Return to Running and Sports Participation After Limb Salvage

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Background: The ability to return to running and sports participation after lower extremity limb salvage has not been well documented previously. Although the ability to ambulate without pain or assistive devices is generally a criteria for a good limb salvage outcome, many patients at our institution have expressed a desire to return to a more athletic lifestyle to include running and sports participation. The purpose of this study was to investigate the types of athletic endeavors our high-energy lower extremity trauma patients were able to pursue after limb salvage.

Methods: We retrospectively analyzed lower extremity limb salvage patients who were at least 12 weeks status after external fixation removal and participated in our limb salvage return-to-running clinical pathway. Patients were rehabilitated to their highest functional level through a sports medicine-based approach. A custom energy-storing ankle-foot orthosis was implemented to help augment plantarflexion strength in conjunction with running gait retraining.

Results: The first 10 patients to complete the clinical pathway were identified. All patients were treated at the same institution by the same orthopedic surgeon and physical therapist. Eight patients have returned to running, and 10 patients have returned to weight-lifting. Seven patients have returned to cycling, three have returned to golf, three to basketball, and two to softball. Two patients have completed a mini-triathlon.

Conclusion: Aggressive rehabilitation, an energy-storing ankle-foot orthosis, and running gait retraining can restore an active recreational lifestyle to patients who have undergone lower extremity limb salvage.

Key Words: Limb salvage, Combat wounds, Ankle-foot orthosis, Trauma rehabilitation.

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Limb salvage of lower extremities involved in high-energy lower extremity trauma (HELET) has made significant advancements. Mangled limbs once destined for amputation are now afforded the opportunity for reconstruction. At Brooke Army Medical Center (BAMC), a large number of HELET patients are seen due to the injuries suffered from Operation Iraqi Freedom and Operation Enduring Freedom. The majority of these injuries involve lower extremity trauma, specifically open fractures of the tibia and fibula.[1] These high-energy injuries frequently involve massive soft tissue injury, severe contamination, vascular, and neurologic damage.[2] Additional comorbidities are often associated with HELET, including multiple extremity injuries, thoracoabdominal trauma, traumatic brain injury, and posttraumatic stress disorder, all of which can complicate the recovery process.[3]

The ability for limb salvage patients to return to a high level of physical activity has been poorly documented. A recent meta-analysis found high levels of reported disability and a deteriorating functional status over time in the limb salvage population.[4] In fact, the ability to ambulate with minimal pain has often been considered a successful outcome of limb salvage programs.[5] At BAMC, many limb salvage patients are not satisfied with such limited outcomes and are willing to undergo amputation if it means a potential return to higher levels of physical function. However, poor functional outcomes and perceived disability seem to be equal for both amputated and limb salvage patients. The largest study to date comparing these two groups, the Lower Extremity Assessment Project Study Group, demonstrated no significant difference in functional outcomes at 2 years and 7 years postinjury, and both patient groups were found to be severely disabled as compared with a normative population.[6] Nonetheless, many limb salvage patients witness their amputated peers walking and running earlier in the rehabilitation process and may question further attempts at limb sparing procedures.

To combat this dilemma, the limb salvage run clinical pathway was developed, through a partnership between the orthopedic, physical therapy, and prosthetic and orthotic departments, as well as the Center For the Intrepid at BAMC. This multidisciplinary program is built around an aggressive rehabilitation plan both while in circular fixation and out of fixation along with a unique energy-storing ankle-foot orthosis that has enabled our limb salvage patients the ability to return to running, sports, and military deployment.

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MATERIALS AND METHODS

After institutional review board approval, a retrospective analysis identified the initial HELET limb salvage patients who were at least 12 weeks status after circular external fixation removal and participated in our institution's limb salvage return-to-run clinical pathway from October 2009 to June 2010. October 2009 was chosen as it marks the first implementation of the current ankle-foot orthotic design, as described below. All patients were treated at the same institution by the same orthopedic surgeon and physical therapist. Outpatient medical records, physical therapy clinical notes, video analysis, and patient interviews were used for data collection. Patients were excluded if they were treated by a different orthopedic surgeon or therapist, or spent <12 weeks in a circular external fixator. All patients gave their written consent to be photographed and recorded for the purpose of this study.

All patients underwent an aggressive rehabilitation program focusing on strength, plyometrics, power, and agility training both in circular external fixation and out of fixation. The program was broken into two phases, the "in-frame" phase and "out-of-frame" or "brace" phase. Each patient in the cohort was fit with a custom carbon fiber energy storing ankle-foot orthosis to use during the brace phase of the program. The energy storing orthosis, the Intrepid Dynamic Exoskeletal Orthosis (IDEO), is a custom brace designed by the Orthotics and Prosthetics Department at the Center For the Intrepid at BAMC under the direct supervision of one of the coauthors (R.V.B.; Fig. 1). It is crafted primarily from carbon fiber, incorporating a modified Littig posterior mounted strut, a proximal ground reaction cuff, and a distal supramalleolar ankle-foot orthosis. The IDEO stores energy in the brace as the tibia progresses forward and the ankle dorsiflexes during mid and terminal stance. It then returns the energy to the patient in the form of ankle plantarflexion power as the limb is unloaded.[7]

The rehabilitation program was initiated as soon as patients were discharged from the hospital. All patients began with a strength training program to develop the normal force-generating capacity required for gait, running, and sports. Decreased muscle strength has been correlated with an abnormal gait in limb salvage and able-bodied persons, and an improved running economy has been seen with a strength training program in normal individuals.[8–10] The strength program focused on functional patterns such as squats, lunges, and dead lifts (Table 1). Once the patient was able to complete 3 sets of 10 repetitions of any given exercise, an external load such as a weight vest or dumbbell was applied to enhance strength gains.

Patients began leg press training once they could perform a body weight squat. The ability to perform this task was highly variable in our population with factors such as foot plates on the frame or increased pain from making modifications to their frames for bone transport or bone corrections. All patients could perform a leg press at 50% body weight by the time they were performing body weight squats. Once able to leg press or squat to at least 80% of their body weight, the in-frame plyometric training began (Table 2). This training starts with a double leg jump on a horizontal plane using a leg press or sled. Once the patient could do 3 sets of 10 repetitions without an increase in pain, they were advanced to horizontal bounding (reciprocal jumping from one leg to the other) and horizontal jumps (jumping on one leg). (Fig. 2). During the brace phase, plyometric training was advanced to the vertical plane, and the same progression from jumps to bounding to hops was used (Fig. 3).

Agility training was initiated using an agility ladder. This was done in linear and multidirectional patterns and progressed from the in-frame to the brace phase. As patients become more comfortable with their footwork drills, cutting and deceleration tasks were incorporated.

Run retraining began once the patient could perform agility training without an increase in pain. The majority of

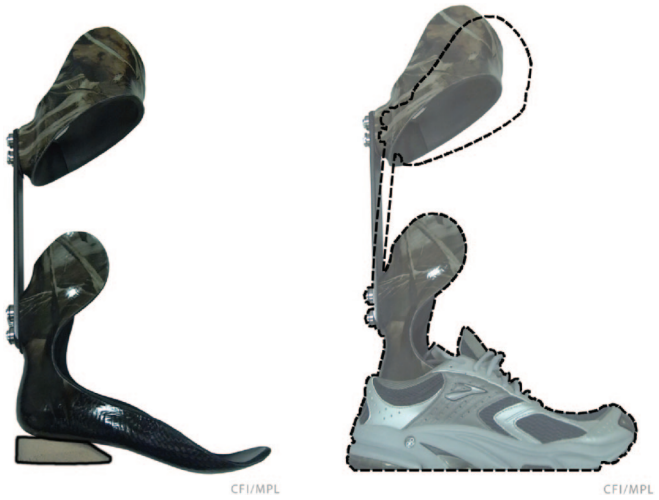

Figure 1. The Intrepid Dynamic Exoskeletal Orthosis (IDEO).

TABLE 1. Sample Strength Progressions

Strength: Knee Dominant	Strength: Hip Dominant
Box squat	Bridge
Wall sit	Marching bridge
Leg press	Eccentric bridge
Split squat	Single leg bridge
Lunge	Dead lift

TABLE 2. Sample Plyometric Progressions

Plyometrics (In-Frame)	Plyometrics (Brace Phase)
Shuttle jump	Box jump
Shuttle bound	Horizontal jump
Shuttle hop	Vertical jump
Box jump	Box bound
Horizontal jump	Horizontal bound
	Vertical bound
	Box jump
	Horizontal jump
	Vertical jump

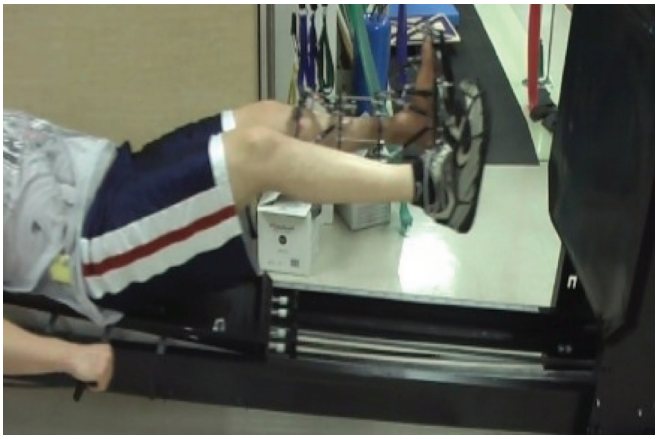

Figure 2. Horizontal plyometric jump training while In-frame.

Figure 3. Vertical plyometric jump training in the Brace phase.

run retraining was done during the brace phase on a treadmill and track. Patients were instructed how to perform a mid-foot strike as opposed to a conventional heel strike while running, thereby maximizing the energy return from the IDEO. Patients were video recorded while running to give biofeedback of their running mechanics. Initially, running distances were kept short (<20 yards) to work on mechanics and avoid too much stress to the leg. Running was progressed to the treadmill for interval distance runs, which were advanced a quarter mile a week. For the purposes of the study, run was defined as the ability to run on a treadmill without stopping for two consecutive miles.

Predeployment training was initiated for the soldiers preparing for a possible return to a military deployment setting. During this phase, soldiers participated in walking and running programs using their IDEO with a weighted backpack or rucksack. The weight of the rucksack was increased progressively up to 80 pounds, which is the approximate weight many of our combat arms patients would actually be carrying while deployed (Fig. 4). Soldiers were also started on push-ups and sit-ups to prepare for the annual physical fitness test that is required of all soldiers.

Figure 4. Pre-deployment training in the Brace phase.

RESULTS

Ten HELET limb salvage patients fit our inclusion criteria. All patients were active duty males with an average age of 28.8 years. A motorcycle collision was the only noncombat injury. All other injuries were from improvised explosive devices (four patients), high-velocity gunshot wounds (four patients), or a motor vehicle collision (one patient) encountered in Operation Enduring Freedom or Operation Iraqi Freedom. All injuries were HELET, as defined by the Lower Extremity Assessment Project Study Group.[7] Injuries sustained included one Gustilo-Anderson (G/A) type IIIB tibial plateau fracture, one G/A IIIA tibial shaft fracture, four G/A IIIB tibial shaft fractures, one IIIC tibial shaft fracture, one G/A IIIB tibial pilon fracture, one G/A IIIB calcaneus fracture, and one distal fibula fracture with exten-

TABLE 3. Patient Demographics

Patient	Age (yr)	Injury (G/A)	MOI
1	25	IIIB tibial shaft fracture	IED
2	33	IIIB tibial shaft fracture	HVGSW
3	25	IIIB tibial pilon fracture, multiple tarsal/metatarsal fractures	MCC
4	24	IIIB calcaneus fracture	HVGSW
5	29	IIIB distal fibula fracture	MVA
6	32	IIIB tibial shaft fracture	HVGSW
7	27	IIIB tibial plateau fracture	IED
8	35	IIIC tibial shaft fracture	IED
9	32	IIIB tibial shaft fracture	HVGSW
10	26	IIIA tibial shaft fracture	IED

G/A, Gustilo-Anderson classification; MOI, mechanism of injury; IED, improvised explosive device; HVGSW, high-velocity gunshot wound; MCC, motorcycle collision; MVA, motor vehicle accident.

TABLE 4. Patient Activities

Patient	Run	Mini-tri	Cycling	Basketball	Softball	Weight Lifting	Golf	Special Forces	Ranger
1	X		X			X	X		
2	X					X		X	
3	X		X	X	X	X			
4	X		X			X			X
5	X	X	X	X	X	X			
6	X		X			X		X	
7		X	X			X			
8	X			X		X	X		
9		X				X			
10	X					X	X		

Mini-tri, mini-triathlon (2-mile run, 5-mile bike ride, and 500-meter swim). Special Forces and Ranger refer to deployment with an elite combat arms unit.

sive soft tissue and bone loss (Table 3). Eight of 10 soldiers successfully returned to running, including 1 patient who has completed both a marathon and a half marathon. While the remaining two patients were able to run, they did not meet our criteria of being able to run 2 miles without stopping. Two patients have completed a mini-triathlon consisting of a 2-mile run, 5-mile bike ride, and 500-meter swim. Seven patients have returned to cycling, three to basketball, two to softball, and three to golf. All 10 patients were able to return to a regular structured weight-lifting program (Table 4). Three patients have deployed again in combat roles including two with the Special Forces and one Army Ranger.

DISCUSSION

By using an aggressive sports medicine-style rehabilitation program along with the IDEO, HELET limb salvage patients are able to achieve higher level functional activities. Rehabilitation is often seen as an integral part of recovery after many common orthopedic injuries. However, the limb salvage population is not always afforded this opportunity despite the beneficial effects of rehabilitation that have been recognized in the literature.[11]

Our clinical pathway is initiated very early in the outpatient setting. This was done not only to combat the loss of range of motion, strength, and functional independence that is problematic with HELET patients but also to allow the patients to begin interacting and rehabilitating alongside other limb salvage patients. Thus, a built-in peer group with similar injuries is established, and patients can see future milestones in their recovery. This type of setting is common in many sports medicine facilities that treat groups of athletes with similar injuries to one another. This type of peer support also helps mitigate the fear many patients have when first using their limb in circular external fixation or attempting to run and jump in the IDEO. In addition, it seems to foster competition among these wounded athletes, further incentivizing the rehabilitation milestones.

We believe that the multidisciplinary approach of our program has played a role in our favorable outcomes. The beneficial effects of a multidisciplinary program is documented in the recovery of patients after injury; however, its role for the limb salvage patient has not been specifically analyzed.[12,13] The constant involvement among the orthopedic surgeon, physical therapist, and prosthetist allows a clear path for a patient's medical team to advance his rehabilitation. It also gives the patient the confidence that decisions are not being made in isolation and that the patient's concerns and goals are always considered first.

A novel element of our program is the standard issue of an energy storing orthosis, the IDEO, to our patients. To our knowledge, BAMC is the only facility to incorporate a device designed specifically to help restore ankle plantarflexion power to HELET patients. Although many innovative and adaptive prosthetics have been created for the amputee population, few options have been available to the limb salvage patients with deficits in ankle strength, motion, stability, as well as nerve damage or pain.[14] The custom patellar tendon-bearing design and the modular foot plate system allow the IDEO to unload specific segments of the lower extremity, whether the problem is a soft tissue injury or a hypesthetic area due to neuropathic pain. This allows us to bring most patients who have pain while weight-bearing to a near pain-free state. Once the patient can weight-bear with minimal pain, proper loading of the brace can occur, giving maximal energy return.

The IDEO also allows the performance of functional tasks with limited to no ankle and foot range of motion. Previously, limited or absent ankle and foot motion left little opportunity for running, sports, and military deployment. The IDEO relies very little on ankle mobility, providing energy return through the posterior strut, much like an amputation running prosthesis. Therefore, our patients with limited ankle mobility and ankle fusions are also able to return to these activities.

A limitation of this program is our homogenous patient population. Our patients are, in essence, moderate- to high-performance athletes. They are in an ideal social setting with essentially unlimited access to very specialized healthcare, world-class rehabilitation, and social work support. This is in stark contrast to the average HELET patient as described by MacKenzie et al.[15] Our relatively short follow-up time leaves the long-term ability to continue running and sports participation in this patient population unknown. Furthermore, the retrospective nature of these data is an inherent limitation.

Patients were progressed through the same rehabilitation program and brace in our pathway. The utilization of different rehabilitation approaches and bracing materials/designs may alter patient outcomes. Application of an aggressive rehabilitation program and the utilization of an energy storing orthosis warrant future investigation in the rehabilitation of limb salvage patients.

CONCLUSION

Application of a structured and aggressive rehabilitation program with a multidisciplinary approach including a specialized energy-storing orthosis allows lower extremity limb salvage patients to return to high levels of athletic activities.

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