, amputee, amputation, therapy, war injury

Introduction

Advances in battlefield medicine, improved body armor, more rapid medical evacuation, and modern resuscitation techniques have led to an unprecedented survival rate among military service members who sustain combat-related injuries. Today, combat casualties from Iraq and Afghanistan are surviving devastating injuries that would have been fatal in previous wars. As a result, the military healthcare system has needed to respond by advancing the field of rehabilitation to help our nation's heroes reach their maximum functional recovery and independence. Nowhere is this more apparent than in the care of the combat multiple-limb amputee.

As of December 2011, nearly 1,400 service members have had a major limb amputation as the result of combat wounds sustained in Iraq and Afghanistan, with over 20% of these members losing more than one limb. A recent report from the Army Surgeon General's "Dismounted Complex Blast Injury Task Force" noted that the incidence of double, triple,and even quadruple amputations has significantly increased over the past 2 years (1). Further distinguishing this group of amputees from their civilian counterparts is their relatively young age and high incidence of multiple other co-morbid injuries, such as fractures, soft tissue damage, peripheral nerve injury, traumatic brain injury, and psychological health problems. To best meet these unique needs, it became necessary for the military to develop Centers of Excellence for Amputee Care, which emphasize coordinated interdisciplinary care, holistic patient management, and the use of innovative technologies applied in a "sports medicine" paradigm. These "state-of-the-art" programs currently exist at Walter Reed National Military Medical Center Bethesda (WRNMMCB) in Bethesda, MD; the Center for the Intrepid (CFI) in San Antonio, TX, and the Naval Medical Center in San Diego, CA.

Medical and Surgical Management

The medical and surgical principles needed to optimize the rehabilitative care for multiple-limb combat amputees

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The authors certify that all individuals who qualify as authors have been listed; each has participated in the conception and design of this work, the analysis of data, the writing of the document, and the approval of the submission of this version; that the document represents valid work; that if we used information derived from another source, we obtained all necessary approvals to use it and made appropriate acknowledgements in the document; and that each takes public responsibility for it. Nothing in the presentation implies any Federal/DOD/DON endorsement.

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are very similar to those used for all trauma patients. First priority is to intervene to preserve life, limb, and vision beginning from the time of injury and continuing throughout the medical evacuation process. When amputation is necessary, wound closure is typically delayed until conditions are optimized for wound healing. This entails debriding all non-viable or infectious tissue, selecting the optimal length of the amputation, and achieving adequate soft tissue coverage of the residual limb. Every effort is made to preserve limb joints, such as the shoulder, elbow, hip and knee, in order to promote improved long-term functional outcomes. This often requires performing creative skin grafts or muscle flaps that may prolong the time of healing and delay prosthetic fitting and training. Nevertheless, it is important to start rehabilitation as soon as possible during the hospital course. Early range of motion exercises should be implemented immediately to prevent joint and soft tissue contractures. Regular skin surveillance, appropriate turning, and pressure relief should be initiated to reduce breakdown and ulceration. In addition, it is essential to challenge the cardiovascular and musculoskeletal system to help minimize the effects of immobility, such as deconditioning and bone resorption.

Achieving adequate pain control is particularly challenging in caring for the combat casualty with multiple limb loss. It is often necessary to use a combination of approaches, including continuous regional anesthesia, epidural blocks, patient-controlled analgesia (PCA), oral medications (e.g., opioids, anticonvulsants, antidepressants, and NMDA receptor antagonists), as well as local modalities, such as heat, ice, massage, and electrical stimulation. A multi-modal approach to pain management can help decrease the required dosage of a single medication, thereby minimizing the risk of side effects associated with dose escalation. This is particularly important when using opioid medications, as this practice may reduce the risk of developing tolerance, dependence, or addiction. Because pain may adversely affect an individual's ability to participate in therapy, premedication with a short-acting opioid prior to therapy sessions may be very helpful. Conversely, over-medication prior to therapy may lead to excessive drowsiness and the inability to attend to tasks. In order to optimize pharmacologic management, frequent communication must occur between the patient, nursing staff, and trauma and rehabilitation teams through regularly scheduled interdisciplinary meetings.

Of particular concern when caring for the combat amputee is the presence of co-existing traumatic brain injury (TBI) and/or psychological health problems. In order for rehabilitation to be successful, the patient must be able to demonstrate the ability to follow commands, attend to tasks, and show steady learning improvements. If the presence of TBI significantly interferes with these requirements, it is best to transfer the patient to a specialized in-patient TBI rehabilitation facility, such as one of the Polytrauma Centers that exist in the Department of Veterans Affairs (VA) system. Upon sufficient recovery from their brain injury, the patient may then return to the military system for advanced amputee care if needed.

Psychological health problems may also negatively impact rehabilitation. Because of the high incidence of conditions such as anxiety, depression, and post-traumatic stress disorder (PTSD) , access to experienced behavioral health experts is a vital aspect of rehabilitative care. At WRNMMCB, all combat casualties are seen by the Preventative Psychiatric Consultative Liaison Service. This not only ensures early evaluation and intervention, but also helps to destigmatize any negative perception about seeking psychiatric help. It is not uncommon, however, for the patient or patient's family to form a closer relationship with one of the members on the rehabilitation team other than with the behavioral health expert. This may lead service members and their families to share very sensitive information about their psychological state, ongoing family stressors, or even concerns about substance misuse, all of which may adversely affect an individual's rehabilitation and recovery. Therefore, regularly scheduled interdisciplinary meetings should encourage open discussion among team members regarding these topics to help formulate the best intervention and support strategies.

A unique consequence of blast injury appears to be the associated high risk of developing heterotopic bone formation within the soft tissues of the residual limb(s). It has been reported that heterotopic ossification (HO) may occur in up to 64% of combat amputees (Fig. 1). The presence of HO may impair joint range of motion and subsequent function of the upper and/or lower limb. In addition, the location of the HO may lead to difficulty in prosthetic fitting, residual limb pain, or frequent skin breakdown. Early evidence indicates that initial treatment with anti-inflammatory medications may provide some prophylaxic benefits, but these treatments are not preventative. Treatment of HO typically involves aggressive range of motion exercises and socket modifications to accommodate the excessive bone formation. This intervention strategy requires prolonged use of thermoplastic materials and more frequent socket replacements compared to civilian practice. Surgical excision may be necessary in the event that non-invasive treatment strategies are not effective, but is generally delayed until the HO has become mature.

In order to meet the ongoing surgical needs of the combat amputee, the orthopaedic surgeon must have regular interaction with the rehabilitation team, even after definitive revision and closure. The historical dogma that

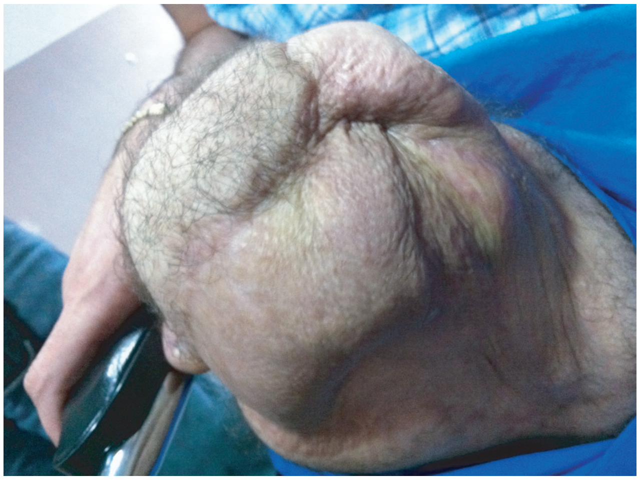

FIGURE 1 During the maturation phase of heterotropic ossification (HO), attempts of accommodation are sometimes successful to preclude surgical revision. In a minority of cases, HO is actually beneficial, to broaden acceptable weightbearing surfaces on the residual limb.

trauma-related amputations heal without substantial problems has been upended by several studies demonstrating that these patients experience rates of infection, symptomatic neuromas, HO, and other maladies. However, recovery may be improved via limited or total operative revision. The complication and operative revision rates following combat-related amputation are as high as, if not higher than, those of their civilian correlates. Rather than approaching these patients with the mindset that "nothing ruins good results like followup," the orthopaedic goal of our post-surgical program is to identify problems that can be corrected with surgery early, before they become severe, chronic, or substantively retard patient progress and rehabilitation. This is not to advocate a return to surgery as soon as any problem arises, but rather to maintain regular and accessible communication with the patient and within the rehabilitation team in order to monitor patient progress and undertake surgical interventions when necessary. Problems such as symptomatic neuromata and HO can be mitigated through less invasive measures including rest, time, medications, local injections, topical therapies, and socket modifications. Accordingly, advisement that surgical interventions are not often needed for these as well as other problems, such as phantom limb pain, prevents wounded warriors from fixating on revision surgery as an absolute necessity. Surgeon counseling throughout this process is crucial in reducing patient frustration and disenfranchisement. Some of our biggest success stories involve patients with ostensibly surgical problems in whom operative intervention was ultimately not necessary. By maintaining communication and closely following their patient's progress in rehabilitation, the surgeon can intervene expeditiously if non-surgical interventions fail.

Optimal management of individuals with multiple limb amputation must also include appropriate education regarding the increased associated risks of developing arthritis, cardiovascular disease, diabetes, and recurrent skin problems. Reducing modifiable risk factors, such as obesity, sedentary life-style, hypercholesterolemia, and tobacco and alcohol use, should be emphasized throughout the rehabilitation course and reinforced over the long-term healthcare management of the individual. Regular physical fitness routines should be incorporated into the rehabilitation process to maintain core and residual limb strength and early, before they become severe, chronic, or substantively retard patient progress and rehabilitation. This is not to advocate a return to surgery as soon as any problem arises, but rather to maintain regular and accessible communication with the patient and within the rehabilitation team in order to monitor patient progress and undertake surgical interventions when necessary. Problems such as symptomatic neuromata and HO can be mitigated through less invasive measures including rest, time, medications, local injections, topical therapies, and socket modifications. Accordingly, advisement that surgical interventions are not often needed for these as well as other problems, such as phantom limb pain, prevents wounded warriors from fixating on revision surgery as an absolute necessity. Surgeon counseling throughout this process is crucial in reducing patient frustration and disenfranchisement. Some of our biggest success stories involve patients with ostensibly surgical problems in whom operative intervention was ultimately not necessary. By maintaining communication and closely following their patient's progress in rehabilitation, if non-surgical interventions fail, the surgeon can intervene expeditiously.

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Physical Therapy

The goal of the physical therapist is to return the patient to the highest level of practicable physical function. For the multiple limb amputee, this goal is primarily accomplished by focusing on core and proximal muscle strengthening and neurological control, regardless of the level of amputation. Both transtibial and transfermoral amputees must rely heavily upon proximal hip muscles to maintain balance because of the lack of intrinsic foot and ankle control. Even individuals with upper limb amputation must rely more on core strength to allow proper prosthetic use and trunk stability. To maximize success, rehabilitation should begin as soon as possible, well prior to prosthetic fitting, and focus on critical core muscles such as the transverse abdominus, rectus abdominus, obliques, serratus, back extensors, iliospoas, gluteals, hamstrings, and the remaining hip adductors. Core muscles should be conditioned in all planes, including rotary movement, to allow the patient to re-learn how to stabilize their body. Hip extensor and abductor strengthening exercises are emphasized because they have been shown to correlate with a more normalized prosthetic gait. Closed kinetic chain body weight exercises are employed to best mimic the manner in which an amputee will use their residual limb inside a prosthetic socket.

Individuals with bilateral lower extremity loss, particularly those with bilateral transfemoral amputation, can be fit with initial prostheses that are much shorter than their pre-injury length. This helps to lower their center of mass, thereby improving their balance by enhancing their ability to control a much lighter and shorter prosthesis. Once gait and balance are mastered at this lower height, the prosthetic pylon can be lengthened sequentially as the patient demonstrates achievement of gait and balance milestones. At WRNMMCB, we have found that the early use of manual locking knees with short prostheses increases prosthetic wear time and patient satisfaction. The ability for the knee to unlock helps facilitate seating (e.g., wheelchair, car, and social environment), or lock to ensure knee stability and confidence during initial gait training.

For individuals with multiple lower limb loss, particularly those with associated upper limb loss or dysfunction, significant challenges arise when utilizing an assistive device, such as a walker, crutch or cane to support ambulation training. Proper gait training necessitates equality of support on right and left sides to create symmetry of lower limb movements as well as trunk lateral flexion and rotation. For these patients, it becomes necessary to make custom adaptations to standard pieces of equipment in order to best accommodate individual patients. At WRNMMCB, we have utilized converted wrist splints and gloves with Velcro straps to accommodate patients with partial hand loss; created platforms for individuals to rest their residual forearms to use lofstrand crutches; and even fabricated customized "crutch arms" by connecting a crutch directly to the patient's prosthetic socket(s) (Fig. 2). These interventions have helped to promote independence and a more rapid functional recovery.

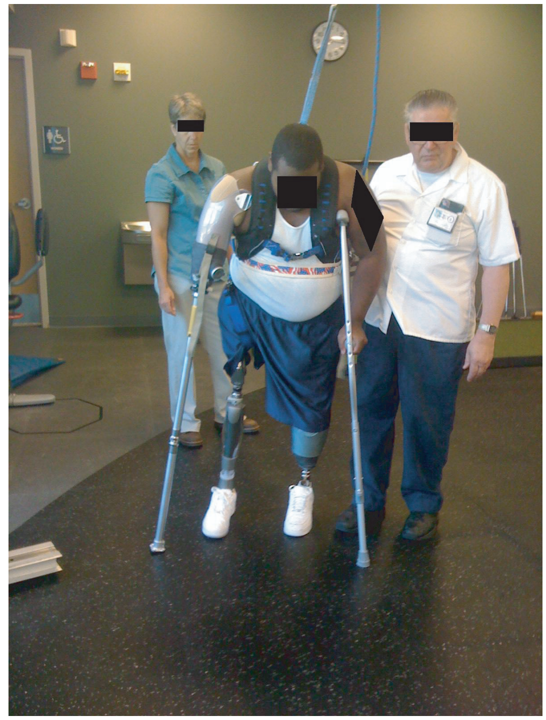

FIGURE 2 The Solo-Step® allows safe progression of walking and running for patients at risk of falling. The "crutch arm" was invented in response to problems with persons with multi-extremity amputations to hold an assistive device with a prosthetic arm. This design has become instrumental in meeting the needs of acute rehabilitation goals and for some, long-term ambulatory requirements.

Aggressive physical therapy also includes cardiovascular conditioning to improve endurance and maintain lean body mass, as strength-to-body weight ratios have anecdotally shown to be important for high level functioning of multiple limb loss amputees. Patients are also encouraged to participate in numerous sports and recreational activities that have been adapted to accommodate for their limb loss. Collaborating with organizations with programs specializing in swimming, rowing, cycling, basketball, volleyball, horseback riding, skiing, target shooting, and recreational hunting and fishing has been very beneficial to the military amputee care programs. Clinicians at WRNMMCB adhere to a sports medicine model that treats the multi-limb amputee similarly to an elite athlete, using adaptive devices and prosthetic components to support high intensity training. Access to cutting-edge technologies allows clinicians to challenge patients in multiple domains, advancing rehabilitation outcomes. For example, the Solo-Step® (Fig. 2) is a free-moving harness suspension system mounted above our indoor track, which allows patients to walk or run using any prosthetic component without fear of falling.

Once level ground performance is mastered, obstacles, ramps, stairs, and agility drills can be added to enhance performance and facilitate the return to higher level functioning, including return to active military service. WRNNMCB also employs a 3D Gait and Motion Analysis Lab to fine-tune gait and enhance human performance. The lab uses an array of motion-capture cameras and force plates to perform precise kinetic and kinematic evaluations and provide specific feedback to patients, therapists, and prosthetists. In addition, patients and rehabilitation professionals within the military Centers of Excellence for Amputee Care have access to a computer assisted rehabilitation environment (CAREN). This unique system consists of a treadmill on a movable platform that is embedded in a virtual reality environment. The system can be programmed to work on multiple rehabilitation domains simultaneously, such as balance, ambulation, cognition and falls recovery (Fig. 3). Using this treatment paradigm, many individuals have managed to return to active military duty or qualify for Paralympic teams in as few as 12 to 18 months following traumatic amputation.

Occupational Therapy

As part of the inter-disciplinary team approach to rehabilitation, all combat casualties with limb loss receive occupational therapy (OT) services in the in-patient and out-patient setting. The goal of OT is to return each patient to the highest level of independence and function possible in performing activities of daily living (ADL) with and without a prosthesis. The definition of the highest level of function varies between patients based on their individual short and long-term goals, as well as the variety of medical, physical, and psychological changes that occur during the rehabilitation process.

FIGURE 3 The CAREN (computer assisted rehabilitation environment) system can simulate navigation of real world environments in a safe matter.

Occupational therapist first work to build the individual's independence in such activities as eating, grooming, dressing, bathing, toileting, transfers, and wheelchair positioning and mobility. For those with upper limb amputation, OT is particularly critical in helping an individual prepare for prosthetic fitting and training, both physically and psychologically. During the pre-prosthetic phase of rehabilitation, occupational therapists educate patients on appropriate residual limb care, edema control, and desensitization techniques. Additionally, they are able to initiate myoelectric control training, even before definitive amputation and wound closure. This training involves placing surface electrodes on the skin of the residual limb. These electrodes are able to sense voluntary muscle contraction beneath the skin and provide computer-generated feedback to the patient, therapist and prosthetist to best develop prosthetic control strategies. Mastering this training early can help the patient adapt to his or her prosthesis more rapidly. For combat casualties, as a matter of routine we initially fit each upper limb amputee with a myoelectric prosthesis. We have found that myoelectric sockets transmit lower sheer forces on residual limbs, thereby decreasing the risk of skin or soft tissue breakdown. In addition, the frequent presence of co-existing proximal arm, shoulder, or neck injuries often prohibits the use of a body-powered (cable-driven) prosthesis.

Throughout the rehabilitation process, frequent communication must occur between the patient, occupational and physical therapist, assistive technology specialists, and prosthetist to help identify best practices and select appropriate adaptive equipment and prosthetic terminal devices to achieve optimal performance. This is especially vital when caring for the individual with multiple limb loss. Recently, a patient with bilateral upper limb loss listed the ability to use a smart phone as one of his primary therapeutic goals. Although he was quickly able to use a bluetooth device for making phone calls, texting required a different strategy. When not wearing his below elbow prosthesis, he was taught to independently don a universal cuff with a pencil attachment that enabled him to text using the eraser; when wearing his below elbow prosthesis, he was taught to turn his terminal device in a way to use his prosthetic thumb to operate his smart phone keypad. This case exemplifies the innovative strategies used to help wounded warriors achieve their rehabilitation goals.

As previously stated, our typical practice is to fit all combat upper limb amputees with a myoelectric prosthesis first and then progress to a body-powered prosthesis or hybrid prosthesis as the patient demonstrates improved strength, range of motion, and residual limb maturation. However, the recent increase in service members returning with multiple limb loss has highlighted the benefits of fitting individuals initially with a body-powered prosthesis. The clinical rationale for this approach is that body-powered upper limb prosthetic systems are generally lighter and easier to operate, especially from a seated position such as a powered wheelchair. Additionally, we have found that operating an above-elbow myoelectric system while seated in a wheelchair can be frustrating for the patient because it often requires repositioning armrests or lowering tabletops.

Individuals with bilateral upper limb amputation face unique rehabilitative challenges. As one would predict, achieving independence in ADL's is largely dependent on the patient's ability to adapt to wearing and operating at least one prosthetic hand. Whichever residual limb is the longest frequently becomes their dominant hand, independent of their pre-injury state. Donning and doffing their prostheses is particularly challenging, requiring the need to develop fine motor dexterity and pinch grip strength. This requires continuous practice, team problem solving, the use of alternative shrinker and liners, learning how to sequence tasks, and often the fabrication of customized adaptive equipment.

Challenging patients in a variety of situations using a multitude of prosthetic systems and configurations is a key part of our occupational therapy program. Use of upper extremity prosthetic systems to accomplish functional tasks and navigate new environments requires individualized attention. One area of particular concern for our patients with multiple limb loss is the ability to operate a motor vehicle. Driving is a critical skill for achieving independence, community integration, and higher quality of life. Therefore, at WRNMMCB an occupational therapy driving specialist evaluates every combat amputee early during his or her rehabilitation course to help establish a return to driving plan. This includes education on motor vehicle choice and accessibility, various options for vehicle modifications and adaptive equipment, as well as the various motor vehicle grants that are available to injured service members and veterans. Many of our multiple limb loss patients successfully drive independently within only a few months of injury.

Prosthetics

Prosthetic selection, fitting, alignment, and training is particularly challenging when caring for combat casualties with limb loss, and even more complicated when treating those with multiple limb loss. Creative solutions are frequently needed to meet the unique needs of this patient population. As mentioned previously, the rehabilitation of an individual with combined upper and lower limb loss often requires the use of a customized prosthesis, like the "crutch arm," whereas those with bilateral lower limb loss typically benefit from using shortened pylon prostheses initially to achieve early socket tolerance, balance, ambulation, and confidence. Considerable debate continues to exist regarding the optimal timing for introducing prosthetic knees for individuals with bilateral above knee amputations. While some providers advocate increasing the height of the "stiff" leg pylons prior to adding knee units, others believe that this only promotes an abnormal "scissoring" gait pattern, leading to excessive hip and lower back strain. At WRNMMCB, we have had considerable success utilizing microprocessor-controlled knees for individuals with bilateral lower limb loss. During the initial programming of these knees, it is often helpful to adjust the settings to be relatively stiff with delayed activation of knee flexion during toe loading in order to provide additional stability. These settings are then adjusted to provide less resistance as the patient demonstrates improved balance and control. We have observed that for the bilateral lower limb amputee, individuals with through knee amputations demonstrate biomechanical advantages over those with more proximal (transfemoral) levels. The relative disadvantage of a more distal knee center clearance can be easily overcome by adjusting the height of the contralateral side in this patient population. The role of powered prostheses is still undetermined in this patient population, but offers great opportunities for further research and development.

Socket design and fit are critical for successful prosthetic use. For individuals with bilateral above knee amputations, we prefer a sub-ischial socket design whenever possible. In addition to providing more comfort, patients report that this design allows more hip mobility and better balance. Furthermore, we have found that the presence of heterotopic bone formation within the residual limb may enhance socket suspension at this level. Further suspension may be added as needed by incorporating an elevated vacuum within the sub-ischial socket as needed. Critics of the sub-ischial socket design cite an increased risk of femur fracture, HO formation, and hip and low back pain. Further investigation is needed to determine the utility and best application of this technology.

Independent household mobility is a primary goal for all individuals with multiple limb amputations. Traditionally, a wheelchair has been required to achieve this level of independence. Unfortunately, for many of our patients, their houses are not very accessible for wheelchair use, particularly when operating in tight spaces. To address this problem, we have found that the use of shorten prostheses as "house legs" (Fig. 4) has allowed increased mobility and independence for individuals with bilateral above knee amputations. Feedback has been overwhelmingly positive from patients and family members who credit the "house legs" for allowing them to be more independent in performing routine household activities. Moreover, shortened prostheses have been shown to require less oxygen consumption and cardiac response than full-length prostheses, advocating their use for elderly patients and civilians who would otherwise be considered poor prosthetic candidates. House legs should be designed to be lightweight, use anatomical suspension (when available), and offer speedy donning and doffing. With bilateral transfemoral prosthetic use rates around 22% for Vietnam veterans, the importance of addressing the future needs of household ambulation for today's recent veterans is essential.

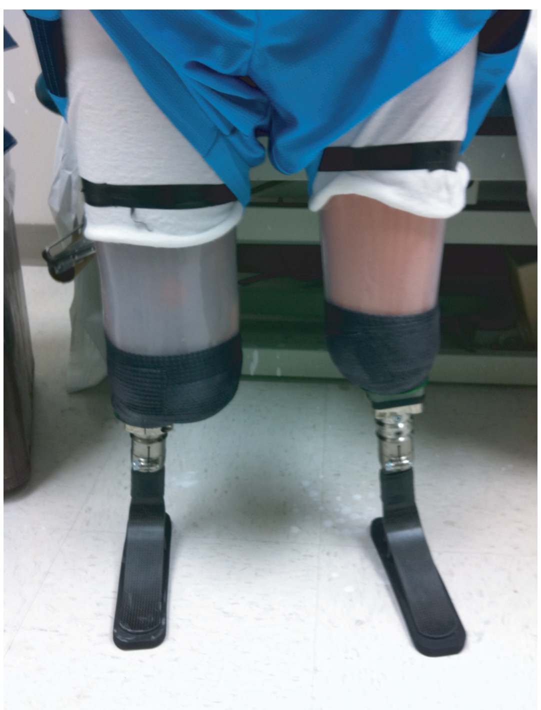

FIGURE 4 "House legs" are simply shortened prostheses that are light- weight and easy to don and doff much akin to slippers. This design and concept addresses needs of household ambulation to very active as well as very inactive persons with bilateral transfemoral and knee disarticulation amputation levels.

The relatively high number of combat casualties with very proximal lower limb amputations has hastened efforts to explore new strategies within the confines of existing technology to help these patients achieve upright walking. Socket design and prosthetic fitting is even more challenging for individuals with hip disarticulation and/or hemipelvectomy coupled with a colostomy. If the site of the colostomy bag is on the side of the amputation, creatively contoured sockets with ratchet straps may be built around the bag. In many of these cases, we have had success working with customized Under Armour® garments (Baltimore, MD) and impregnating them with gel to improve socket interface and suspension. For individuals with biliateral hip disarticulation or hemipelvectomy, incorporating a reciprocating gait orthosis within the prosthetic design has proven to allow successful standing and assisted ambulation for several patients. Unfortunately, achieving household ambulation independence is not currently a realistic expectation for those with high bilateral levels of amputation. Therefore, it is imperative that clinicians pay considerable attention to customizing seating systems and wheelchair fittings to achieve independent mobility. Continued development of powered prostheses and robotic devices may add considerable advantages for these patients in the future.

The importance of an ongoing fitness program is emphasized during rehabilitation to promote long-term physical and psychological health benefits. Low-impact aerobic activities, such as cycling, are often well tolerated. Various styles of bicycle are currently available for injured service members, including hand crank, recumbent, and upright models. Safety and efficiency are the two major requirements when selecting a specific bicycle design. For individuals with transfemoral amputation who desire to ride an upright or recumbent bike, a prosthesis may be fabricated incorporating a Bartlett tendon knee (Leftside Industries Inc., Snohomish, WA) (Fig. 5). Adding a flexion stop to the prosthetic knee joint for cycling is currently under investigation.

Conclusion

Remarkable advances in rehabilitation techniques have changed what we can expect for not only combat casualties, but all individuals with multiple limb amputations. While limitations in current prosthetic technology remain, improvements to past designs have revolutionized amputee care, allowing service members and civilians with high levels of amputation to achieve independence in ways previously thought impossible. Areas in need of further research include the development of better human interface strategies, powered prosthetics, and robotics, as well as optimal strategies for improving functional performance and reducing long-term compilations.

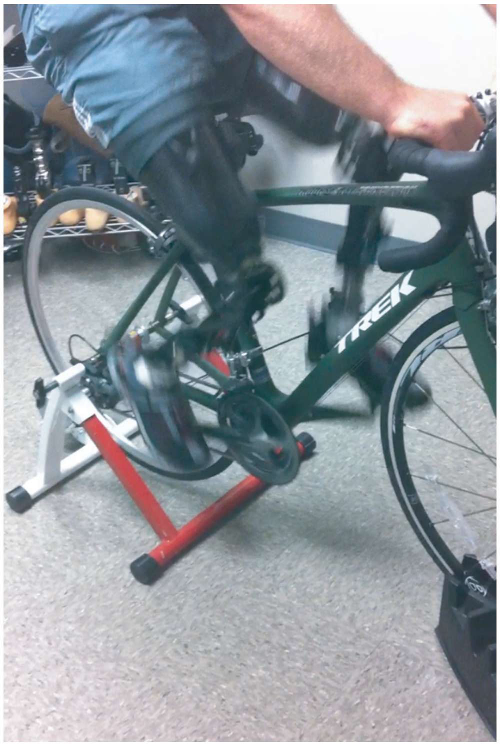

FIGURE 5 New understanding in biomechanics and resultant improvements in cycling prostheses for bilateral transfemoral and knee disarticulation amputation levels, may encourage future participation in various forms of cycling as a recreational sport and physical fitness activity.

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