A Unique Application of Negative Pressure Wound Therapy Used to Facilitate Patient Engagement in the Amputation Recovery Process

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Amputation rates during recent military conflicts were at an all-time high, but medical treatment of those amputations and attitudes of service members to get back to duty are also surging ahead. We present the cases of an active duty rescue C130 pilot with an above-the-knee amputation and a retired army sergeant with a below-the-knee amputation. Successful rehabilitation was augmented in both cases by using negative pressure incorporated in a custom prosthetic socket to accelerate incision closure, improve self-efficacy in wound care, and self-management, ultimately leading to faster recovery times, full engagement of the rehabilitation process, and return to active duty.

Keywords: amputation, wound, negative pressure

INTRODUCTION

SINCE THE ONSET of Operation Iraqi Freedom and Operation Enduring Freedom, there have been a staggering 1,631 major limb amputations among service members. Medicine is advancing in the care and survival techniques available for amputees, but advancing warfare technology is also causing more severe injuries. Amputation rates in the recent military conflicts have increased to an all-time high, while combat-related mortality rates have been decreasing.¹ There is an ever-present battle to preserve lives and help soldiers return to duty after injury if they so desire. In the most recent conflicts, return-to-duty rates have been the highest of any time in our history, but those rates are still very low at 18% for above-the-knee amputees and as

low as 3% for soldiers with multiple amputations.² Clearly, there is still much work to be done.

Shortly after the September 11, 2001, attacks on the World Trade Center, the United States Armed Forces Amputee Patient Care Program was started to care for the amputees from Operation Enduring Freedom and Operation Iraqi Freedom. Currently, the majority of military amputees are treated at either Walter Reed National Military Medical Center, San Antonio Military Medical Center, or Naval Medical Center San Diego.³ During this time of decreased battle injuries, it is crucial that the Department of Defense maintain their rehabilitation centers at full working preparedness should new conflicts arise. Aside from wartime injuries, many active

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duty military members sustain injuries off the battlefield. Statistics on U.S. service members from 2001 to 2011 showed the most common nonbattle-related amputations to be caused by either motor vehicle accidents or gunshot wounds.¹ The rehabilitation centers at each of the three major military medical centers can maintain medical readiness as we transition to an interwar period by serving as the regional referral centers providing continued superior amputee care to all military members sustaining an amputation. New therapy and technology are being tested and researched every day at these facilities to maximize our ability to return these injured service men and women to duty after amputation.

One positive contributing factor to amputees' successful recovery and their ability to return to duty is their self-efficacy. Self-efficacy is defined as a person's confidence about being able to perform specific tasks or life activities.⁴⁻⁶ Multiple factors contribute to a positive self-efficacy, such as a rehabilitation program that teaches adaptive skills, decreased waiting time in returning to activity, and being in an environment with others who are successful on a similar process. Having a well-designed program that introduces adaptations to preinjury activities can have a significant impact on the patient's confidence. In patients who sustained a high-energy lower extremity trauma, having low self-efficacy was a predictor of a poorer score for the sickness impact profile regardless of whether patients underwent limb salvage or amputation.⁷ Medical setbacks such as delayed wound closure and infections are large contributors to decreased self-efficacy and must be prevented or minimized. Last, continued forward progress in a patient's recovery is very important. Gradual improvements, even small, contribute to increased self-efficacy, whereas plateaus in progress or medical setbacks cause patients to become frustrated and impatient, losing confidence in their own recovery.⁸

Negative pressure wound therapy (NPWT) has been shown to be successful in stabilizing the wound environment, reducing wound edema, improving tissue perfusion, and stimulating cell growth at the wound surface. In addition, it is commonly used to treat slow healing wounds and complex surgical incisions.^{6,9,10} We present the novel concept of utilizing NPWT incorporated into a removable rigid prosthetic cap to decrease wound healing time and thus promote self-efficacy through encouraging active patient participation in the rehabilitation process. What makes this technique unique is that it allows the patient to continue progressing in rehabilitation while simultaneously aiding in the closure of their wound.

In the past, patients with delayed wound healing would wait weeks to months for complete incision wound closure before beginning prosthetic training, a delay that can now potentially be reduced. Similar approaches have been demonstrated to achieve success in encouraging wound healing of the residual limb.^{11,12} In 2011, Sumpio *et al.* used NPWT as a postoperative dressing modality for below-knee amputation wound closure.¹³ Unlike our approach, the NPWT was used as a postsurgical dressing in patients with chronic venous insufficiency of Charcot Disease. The wound vac was placed over closed fascia to condition the open skin of the stump for successful closure. There was no protective cap incorporated, nor was the patient in direct control of utilization of the NPWT. Our technique is simple and does not require the same level of professional intervention and monitoring as traditional NPWT. That being said, the NPWT cap, as we describe, is best applied when the patients have the cognitive ability to don and doff the device, apply vacuum to the system, and self-dress their wounds. It would not be recommended for large surface area treatment and was only utilized on traumatic wounds with otherwise healthy vascular patients.

CASE PRESENTATION 1

A 28-year-old active duty Air Force HC-130 pilot was injured when a motor boat ran her over while paddle boarding. She was evacuated to a nearby hospital. She sustained a traumatic above-the-knee amputation upon injury and had a tourniquet applied at the site of injury. She underwent completion amputation on the day of injury due to a mangled lower right extremity. Repeat debridement occurred 2 days after the injury before transfer to a Military Hospital. Six days after the initial accident, she underwent revision of her transfemoral amputation, including definitive wound closure. Her postoperative course was uneventful except for delayed wound healing at two locations: centrally and laterally each measuring ~1.5 cm long by 1 cm deep and 3 cm long by 0.25 cm deep. These two wounds were slowly healing with traditional wet-to-dry dressings, but impeding progress toward prosthetic limb fitting and further rehabilitation. The patient was participating in daily physical therapy, but had yet to undergo prosthetic fitting due to her slowly healing wounds (Fig. 1).

To proceed with rehabilitation and after waiting 4 weeks from the incision closure in surgery, we elected to incorporate NPWT into a custom removable rigid limb protector.

Figure 1. Case Presentation 1: incision and wound dehiscence.

She was treated for ~3 weeks with this modification, allowing her to participate in more rehabilitation activities while protecting the unclosed incision during the wound closure time (Fig. 2A). She was able to do activities such as sled-ice hockey and hand cycling without fear of injury to the open wound. Her NPWT prosthesis was discontinued when her wounds healed enough to be casted for her first temporary prosthesis. She was able to take her first steps on her prosthesis at 7 weeks, and the wounds completely healed at 9 weeks postoperative.

CASE PRESENTATION 2

A 23-year-old Army Sergeant was injured when he sustained an improvised explosive device blast on June 27, 2008, resulting in multiple surgical procedures, including ORIF of his right closed

medial malleolus fracture, right closed talus fracture, and external fixation and ORIF of his left tibial plateau fracture and open tibial pilon fracture. Seven months after his surgical repair, the patient was diagnosed with having osteomyelitis in his left lower limb, resulting in hardware removal, distal tib/fib ostectomy, partial tibial osteotomy, and subsequent Taylor spatial frame placement (Fig. 3A). Eighteen months later, the Taylor spatial frame was removed, and a left ankle fusion was performed (Fig. 3B). He developed an asymptomatic nonunion, but following a motor vehicle collision in 2014, the patient's hardware broke and he developed pain at the nonunion site (Fig. 3C). A year later, due to increasing pain and limited mobility, the patient elected to pursue amputation of his left lower extremity. The patient underwent a left transtibial amputation on October 14, 2015 (Fig. 3D). His postoperative course was also complicated by delayed incisional wound healing.

His incision was still not completely closed more than 8 weeks after the operation (Fig. 4). The decision was made at that point to aid his wound closure with an NPWT device incorporated into a custom removable rigid limb protector so that the patient could continue physical therapy and progress toward prosthetic fittings (Fig. 5A). He was treated for ~7 weeks with this modification. His NPWT prosthesis was discontinued when his wounds healed enough to be casted and begin prosthetic training.

PHYSICAL THERAPY OUTCOME ASSESSMENT CASE 1

The main goals of prosthetic rehabilitation are to achieve appropriate residual limb skin tolerance in

Figure 2. Case 1: NPWT device in use by the patient. The pump is removed once desired vacuum is achieved. **(A)** NPWT device for AKA. NPWT, negative pressure wound therapy.

Figure 3. (A) Case 2: Anteroposterior radiograph of the left tibia/fibula after osteomyelitis infection, resulting in initial hardware removal, distal tib/fib osteotomy, partial tibial osteotomy, and Taylor spatial frame placement. (B) Anteroposterior radiograph of the left tibia/fibula after hybrid fusion nail. (C) Lateral radiograph after car accident, resulting in a nonunion fracture of the hind foot and broken fusion nail hardware. (D) Anteroposterior radiograph of the left tibia/fibula after below-knee amputation using the ERTL technique.

the socket as well as proper functionality and trust of the prosthetic device. This is accomplished as part of a typical therapeutic program, which includes incremental increases in wear time while navigating uneven terrain, ascending/descending stairs and ramps, agility drills, proprioception activities, and cardiopulmonary reconditioning with the prosthesis.

The highest indicator of functional postamputation success is the activity level of the patient before amputation.¹⁴ This suggests that a highly active patient will demand higher functional goals to return to their previous levels of activity. To complete the first patient's job-specific duties, she was able to

learn to ascend/descend the plane, HC-130, steps of at least eight inches in height, extend the prosthetic limb with the force required to depress the rudder pedal of the plane, run 1.5 miles in less than 14 min, and maintain stable position during free fall when parachuting with the prosthesis.

This patient was expressing significant frustration with her lack of progress and inability to proceed with the prosthetic fitting. As the NPWT was introduced, the patient was also given instructions for use and asked to keep an informal log of her wear time and at what level she found the vacuum to be comfortable for use. She later stated how being given tasks associated with the NPWT gave her

Figure 4. Case Presentation 2: incision and wound dehiscence.

a sense of empowerment and control of being a partner in the progression of her rehabilitation. This technique not only accelerated wound healing but also engaged her in her own treatment.

To return to her predetermined hobbies, she was also able to learn to stand on a paddleboard, maintain an upright position while wakeboarding, swim underwater with and without a prosthesis, enter and exit the water while wearing dive equipment, and accurately bat and field as part of a softball team. At 6 months postamputation, she completed the Army Ten-Miler Race in Washington D.C. At a year and a half after her amputation, she returned to full flying status as a C-130 Pilot.

At 6 months postamputation, the patient was tested and was able to demonstrate an amputee mobility predictor–prosthetic (AMPPRO) score of 46/47, essentially a perfect score.¹⁵ She also achieved a total comprehensive high-level activity mobility

predictor (CHAMP) score of 19/40, with an average total score of 19.7 ± 3.3 for unilateral transfemoral amputees.¹⁶ Ultimately, the patient would be considered within normal limits for three of the four measurements and slightly less than typical with the Edgren Side Step Test (Table 1).

PHYSICAL THERAPY OUTCOME ASSESSMENT CASE 2

Rehabilitation of patients with amputations is dependent upon the psychological adjustment process and motivation of the patient.¹⁷ In this particular case, the patient had decided to amputate after a complicated limb salvage process. Patients undergoing limb salvage secondary to a combat injury may not experience an improvement in their mental health after amputation.¹⁸ Length of time using a prosthesis is negatively correlated with general psychiatric symptoms. In other words, the faster a patient is able to stand with a well-fitting prosthesis and maintain standing in that limb, the better their well-being could become.¹⁹ Incorporating the NPWT allowed the patient to decrease wound healing time and promote socket tolerance, thus allowing him to return to his previous level of function in less time than anticipated. The NPWT was utilized in an effort to improve the patient's well-being and motivation postamputation after limb salvage.

To return to his predetermined activities, the patient was able to learn to stand for 8 h in preparation for an occupation in criminal justice, use prosthesis to engage a pedal as necessary to drive a stick shift vehicle, navigate safely over even and uneven ground while carrying a load to care for his daughter, walk 7 miles for the Bataan Memorial Death March Event, and complete the Army Ten-Miler Race.

At 5 months after the amputation, the patient was able to demonstrate an AMPPRO score of 45/47, presenting at a K4 level. He also achieved a total CHAMP score of 25.5 at 6 months postamputation compared with an average total score of 26.8 ± 5.4 for unilateral transtibial amputees. See individual case scores and study averages in Table 1.

TECHNIQUE

Once the decision was made to take this approach, the patient's residual limb was casted with 3" fiberglass (Delta-Lite Conformable Fiberglass Cast Tape, BSN Medical, Inc., Rutherford College, NC) in a circumferential wrapping technique. A negative impression was obtained from the distal end of the transfemoral limb up to, but not

Figure 5. NPWT device for BKA.

Table 1. Average CHAMP test scores for TTA (unilateral transtibial amputation) and TFA (unilateral transfemoral amputation) among active duty army service members accompanied by Case Presentation 1 and Case Presentation 2 CHAMP scores

	Single Limb Stance (sec) (Amputated Side)	Single Limb Stance (sec) (Intact Side)	Single Limb Stance Total (Both Sides)	Edgren Side Step	T Test	Illinois	Total CHAMP Score
Average TTA $\pm$ SD			32.0 $\pm$ 11.4	18.8 $\pm$ 4.5	17.2 $\pm$ 7.7	23.9 $\pm$ 6.6	26.8 $\pm$ 5.4
Average TFA $\pm$ SD			29.9 $\pm$ 5.1	12.7 $\pm$ 2.7	27.7 $\pm$ 6.0	38.6 $\pm$ 7.7	19.7 $\pm$ 3.3
Case 1 (TFA)	3	30	33	14	31.82	40.04	19
Case 2 (TTA)	4.41	2.35	6.75	24	16.04	24.90	25.5

CHAMP, comprehensive high-level activity mobility predictor; TFA, transfemoral amputation; TTA, transtibial amputation.

including, the ischial tuberosity. The transtibial limb was casted circumferentially to the distal third of the patella. The negative impression was then filled with molding plaster to produce a positive model of the residual limb. This model was reduced 1.5% in circumference to provide slight compression on the residual limb when applied. Vivac™ (Southern Prosthetic Supply, Alpharetta, GA) plastic in 4 mm thickness was then vacuum formed over the model and once cooled, was removed and trimmed in preparation for fitting. The transfemoral cap was trimmed 1.5" below the ischial tuberosity. The transtibial cap was trimmed to standard patella tendon bearing prosthesis trim lines. A valve fitting and one-way expulsion valve (Otto Bock USA, Austin, TX) were then attached at the anterior distal 1/3 of the cap. A suspension sleeve was adhered to the proximal third of the cap to maintain an airtight seal when donned. Donning procedure occurs as follows:

1. Apply dressing to the wound and secure.
2. Apply a single-ply sock over the residual limb (Knit-Rite, Inc., Kansas City, KA).
3. Don the suction cap and roll the liner onto the exposed skin of the residual limb proximal to the cap.
4. Attach the VitiVac hand pump (Lincoln, St. Louis, MO) to the valve and evacuate the air in the cap.
5. Apply $\sim$ 15 inhg to the system and remove the pump.
6. Vacuum will be maintained until air is purposely (or inadvertently) introduced to the system.

The patients were advised to wear the device as often as they could tolerate it throughout the day and at night if tolerable while sleeping. The device should be worn as a new patient would wear a new suction suspension prosthesis, gradually acclimating to the pressure instead of constant wear as in a normal wound vacuum. In our cases, both patients reported progressing the wear time until

they wore the cap up to 18 h a day and removed it only for sleeping. Whenever the cap was removed, they were instructed to reapply their residual limb compression garment. In both cases, the cap was removed and reapplied multiple times throughout the day.

DISCUSSION

In the presented cases, the NPWT incorporated into a prosthetic cap allowed the wounds to close in 3 weeks for the above-the-knee amputee and in 7 weeks for the below-the-knee amputee. During this period, the patients were able to continue doing physical therapy exercises without fear of injuring their wound and began adjusting to wearing a prosthetic device full-time. By the time the patients were fit for their first prosthesis, they were well acclimated to the feeling of constant pressure they would have on their residual limb. NPWT has been shown to be successful in reducing wound edema, improving tissue perfusion, and stimulating cell growth at the wound surface, all of which occurred while the patient continued training and started prosthetic conditioning.^{6,9,10} Patients noted that the negative pressure keeps the sides of the wound suctioned together more than a typical wound dressing would, further promoting healthy tissue adherence and wound closure.

The most important effect of utilizing this NPWT-incorporated removable rigid prosthetic cap was that it allowed the patients to maintain their self-efficacy or confidence in their ability to perform tasks. Self-efficacy is promoted by continued progress in rehabilitation, including gradual improvements even if they are small, whereas plateaus in progress caused by wound closure setbacks decrease self-efficacy. In highly motivated service members who are looking to return to duty, self-efficacy many times will determine their success in returning to duty. To date, there have been five Air Force pilots who returned to active duty after lower limb amputations, including three above-the-knee amputees and two below-the-knee amputees. The pilot in this case report also

returned to duty and has now officially returned to the cockpit as the first female above-the-knee amputee pilot. The patient with the below-the-knee amputation completed both the Bataan Memorial Death March and the Army 10-Miler Race within the first year after amputation. The latest return-to-duty rates for soldiers are 18% for above-the-knee amputees, 22% for below-the-knee amputees, and as low as 3% for soldiers with multiple amputations.² This device has the potential to improve these rates among the highly motivated active duty populations. It can also impact the lives of medically retired service members who are looking to go back to an active lifestyle.

CONCLUSION

This case demonstrates the success of the NPWT device incorporated into a removable rigid prosthetic cap to promote wound closure, continue rehabilitative progress, and promote self-efficacy. Further research is needed to determine exact wound closure time periods and effects of the device. We propose that it be considered for amputees with incision closure difficulties to promote wound healing and initiation of prosthetic training.

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Abbreviations and Acronyms

AMPPRO = amputee mobility predictor, prosthesis
 CHAMP = comprehensive high activity
 mobility predictor
 NPWT = negative pressure wound therapy
 TFA = transfemoral amputation
 TTA = transtibial amputation