Abstract: The role of negative pressure wound therapy (NPWT) in below knee amputation (BKA) stump closure is not well described. The purpose of this series was to analyze morbidity outcomes, particularly related to dehiscence, of BKAs treated with postoperative NPWT prior to definitive closure. Methods. Medical records were retrospectively reviewed from six patients with large diameter legs due to chronic venous insufficiency of Charcot disease, who underwent a BKA and received postoperative NPWT between April 2006 and December 2008. NPWT was applied as a postsurgical dressing over closed fascia to help condition the open stump for successful closure. Mean patient age was 56 years. The average hospital stay after BKA was 10 days (range, 6–15 days). Average duration of NPWT was 7 days (range, 4–9 days).

Results. All patients survived to discharge. Complete reepithelialization and healing of the stump averaged 84 days (range, 39–182 days) following initial placement of NPWT. Patients were casted for prosthesis in an average of 90 days (range, 42–187 days). The average follow-up time was 311 days (range, 210–440 days). None of the wounds dehisced or required repeat procedures during follow up. Complete wound closure was achieved in all cases, and no local or systemic complications were recorded for any of the patients.

Conclusion. This experience suggests that early, short-term application of NPWT may be a valuable adjunct in BKA stump closure.

Healing of postoperative below-the-knee amputation (BKA) wounds has always been a challenge, particularly in cases of compromised circulation. Reported primary healing rates for BKAs vary widely, from 30% to 92%, with a reamputation rate of up to 30%. One study concerning lower limb amputation found that the most common stump-related complications were wound infection and poor healing (70%), poorly fashioned stumps (20%), and phantom pain (10%).

Lower extremity amputation, one of the oldest known surgical procedures, is still commonly performed even in hospitals with aggressive revascularization programs for limb salvage. It is unavoidable in many cases of uncontrollable soft-tissue or bone infection, nonreconstructable disease...
with persistent tissue loss, or unrelenting rest pain due to muscle ischemia.

Despite advances in technology and surgical techniques, the number of amputations in the United States is rising due to increased incidence of diabetes and peripheral vascular disease (PVD) in an aging population. In the United States, 30,000–40,000 amputations are performed annually. In 2005, an estimated 1.6 million individuals were living with the loss of a limb; by the year 2050, it is estimated this number will more than double to 3.6 million.5

The effects of previous surgery, altered anatomy, muscle and bone atrophy, and aerobic deconditioning are important variables in predicting the success of amputation surgery. Improvements in amputation surgical technique and surgical decision making have resulted in fewer complications and better rehabilitation, but the optimal postsurgical dressing management system continues to be debated.

In the authors’ practice, we have been applying negative pressure wound therapy (NPWT) as a postsurgical BKA dressing over closed fascia in patients who have large lower extremities, due to Charcot disease-related chronic venous insufficiency, to help condition the open stump for successful definitive closure. Literature has shown a reduction in postoperative inflammation, stump edema, and incidence of wound dehiscence, as well as increased granulation tissue formation with adjunctive use of NPWT.6–9 The authors’ goal with this technique has been to employ the mechanisms of NPWT early in the process of wound healing to enhance longer-term closure rates. The purpose of this case series was to analyze morbidity outcomes, particularly related to dehiscence and longer-term closure, of BKAs treated with temporary NPWT prior to definitive closure.

**Methods**

This retrospective analysis was approved by the institutional review board of Yale University School of Medicine in New Haven, CT. Records of patients with a single BKA stump who received NPWT between May 2006 and April 2008 were randomly selected and analyzed.

All patients had vascular insufficiency, including arterial or venous insufficiency, and were treated with a similar protocol. Chronic conditions were treated with conventional methods of treatment including arthrodesis and split-thickness skin graft while awaiting spontaneous closure (Table 1). After failure of conventional treatment...
methods, patients were referred to the vascular surgery service for potential BKA. Satisfactory vascular status of the legs following Doppler examination was required prior to amputation. All patients also received consultation with an internal medicine specialist for evaluation of the patient’s general health and any cardiovascular disease, as well as control of diabetes mellitus, if appropriate.

Under general or epidural anesthesia, the BKA was performed utilizing a posterior flap incision. The flap was well irrigated with antibiotic containing normal saline solution. A large Jackson-Pratt drain was placed into the lateral aspect of the wound and the fascia was then closed using interrupted 2-0 Vicryl sutures. The subcutaneous wound was irrigated with sterile normal saline with the pulse irrigation system to ensure removal of all contaminants, and until it appeared local hemostasis had been achieved.

Although the fascia remained closed, the skin was left open (Figure 1) and the NPWT dressing was applied intraoperatively to the area over the closed fascia (Figure 2). The NPWT system includes a reticulated open cell foam (ROCF) dressing, adhesive drape, pressure-sensing pad (Sensa T.R.A.C.™ Pad, KCI Licensing, Inc, San Antonio, TX), evacuation tubing, collection canister, and a software-controlled therapy unit responsible for generating the negative pressure. Continuous therapy is recommended to provide a constant bolster, with a target pressure range between 75 mmHg-125 mmHg. The unit regulates negative pressure to ensure safe delivery of the prescribed therapy setting as well as consistent distribution of pressure across the wound surface.

The ROCF (V.A.C.® GranuFoam™, KCI Licensing, Inc., San Antonio, TX) was placed directly over the wound and covered with a transparent adhesive drape. The Jackson-Pratt drain remained in place for at least 24 hours or until drainage was less than 50 mL/8 hours to evacuate fluid and prevent hematoma in the deep space. Subatmospheric pressure of -125 mmHg was initiated. Surgeons ensured compression of the foam to confirm a sealed environment and proper function of the negative pressure device. The dressing was changed every 72 hours, and the condition of the wound bed was reassessed at that time. NPWT was discontinued after confirmation of at least 90% granulation tissue at the wound base. The stump wound was then dressed with conventional dressings until closure via secondary intention.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Sex</th>
<th>Preoperative Diagnosis</th>
<th>PVD</th>
<th>DM</th>
<th>HTN</th>
<th>Vascular insufficiency</th>
<th>Stump area (cm²)</th>
<th>Duration of NPWT (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>Male</td>
<td>Left metatarsal amputation stump, nonhealing ulcer</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>30.1</td>
<td>4</td>
</tr>
<tr>
<td>63</td>
<td>Male</td>
<td>Left ankle disarticulation ulcer for a nonhealing infected ulcer</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>40.2</td>
<td>6</td>
</tr>
<tr>
<td>73</td>
<td>Male</td>
<td>Left leg osteomyelitis</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>33.9</td>
<td>8</td>
</tr>
<tr>
<td>59</td>
<td>Male</td>
<td>Left Charcot foot with nonhealing ulcer</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>37.5</td>
<td>7</td>
</tr>
<tr>
<td>49</td>
<td>Male</td>
<td>Left Charcot foot with osteomyelitis and draining sinus</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>36.4</td>
<td>9</td>
</tr>
<tr>
<td>57</td>
<td>Male</td>
<td>Left heel osteomyelitis with severe infection</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>35.0</td>
<td>6</td>
</tr>
</tbody>
</table>

PVD: Peripheral vascular disease  
DM: Diabetes mellitus  
HTN: Hypertension
Hospital stay, duration of NPWT, time to closure, closure rate, and follow-up period were recorded for each patient based on chart review. Averages were then calculated for the series.

**Results**

A total of six patient records were analyzed. Preoperative diagnoses of all patients are listed in Table 1. The mean age was 57.7 years (range, 45 to 73 years) and all patients were male. The average wound size before NPWT was 35.5 cm² (range, 30.1 cm² to 40.2 cm²).

The average hospital stay after BKA was 10 days (range, 6 to 15 days). Average duration of NPWT use was 6.7 days (range, 4 to 9 days). All six patients survived to discharge. Complete reepithelialization and healing of the stump averaged 84 days (range, 39 to 182 days) following initial placement of NPWT. Patients were casted for prosthesis in an average of 90 days (range, 42 to 187 days). The average follow-up time was 311 days (range, 210 to 440 days).

**KEYPONTS**

- BKAs were performed utilizing a posterior flap incision. Although the fascia remained closed, the skin was left open (Figure 1) and the NPWT dressing was applied intraoperatively to the area over the closed fascia.
- NPWT was discontinued after confirmation of at least 90% granulation tissue at the wound base.

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**KEYPONTS**

- All six patients survived to discharge. Complete reepithelialization and healing of the stump averaged 84 days following initial placement of NPWT.
- None of the wounds dehisced or required repeat procedures during the follow-up procedure.
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**Discussion**

Closure was achieved throughout follow-up in all stumps in the present series, even in the presence of venous insufficiency or Charcot disease. Delayed sutured closure was not considered in any of the cases since the wounds had sufficiently granulated and contracted to avoid further surgical intervention after a relatively short duration of NPWT. The authors have found in most cases that closing the fascia brings the skin edges close enough that the application of NPWT contracts the wound quickly. Although it is impossible to determine the exact mechanisms of action within this small, uncontrolled pilot study, the authors propose several contributing factors. Particularly in patients with PVD who are already at risk for delayed wound healing, in addition to their large leg due to venous congestion, the dynamic nature of the NPWT dressing system may play an important role during the inflammatory phase by distributing equal pressure across the wound and constantly evacuating excess interstitial fluid.

Since the majority of amputations are carried out because of ischemia, this patient population is particularly susceptible to the development of tissue necrosis due to poor tissue perfusion. Unevenly distributed or excessive pressure from conventional dressings, when used in large edematous legs, can lead to further limb strangulation or tissue necrosis—if not evacuated, postoperative local accumulation of blood can distend the tissues enough to compromise local vascularity, cause pain, and form a nidus for infection. NPWT causes a decrease in soft tissue swelling, encourages essential inflow and outflow, and allows transport of oxygen and nutrition to the wound bed while clearing inhibitory factors. The uniform mechanical stress applied to the wound results in positive growth factor production needed during wound healing, and is known to stimulate proliferation of generative cells and granulation tissue formation to condition the wound for successful closure. NPWT also facilitates easier and less frequent dressing changes, which reduces pain and anxiety.

Recent evidence also suggests NPWT may be particularly beneficial in the earlier stages of wound healing. One study showed levels of tumor necrosis factor-alpha (TNF-α), a proinflammatory cytokine, decreased in wound fluid from adults with chronic pressure ulcers treated with NPWT over a 7-day period. In a swine model, Kilpadi et al demonstrated earlier and greater increases in serum levels of IL-10 and maintenance of IL-6 compared with saline-moistened gauze controls during the initial 4 hours following creation of an excisional wound. Systemic effects related to NPWT in another porcine wound healing model included post-wound reduction in the number of peripheral blood monocytes and neutrophils during the inflammatory phase of wound healing, as well as changes in certain proinflammatory cytokines present in serum compared to the control group. Considerably more controlled research is needed to further elucidate the effects of NPWT on the inflammatory response associated with wound healing.

In the authors’ experience, many of the complications associated with lower extremity wounds, such as hemorrhage and mild exudate, can be managed with conventional dressings. Hemorrhage can be prevented by a pressure absorbency dressing. Conversely, the authors have found that tissue necrosis, dehiscence, bone erosion/osteomyelitis, postoperative inflammation, stump edema, and pain and anxiety at dressing changes are best controlled with adjunctive NPWT, in addition to drains.

Since conducting this pilot study, the authors have incorporated short-term NPWT into our post amputation treatment algorithm for high-risk patients (Figure 3). Prior to NPWT use, the authors experienced that use of any conventional stump management dressing required a longer period for wound bed preparation. Other studies have reported more timely delayed closure with NPWT versus conventional dressings. Sepulveda et al reported in a controlled study a 40% reduction in time to reach 90% granulation of diabetic amputation wounds with NPWT versus standard wound dressings.

Still, there remains a paucity of clinical criteria for decision making regarding postoperative dressings, somewhat due to variability in comparative study parameters and a lack of definitive evidence. Surgeons have yet to uniformly adopt a particular post amputation dressing technique, yet many have steered away from sole use of soft dressings, which are limited by their inability to control postoperative edema.

Successful management of a patient’s wound at or distal to the knee includes accurate site assessment, meticulous debridement, and planning and execution of a reasonable operative procedure. Major goals of post amputation dressing and management strategy are to im-
prove wound healing, control pain, allow early prosthetic fitting, and enable a rapid return to function. Strategic goals include preventing knee contractures, reducing edema, protecting from external trauma, and facilitating early weight bearing.

Reported usage of NPWT for temporary postoperative coverage of complex extremity wounds has become widespread during the past decade. DeCarbo et al recently reported on short-term postoperative use of NPWT over tenuous incisions used to perform total ankle replacement and to open reduce and fixate joint depression fractures of the calcaneus, in an attempt to reduce risk of infection and dehiscence.

Use of NPWT in diabetic foot wounds, including those secondary to amputation, is also fairly well reported. A randomized controlled trial (RCT) evaluating healing rates after partial foot amputation in 162 patients with diabetes reported a faster time to closure and rate of granulation tissue formation among the NPWT group, versus standard moist wound care (P = 0.005 and P = 0.002, respectively). The results of this RCT were further supported by Apelqvist et al’s follow-up economic analysis which showed that fewer reamputations occurred in the NPWT group, compared to the moist wound therapy control group, with all major amputations occurring in the control group.

Considerably less explored in the literature is the use of NPWT as a stabilizing postoperative dressing immediately following amputation. Instead, comparative postoperative amputation stump dressing studies have been focused on conventional postoperative dressings including soft dressings (with or without pressure wrap), semirigid dressings, rigid dressings (conventional or removable), and silicon or gel-liners. It is possible that the duration of hospitalization and overall treatment time might be shorter with NPWT than with conventional dressings, but larger randomized clinical trials are needed to validate this hypothesis.

This technique is not always successful and it is not indicated in the heavily contaminated wound bearing substantial amounts of devitalized tissue. All of the amputation sites in this series were noninfected. White et al described a case of arterial erosion and hemorrhage during use of NPWT. Surgeons should exercise caution when instituting NPWT and it should not replace adequate surgical debridement or antibiotic therapy. However, large extremity wounds of varying complexity have healed with use of NPWT, through either secondary intention or delayed closure via split thickness skin graft. If a lower extremity wound is clean, bony stability is present, and no vital structures are exposed, application of NPWT may be indicated. All of our subjects were assessed for these criteria before NPWT application.

This pilot analysis has all of the limitations of a descriptive, noncontrolled study. Lack of consideration of other factors in the analysis that are known to affect clinical outcome, such as amputation level selection, skill and surgical technique, extent of patient comorbidities, and physiologic factors also bias study results.

Conclusion

Although anecdotal, the presented closure data suggest NPWT may be an important tool with limited morbidity in aiding BKA stump closure in patients with large extremities due to chronic venous congestion or Charcot disease. Future comparative studies with consistently defined outcome measures, impact of complications, and measures of postoperative pain, as well as quantified healthcare use and rehabilitation costs are desirable and needed. These studies should include accurate documentation and control for variables such as amputation-level selection, surgical skill and technique, healing potential, comorbidities, nutrition, immune status, and functional ability to establish a definitive analysis.

Acknowledgements

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References

2. White SA, Thompson MM, Zickerman AM, et al. Low-


