Standard Review Article

OPEN

Negative pressure wound therapy: Where are we in 2022?

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Summary: The use of negative pressure wound therapy (NPWT) continues to be an important tool for surgeons. As the use and general acceptance of NPWT have grown, so have the indications for its use. These indications have expanded to include soft tissue defects in trauma, infection, surgical wound management, and soft tissue grafting procedures. Many adjuvants have been engineered into newer generations of NPWT devices such as wound instillation of fluid or antibiotics allowing surgeons to further optimize the wound healing environment or aid in the eradication of infection. This review discusses the recent relevant literature on the proposed mechanisms of action, available adjuvants, and the required components needed to safely apply NPWT. The supporting evidence for the use of NPWT in traumatic extremity injuries, infection control, and wound care is also reviewed. Although NPWT has a low rate of complication, the surgeon should be aware of the potential risks associated with its use. Furthermore, the expanding indications for the use of NPWT are explored, and areas for future innovation and research are discussed.

Keywords: wound vac, negative pressure wound therapy, soft tissue injury, infection, orthopaedic trauma

1. Introduction

Negative pressure wound therapy (NPWT) represents a mainstay in the management of soft tissue wounds associated with extremity trauma. In challenging clinical scenarios requiring soft tissue coverage, NPWT is an ideal temporizing measure allowing for isolation of the wound and preparing it for coverage. Once a wound is covered or closed, NPWT can also be used as an adjunct therapy to enhance skin graft survival and to augment healing of tenuous incisions. Because of its effectiveness and versatility, the use of NPWT has become ubiquitous in the management of extremity trauma, and the indications for its use continue to expand, outpacing the currently available body of evidence. The purpose of this review was to provide the orthopaedic trauma surgeon with a foundational understanding on NPWT as it will undoubtedly remain a necessary part of one's armamentarium in the treatment of complex extremity soft tissue injuries.

The authors declare no conflicts of interest.

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Source of funding: Nil.

OTAI (2023) e247

Received: 23 November 2022 / Accepted: 22 December 2022
Published online 11 July 2023

http://dx.doi.org/10.1097/OI9.0000000000000247

2. Components

There are 3 primary components that comprise the NPWT system: (1) an open-pore foam sponge, (2) a semiocclusive dressing, and (3) a negative pressure source.[1] The open-pore foam comes in 2 commonly used forms—a black polyurethane ether sponge and a white polyvinyl alcohol sponge. The black sponge contains larger pores that foster fibrovascular tissue ingrowth and thereby granulation tissue. White sponges have smaller pores which stimulate less ingrowth, making them more ideal for application over exposed nerves, vessels, or tendons.[2,3] The sponge can be customized by the surgeon to fit the unique shape of the wound bed, and a semiocclusive adhesive dressing is applied to seal the circuit. A suction pad and tubing are used to join the wound bed to the negative pressure source, a device containing a control panel which allows the user to adjust therapy settings and a canister to collect wound effluent.[1,4]

While the sponge, the adhesive, and the negative pressure source represent the core components of NPWT, the technology continues to evolve. Silver-impregnated sponges and fabrics have been introduced and been shown to be beneficial adjuncts to traditional NPWT, achieving lower bacterial colonization of wounds and reducing the number of debridement procedures and shortening length of stay.[5,6] For example, Silverlon, a fabric knit from silver ion coated fibers, can be safely applied by shaping the fabric to the shape of the wound bed and then applying the vacuum sponge over it. This can be left in place for up to 7 days according to manufacturer instructions, reducing the need for more frequent debridement procedures and shortening hospital stays.[6]

Another common modification involves the use of antimicrobial impregnated adhesive drapes to seal the wound. Pliable strips of these adhesive drapes can be customized to navigate difficult areas, such as external fixation pins (Fig. 1.), and may offer improved defense against bacterial colonization.[7] Moldable ostomy strip paste or gel adhesive dressings can also be used around external fixator pins before placing the adhesive drapes to improve the success of achieving a good seal. The seal can also be augmented with application of liquid adhesives such as Duraprep or Mastisol before placement of the adhesive drapes.

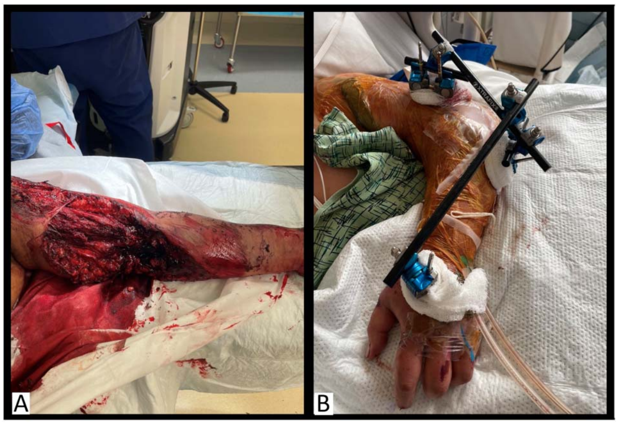

FIGURE 1. A, Wound vac application can be challenging in soft tissue injuries encompassing a large surface area, across flexion and extension surfaces, or when external fixation is needed and pins encroach the wound edges. B, The use of an antimicrobial adhesive drape can be used primarily or as an adjunct to the traditional semiocclusive dressing to achieve a seal around challenging anatomical structures and external fixation pins.

Additional techniques can be used to enhance wound contraction. One technique is to use vessel loops anchored at one end of the wound and then interlacing them sequentially along the edges of the wound or incision while securing them with staples along the length of the wound to generate a crossing pattern such as a shoelace or Jacobs ladder (Fig. 2). We recommend placing the foam sponge deep to the vessel loops. Combining the shoelace technique with NPWT may shorten time to closure than using either in isolation.[8]

2.1. Mechanisms of Action

There are multiple proposed mechanisms underlying the effectiveness of NPWT. These processes can be grouped into 2 general categories: macrostrain and microstrain.[1] The most robust evidence suggests that microstrain is the predominant mechanism and is produced through the generation of subatmospheric pressure in the wound environment, which then induces the mechanotransduction pathways. The mechanical stimulation of individual cells stimulates growth factor production, which in turn leads to cell proliferation, angiogenesis, and granulation tissue formation.[9] These downstream effects are potentiated by the interplay between negative pressure and

FIGURE 2 . Use of elastic vessel loops can be used to achieve tension free closure of challenging skin incisions. A, When a fasciotomy incision is unable to be closed primarily, B, the use of an interlacing elastic vessel loop and a NPWT system can assist in the approximation of the skin edges. C, Primary closure may be possible after using this method and is assisted with the use of clamps. (D) Closure can be achieved using a tension relieving suture in an interrupted pattern. If primary closure is unachievable, this method still allows for the formation of a healthy granulation tissue bed and reduces the surface area that might require split-thickness skin grafting.

the open pore sponge which behaves like a scaffold for fibroblasts and tissue ingrowth.[10]

Macrostrain is more of a mechanical process whereby negative pressure causes contraction of the foam sponge decreasing the surface area of the wound. The suction generated also leads to a reduction in interstitial tissue edema, removal of infectious debris and exudates, and changes in tissue perfusion.[11]

The occlusive dressing stabilizes the wound in a sealed environment. Because dressing changes need to occur less frequently with NPWT than with traditional dressings, the potential for contamination or colonization is diminished. Ultimately, the mechanism of action is multifactorial, and our understanding continues to evolve.

2.2. Types of Therapy

There are many variables that may be adjusted when applying NPWT to a wound. The 2 most commonly adjusted settings are the level of negative pressure applied and the therapy mode at which negative pressure is applied. Traditionally, most wounds are treated with a negative pressure of −125 mm Hg based on animal models that demonstrated optimal perfusion and granulation tissue formation at this pressure.[12] At negative pressure of −75 mm Hg, perfusion increases from baseline but is not as robust as at −125 mmHg. At negative pressures greater than −125 mm Hg, perfusion is depressed compared with that of −125 mm Hg, and at very high negative pressures (over −400 mm Hg), perfusion is impeded below baseline.[13] Based on limited evidence in humans, the optimal negative pressure is likely around −75 mm Hg to −125 mm Hg depending on the goals of therapy.[14]

The mode at which pressure is applied to the wound bed may also be controlled. The operator can typically choose between intermittent, continuous, and variable pressure settings. Intermittent pressure is associated with enhanced granulation tissue generation, but patients may experience greater discomfort during the transition between pressure levels. For this reason, continuous pressure is more commonly used in the clinical setting. Variable pressure offers an alternative that generates similar quality of granulation tissue to that of intermittent pressure therapy while easing the transition between pressure states, which may be better tolerated by patients.[15]

3. Indications

Ultimately, there are an incredible number of applications and uses of NPWT for the management of various types of wounds. The type of therapy and materials should be tailored to each individual patient's clinical scenario.

NPWT can be applied to soft tissue problems where wound stabilization, contracture, and drainage are desired to improve the soft tissue environment for healing. In orthopaedic trauma, indications for NPWT use include temporary open fracture coverage, closed incision NPWT, infection control, and split-thickness skin grafting.

The use of NPWT is commonly used in the setting of an open fracture to prevent infection and stabilize the wound environment for subsequent coverage procedures. A significant reduction in the rate of deep infection has been shown when comparing NPWT with conventional dressings in severe open fractures.[16] This finding was further supported by a recent meta-analysis evaluating the effectiveness of NPWT on infection prevention in open fractures temporarily covered with NPWT as opposed to conventional dressings.[17] A secondary benefit to the use of NPWT in open fracture care is the significant reduction in the rate of subsequent coverage procedures, skin grafting, and flap failures.[17]

Incisional NPWT use has gained popularity where primary closure can be achieved over high-risk fractures, tenuous incisions, or traumatized soft tissues. Incisional NPWT demonstrates lower rates of wound complications particularly dehiscence, infection, hematoma, and seroma formation.[18–20] The reduction in the infection rate can be profound and has been reported to be as high as 40% in 1 recent meta-analysis.[21] Incisional NPWT involves the application of nonadherent dressings to a closed surgical incision before placement of the foam sponge (Fig. 3). This protects the skin around the incision from excoriation by the polyurethane foam while reducing edema and increasing perfusion at the wound edges. Alternatively, the standard black sponge can be placed directly on the skin incision, but it must be removed within 72 hours to prevent ingrowth. Various single-use proprietary incisional NPWT systems have entered the market making the ability to apply incisional NPWT easier and more accessible. Incisional NPWT can be used in postamputation care and has been shown to be effective in minimizing stump dehiscence, infection, and hematoma.[22]

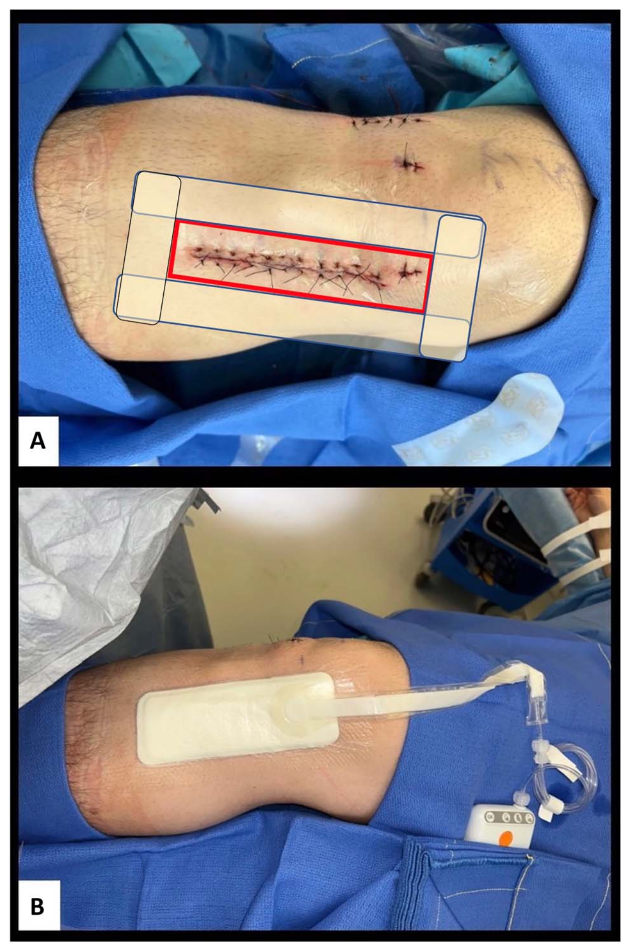

FIGURE 3 . Application of a single-use incisional wound vac system. A, Using the supplied nonocclusive adhesive tape provided in the kit (tan) a 2–3-mm margin of the peri-incisional skin (red) along the periphery of the incision is left exposed. The tape provides a barrier to the vacuum sponge to prevent maceration and injury to the healthy surrounding skin. B, A single-use motorized vacuum pump and absorbent occlusive sponge are then applied. The pump is activated, and suction is verified. The patient can be sent home with the manufacturer insert and counseled on the operation of the device, signs of malfunction, and when to remove it.

NPWT has been used and found to be a useful adjunct in skin grafting survivorship. When applied over split-thickness skin grafts, survivorship and integration of the graft were shown to be superior to conventional dressings. There was also a lower relative risk of reoperation and shortened hospitalizations.[23] However, in low-risk wounds covered with split-thickness skin grafts, successful healing is similar with NPWT compared with traditional bolster dressings.[24]

4. Contraindications/Complications

NPWT is overall a safe intervention, but surgeons should be hesitant to use NPWT in certain clinical situations and be aware the complications associated with its application (Table 1). NPWT can be used to achieve acute stabilization of an injury involving devitalized soft tissue and bone, but the surgeon must be aware of its ineffectiveness in achieving secondary closure through granulation tissue formation in a wound bed where devitalized bone striped of its periosteum, exposed surgical implants, or other nonvascularized structures such as tendons exist.[25] If the treating surgeon lacks familiarity and experience in soft tissue coverage procedures, then early involvement of the plastic surgery team is advised. Experimental animal studies have shown that fat grafting or grafting with collagen scaffolds over these nonvascularized structures first may allow for viable granulation tissue formation, but these techniques have not yet been fully developed in clinical practice.[26,27]

Surgeons should be hesitant to apply NPWT directly to sensitive anatomical structures such as exposed nerves, vessels, or eviscerated organs. This can lead to ischemic necrosis of these sensitive tissues or erosion through blood vessel walls leading to massive, sometimes fatal hemorrhage.[25] Transposing these structures out of the traumatic wound bed, rotating healthy soft tissue over them, or using a saline-soaked polyvinyl alcohol sponge (white sponge with an increased pore size of 60–270 μm) can help prevent tissue ingrowth of these sensitive structures into the black sponge and help avoid injury to them.[4]

In high-energy blast injuries, there is some evidence to suggest that the use of NPWT may be a risk factor for the development of heterotopic ossification (HO). In the conflicts of Iraq and Afghanistan, it was observed that the NPWT was an independent risk factor for HO development in extremity blast injuries. However, this was a small retrospective study with small sample size. Furthermore, injury severity and mechanism of injury may be the more influential risk factors when determining HO risk.[28] While further research has failed to demonstrate an association between NPWT and HO in the combat wounded, it has found an association with higher injury severity and level of wound bioburden and these combat casualties may be more likely to receive treatment with NPWT.[29]

Failure of the NPWT system from loss of seal, puncture, blockage of the drainage system, or power loss may produce a prolonged interruption of therapy, and this is associated with an increased risk of wound dehiscence and wound infection[30] making it important to properly educate care givers and patients on the importance of reporting early failures and how to manage them.

Clinicians should be aware of the pain, and psychological burden that prolonged NPWT has on their patients. In non-neuropathic, traumatic wounds, patients may experience moderate to severe pain at the time of NPWT exchange. Local anesthetic infusion through the NPWT system has been shown to reduce the discomfort of this procedure.[31] The use of NPWT can lead to patient anxiety and lower quality of life when compared with conventional dressing application and maybe poorly tolerated in certain patients for these reasons.[25]

TABLE 1

Considerations Before Negative Pressure Wound Therapy

Indications	Contraindications	Considerations
•Open fracture •Severe soft tissue injury •Infection control •Incisional/amputation care •Skin grafting	•Exposed neurovascular structures •Anastomosis in wound •Malignancy in wound bed •Necrotic devitalized eschar	•Circumferential injuries •Hand and foot injuries •Junctional injuries: axilla, groin •Exposed implants •Exposed bone and tendon

4.1. Application

There are several technical considerations when applying NPWT to traumatic extremity injuries. The ultimate goal is to obtain a fully occluded seal so that negative pressure can be applied without an interruption in therapy and to avoid injury to the healthy noninjured soft tissues.

First, the surgeon must create a decontaminated wound bed by thoroughly and systematically removing all contamination, debris, and devitalized tissues. If primary closure is achievable after debridement and can be performed without tension to the traumatized soft tissues, this is preferable to NPWT because early primary closure has demonstrated superiority to delayed closure in the prevention of deep infection.[32,33] When primary closure is not possible, early definitive fixation and closure achieved through rotational or free flap coverage has consistently been shown in the literature to be superior to delayed definitive soft tissue coverage.[34]

If primary closure is not achievable, significant contamination is present, or there is an evolving soft tissue injury where the surgeon anticipates the need to return for subsequent debridement or procedures, then NPWT should be considered. In assessing the wound, the surgeon should note the presence of exposed nerves, vessels, or bone fragments and plan on how to address these factors when applying NPWT. Specialized white sponges or rotation of subcutaneous tissue, fascia, or muscle may be used to provide a barrier between these delicate structures and the sponge to prevent injury to them.

Certain wound types can pose a challenge to the safe application of NPWT. Circumferential injuries can be difficult to achieve a vacuum seal during application, and the circumferential compression on the extremity from the NPWT could threaten distal perfusion. Available literature suggests that the application of a circumferential NPWT is safe, and O_2 saturations in the distal extremity can be maintained to >96% during prolonged application.[35]

The delicate anatomy of the hand and foot can make it difficult to achieve an appropriate seal and close the NPWT circuit. Often, the surgeon must make decisions on the appropriateness of NPWT over sensitive structures such as exposed bones and tendons, and care should be taken to protect nerves, arteries, veins, and vascular anastomosis or nerve repairs.[36] When the wounds extend into the web spaces of the digits, a pressure seal can be difficult to achieve; however, using a surgical glove over the hand may aid in leak prevention.[37]

5. Special Modalities

As the use of NPWT has expanded, newer adjuncts to traditional NPWT have been developed. NPWT with instillation (NPWTi-d) involves the cyclical instillation of topical solutions that irrigate the wound and dressing for a defined period of time (dwell time) and are then removed by suction. This process is termed NPWT with instillation (NPWTi-d) and relies on additional components—a storage vessel containing the topical instillation solution and a cassette with tubing that conveys the solution to the pressure sensing pad that is normally connected to the occlusive dressing. NPWTi-d also uses an updated reticulated open-cell foam sponge with 1-cm diameter holes dispersed 0.5 cm apart.[38] The surgeon can control the type of solution instilled, the dwell time, the duration of negative pressure, and the frequency of cycles. There are a variety of options for the instillation solution including saline, antimicrobials, and debridement solutions. Emerging evidence suggests that NPWTi-d offers superior outcomes to traditional NPWT with fewer

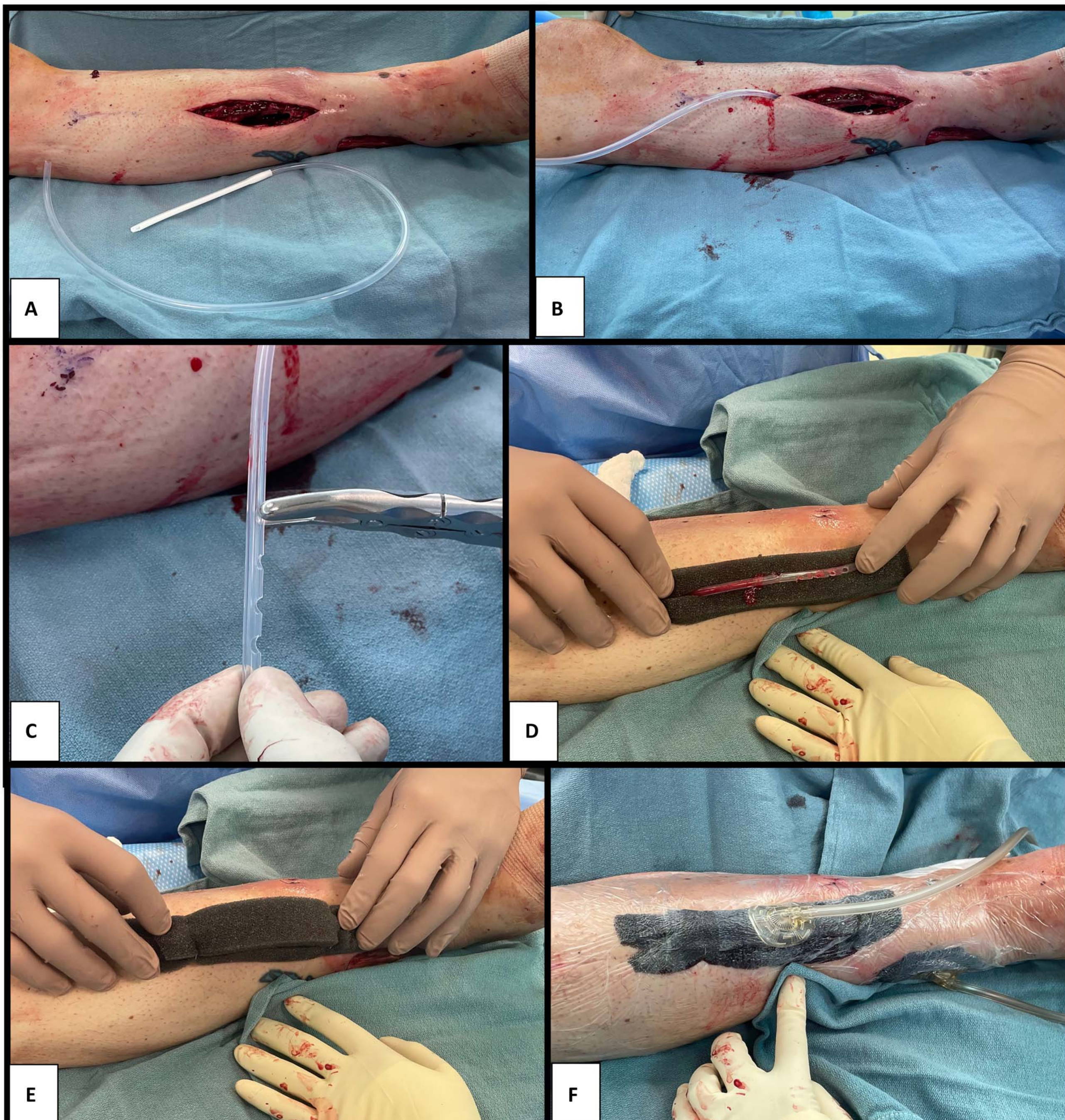

FIGURE 4. In this example, a 15 French, flat, fenestrated drain was used (A). The drain is placed in a similar manner to when used without incorporating into a NPWT dressing, but the exit point should be in close proximity to the incision to allow incorporation into the dressing. The authors prefer to have the drain come out through a stab incision in-line with surgical incision at either end of the incision (B). A small rongeur is used to "bite" out a series of holes within the tubing, so the suction applied to the dressing is applied to the drain (C). The incisional NPWT dressing is then applied, in this case, directly to the skin with the drain draped over the foam sponge (D), which is then covered by an additional piece of the foam sponge (E). Suction is applied allowing for a deep drain incorporated into the incisional NPWT dressing (F). The incisional NPWT dressing with the drain incorporated into it should be removed at no more than 72 hours postoperative when the black open-pore foam sponge is placed directly on the skin to minimize ingrowth.

debridement's, shorter time to wound closure, improved granulation, and a reduction in bacterial bioburden.[39] However, existing studies have predominantly focused on chronic and/or superficial wounds with little supportive research performed in wounds with associated fractures.

In grossly contaminated wounds, the surgeon may opt to use local antibiotic delivery methods with powdered antibiotics, bead pouches, or antibiotic cement spacers where gross contamination exists or there is a large bony void. Local antibiotics may also be advantageous in the event of loss of suction where the wound would subsequently be converted to an antibiotic bead pouch or similar wound environment.[30] The use of NPWT over these antibiotic delivery methods does not significantly affect the elution and concentration of antibiotics within the wound bed, and in an animal model, the use of these modalities in combination with NPWT significantly reduced the bacterial bio burden compared with NPWT alone.[40,41] Finally, the incorporation of a drain into an incisional NPWT dressing can also be used to help manage dead space. This is particularly useful in wounds that would otherwise be closed primarily, and a deep drain is desired (Fig. 4). In this example, the black open-pore foam sponge is placed directly on the skin with the deep drain incorporated into the dressing. Therefore, it should be removed no later than 72 hours postoperative to minimize tissue ingrowth into the sponge.

6. Conclusion/Discussion/Areas for Further Research

NPWT and NPWTi-d modalities represent a highly promising advancement in the treatment of traumatic wounds, infected wounds, and high-risk surgical incisions. Given their effectiveness in treating these complicated surgical situations and their proven effectiveness in minimizing hospital stays, number of surgical procedures, and increasing the success of graft survival all while reducing overall cost of care, it is not surprising that the use of NPWT has flourished across many surgical subspecialties. However, the currently available literature lacks specific guidance on the use of NPWT in challenging clinical situations such as in the presence of devitalized bone and tendons and exposed neurovascular structures. Regardless, NPWT continues to be a powerful tool in the surgeon's armamentarium when treating complex soft tissue injuries, infections, and high-risk incisions.

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