Negative Pressure Wound Therapy

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INTRODUCTION TO NEGATIVE PRESSURE WOUND THERAPY

Open wounds are regularly addressed in veterinary medicine and can be challenging to manage, especially when there is significant loss of full-thickness skin (Fig. 1). Injuries include traumatic anatomic degloving wounds, shear injuries, penetrations, avulsions resulting in physiologic degloving, envenomations, burns, necrotizing fasciitis or vasculitides, incisional dehiscences, and surgical wounds left open to heal by second intention. Involvement of the underlying subdermal fat, fascia, muscle, and even bone may compromise perfusion and impede healing of the tissues. Traumatic wounds are typically contaminated or infected and additionally may contain devitalized tissues and foreign debris. Management of these wounds is intensive, requiring repeated debridement and lavage events. Multiple dressing changes over a prolonged

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KEY POINTS
• Negative pressure wound therapy (NPWT) transforms an open wound into a closed, moist environment through which a controlled vacuum is applied.
• The modality is widely used in human medicine in acute, subacute, and chronic open wounds; plastic and reconstructive surgery; dehiscences; open abdominal drainage; and closed incisions.
• NPWT has been shown to reduce interstitial edema, stimulate fibroplasia, and enhance angiogenesis, although some mechanisms remain to be elucidated.
• Veterinary studies have recently shown that NPWT is beneficial in open wounds, in which it promotes the early appearance of a smooth granulation tissue bed; NPWT also improves free graft survival and has been used in several other indications.
• Further studies are needed to refine NPWT protocols for different species, to identify different indications, and to determine which protocols are best suited for each application type.

Video content accompanies this article at http://www.vetsmall.theclinics.com.

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period have traditionally been necessary, often continuing through the inflammatory phase into the proliferative phase of healing. Intensive wound care continues until the wound is either suitable for a reconstructive procedure or until it has largely healed by second intention and can be managed in the home setting.

During the early phase of wound healing, dressings have historically been changed frequently with saline-dampened wet-to-dry dressings to aid in ongoing debridement and exudate management. Although effective in the inflammatory phase, these bandage changes require daily sedation, and significant nursing time and expenditure on consumables. As the understanding of the cellular and molecular events orchestrating wound healing increased in the last half-century, the importance of the extracellular matrix was appreciated. Subsequently, many modern wound dressings and biologics have been developed, not just to protect but also to nurture the wound, resulting in an extensive choice of products. Several mechanical adjuncts have also been developed to enhance wound healing over the last few decades, including electromagnetic stimulation, magnetic therapy, ultrasonography therapy, radiofrequency energy, low-intensity laser, hydrosurgical debridement, oxygen therapies, and negative pressure wound therapy (NPWT). Of these, NPWT has shown particular clinical advantages, not only for open wound management but also in reconstructive, orthopedic, and general surgical applications.

NPWT refers to the application of a vacuum evenly distributed across the surface of a wound, typically through a foam dressing. An open-cell polyurethane or polyvinyl alcohol foam is conformed to the wound and sealed from the environment with occlusive drapes. Specialized access tubing connects the dressing to a programmable vacuum pump, which subjects the entire wound to an evenly distributed negative pressure. Wound exudate is collected in a canister attached to the pump (Fig. 2). The level of vacuum is programmable, ranging from 75 to 150 mm Hg with 125 mm Hg being commonly used for open wounds. NPWT can be continuously, cyclically, or intermittently applied. There are several synonymous terminologies for NPWT, including topical negative pressure therapy, vacuum-assisted closure, subatmospheric wound therapy, closed-suction wound drainage, and microdeformational wound therapy.

**MECHANISMS OF ACTION**

The aims of the NPWT modality are to remove wound exudate; decrease interstitial edema; draw wound edges together; promote blood supply to the wound; and, by
applying mechanical strain, stimulate cells involved with modulating the inflammatory and proliferative response to injury.19

Early studies to investigate the effects of NPWT on full-thickness wounds were performed in swine. These studies concluded that, at −125 mm Hg, NPWT increases blood flow to a wound, accelerates the rate of granulation tissue formation, decreases bacterial counts, and improves flap survival.25,26 Despite a lack of mechanistic proof, the modality rapidly penetrated human wound care and trauma departments, largely because of its remarkable clinical outcomes.27–32 NPWT was subsequently adopted into other surgical applications, such as free skin grafts, pedicled muscle and skin flaps, incisional dehiscences, cytotoxic sloughs, complex orthopedic trauma, envenomations, extravasations, and burns.33–36 There is no doubt that NPWT has revolutionized wound management. It is the modality of choice to address complex soft tissue wounds sustained in the US military.37,38 More recently, it has been used for abdominal drainage and incisional management.13–15

Although new therapeutic applications for NPWT continue to be reported, the physiologic, cellular, and molecular mechanisms of the modality are still being elucidated.19,39 Animal and human clinical studies support the original data showing that chronic, subacute, and acute wounds, flaps, and free grafts respond favorably to NPWT.20,40–42 The originally reported increase in wound perfusion was corroborated, although an area of hypoperfusion adjacent to the wound edge that rebounded following termination of NPWT was also reported.43,44 An earlier appearance of granulation tissue was also substantiated, with intermittent or variable NPWT shown to be more effective at stimulating fibroplasia and neovascularization than continuous mode.45–48 It is postulated that the benefits result from the cycling of increased blood flow (facilitating oxygenation and nutrient supply) and decreased blood flow (hypoxic stimulation of angiogenesis and fibroplasia). The evidence regarding the role of NPWT in bacterial clearance remains conflicting, with some studies showing no difference or an increase in bacterial load, despite the positive effect on wound healing.49–52

It is also postulated, and some data show, that the strain and microdeformation induced by NPWT on the cells within the wound, and the creation of a hypoxic gradient within the microenvironment, promotes cell recruitment, proliferation, and differentiation, resulting in enhanced neovascularization and fibroplasia.22,53,54 The mechanical

Fig. 2. The same dog as in Fig. 1, with NPWT applied to the wound. An open-cell polyurethane foam has been conformed to the wound and sealed from the environment with occlusive drapes. Tubing connects the dressing to a programmable vacuum pump and wound exudate is collected in a canister attached to the pump.
strain of negative pressure on fibroblasts seems to stimulate them to divide and increase collagen synthesis through mechanotransduction. The mechanical deformation of other cells within and around the wound and shear forces that deform the extracellular matrix are also thought to result in a higher mitotic rate and increased production of granulation tissue.

To facilitate understanding of the underlying molecular mechanism of how NPWT enhances wound healing, a systematic review of studies that had evaluated the effects of NPWT on cytokine and growth factor expression profiles was performed. This review concluded that the promotion of wound healing with NPWT occurs by modulation of cytokines to an antiinflammatory profile, and mechanoreceptor-mediated and chemoreceptor-mediated cell signaling, resulting in angiogenesis, extracellular matrix remodeling, and deposition of granulation tissue. The mechanism of enhanced wound healing is likely from a combination of local immune modulation, mechanoreceptor stimulation, and hypoxia-mediated signaling.

NEGATIVE PRESSURE WOUND THERAPY IN VETERINARY MEDICINE

Experience with NPWT in veterinary medicine is not as extensive as in human medicine; the literature consists of a few controlled studies, several case series, some reviews, and many case reports in a variety of species, including dogs, cats, horses, a tiger, a tortoise, and a rhinoceros. NPWT has also been reported successfully in avians. Results have been promising for many indications in veterinary medicine, including acute open wounds, dehiscences, burns, skin grafts, skin flaps, pad transfers, perforating thoracic trauma, high-risk incisions, and open abdomens. It is likely that this modality will be widely adopted for companion animals, becoming an invaluable adjunct to wound management and other surgical applications in both large and small animals.

One of the earliest veterinary reports was a clinical case series evaluating outcomes in 15 dogs with traumatic extremity open wounds. Following NPWT, all animals experienced rapid appearance of granulation tissue within the wounds and underwent successful reconstruction at an average of 4.6 days (range, 2–7 days). Complications were considered minor and included dermatitis at the wound margin and loss of vacuum causing wound desiccation. Subsequently, a randomized, controlled, experimental study in dogs compared NPWT with standard-of-care wound management in 20 forelimb wounds on 10 dogs. Granulation tissue appeared in the NPWT wounds significantly earlier (day 2) than in the control wounds (day 7), and the granulating bed was smoother in the NPWT wounds than in the control wounds (Fig. 3). However, the NPWT wounds did not contract or epithelialize as well as the control wounds after days 7 and 11 respectively. On histology, NPWT wounds appeared to reach an acute inflammation peak earlier than control wounds, transitioning into the proliferative phase more rapidly. The modality has been shown to be well tolerated and allows several days between dressing changes in the inflammatory phase, in which previously daily bandage changes were indicated. It is often used to shorten the time period to surgical closure but can also be used into the proliferative phase. Time to healing in dogs when NPWT is used is significantly shortened compared with both nonadhesive impregnated gauze dressings and highly absorbent foam dressings. Overall, these studies show that NPWT is a valuable mechanical adjunct to healing in large, complicated wounds, providing a bridge to reconstruction. In addition to the enhanced wound healing effects of NPWT, the distinct logistical advantage of the prolonged time between dressing changes (up to 72 hours) compares favorably with the traditional daily wet-to-dry dressing for open wounds still in the inflammatory phase.
Several studies have additionally shown the feasibility and beneficial effects of NPWT in securing and enhancing acceptance of free full-thickness skin grafting in dogs and cats.\(^{59,66,76,77,82}\) Not only does granulation tissue appear earlier in the interstices of the meshed graft but the open meshes close more rapidly, and percentage of graft take is higher. There is also better early adhesion of the graft to the recipient bed when under NPWT, and decreased reported seroma formation. It seems that NPWT can be used to optimize graft survival, and it may be especially valuable for large grafting procedures in which immobilization is challenging.

NPWT has also been reported as being used successfully over high-risk skin flaps and closed incisions.\(^{61,68,73,78,80}\) These reports support the use of NPWT over incisions that are at high risk of complications such as swelling, infection, dehiscence caused by tension or motion, and necrosis, but further studies are indicated.

There are more than 14 different commercially available NPWT systems on the market, several of which have penetrated the veterinary market.\(^{19,84}\) Some of the more advanced modifications associated with NPWT, such as concurrent instillation therapy and abdominal sepsis management, have also been reported in veterinary patients.\(^{82,83,74}\) Ad hoc negative pressure devices have been devised in resource-poor settings, in both human and veterinary hospitals. These devices tend to use moistened wide-weave gauze or sterile speaker foam with negative pressure generated by hospital suction pumps.\(^{85}\) The efficacy of these systems compared with commercial systems has not been rigorously evaluated.

NPWT shows much promise to enhance veterinary wound care and reconstruction and commercial veterinary units are now used throughout referral institutions in North America, Europe, and the United Kingdom. Although most NPWT is used in hospital patients, smaller mobile units can be used in the home setting. It can be used in the hospital setting as well as in the home in selected cases. However, as in human wound care, further controlled studies are indicated, not only to further the understanding of the mechanisms of the modality but also for optimizing the methodology. Given the widespread use of NPWT in human and veterinary medicine, it is important to develop robust guidelines and protocols for different indications.\(^{85}\)

**INDICATIONS/CONTRAINDICATIONS OF NEGATIVE PRESSURE WOUND THERAPY**

Early treatment of contaminated or dirty wounds is intended to provide an environment conducive to healing by removing devitalized tissue and debris, decreasing the bacterial bioburden, preventing further contamination, and providing effective...
<table>
<thead>
<tr>
<th>Type of Wound</th>
<th>Description</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Acute, subacute, traumatic</td>
<td>Including anatomic degloving and shear wounds with exposed bone</td>
<td>NPWT dressing is placed following cleansing, debridement, and lavage</td>
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<tr>
<td>Acute surgical wounds, managed open</td>
<td>Useful in preparing wound bed for grafting, also if significant contamination occurred intraoperatively</td>
<td>NPWT dressing is placed while patient is still in the operating room</td>
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<tr>
<td>Physiologic degloving</td>
<td>Cutaneous blood supply is disrupted from underlying fascia</td>
<td>Fenestrate the skin in several areas, and place NPWT dressing over the affected area</td>
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<tr>
<td>Necrotizing fasciitis or vasculitis</td>
<td>Necrotizing lesions of unknown cause. Early establishment of extent of compromise is recommended before NPWT</td>
<td>NPWT dressing is placed following cleansing, debridement, and lavage. Wound should be checked in 24–48 h</td>
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<tr>
<td>Abscesses</td>
<td>Large deep abscesses associated with edema</td>
<td>NPWT dressing is placed following lancing and lavage</td>
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<tr>
<td>Burn</td>
<td>Superficial or full thickness</td>
<td>NPWT can be applied with silver-impregnated dressing</td>
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<tr>
<td>Chronic wounds</td>
<td>Including decubital ulcers and atypical infections. Address underlying cause concurrently (eg, relieve pressure, microbial work-up, search for foreign body)</td>
<td>NPWT can stimulate a chronic wound to a proliferative phase</td>
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<tr>
<td>Multiple wounds</td>
<td>Bite wounds or stab wounds</td>
<td>Several wounds can be connected by connecting strips of foam between the NPWT dressings</td>
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<tr>
<td>Dehisced incisions, sloughs</td>
<td>Including over exposed orthopedic implants</td>
<td>NPWT dressing is placed following cleansing, debridement, and lavage. Shortens time to revisional closure</td>
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<tr>
<td>Skin flaps</td>
<td>Large flaps in mobile areas</td>
<td>NPWT decreases seroma and edema formation</td>
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<tr>
<td>Skin grafts</td>
<td>Mesh the graft generously</td>
<td>NPWT increases survival and immobilizes the graft-bed interface. Use moistened polyvinyl alcohol foam</td>
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<tr>
<td>Closed surgical incisions</td>
<td>High-risk incisions: under tension, when swelling is expected; eg, arthrodeses</td>
<td>NPWT decreases seroma and edema formation</td>
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<tr>
<td>Myofascial compartment syndrome</td>
<td>Rare indication but reported</td>
<td>NPWT dressing is placed following fasciotomy</td>
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Data from Refs. 12,33,61,64,69,73,75,80–82,84,89
There are established, incontrovertible principles of wound management that have been well proven in injuries sustained over centuries of warfare. These principles involve thorough cleansing of the periwound and wound, debridement of necrotic and devitalized tissues, and copious pressured lavage. These main tenets of open wound management should never be neglected, regardless of the dressing that is placed on the wound. Highly exudative, traumatic wounds are ideal for NPWT. The clinical applications and indications for NPWT in small animals have been discussed and are outlined in Table 1. There are certain wound conditions that are not suited for NPWT in veterinary medicine (Box 1). Before managing a wound, assess the patient’s overall cardiovascular, respiratory, and neurologic status, look for comorbid conditions, and administer an appropriate level of analgesia.

**TECHNIQUE**

*Preparation Tips*

- Be meticulous on initial application of the NPWT dressing. Careful initial preparation to ensure the integrity of the seal on the periwound saves time and frustration later.

<table>
<thead>
<tr>
<th>Contraindications for negative pressure wound therapy</th>
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<tr>
<td>Poor periwound skin condition</td>
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<tr>
<td>Necrotic or clearly devitalized tissue</td>
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<td>Coagulopathy</td>
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<td>Exposed major blood vessels</td>
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<td>Open joint</td>
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<td>Neoplastic malignancy in the wound</td>
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<td>Unexplored draining tract</td>
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<td>Untreated osteomyelitis</td>
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<td>Small wounds</td>
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<td>Lack of overnight care</td>
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Fig. 4. A hairdryer is used to dry the periwound during a dressing change.
The NPWT dressing should be applied to a wound that has already been clipped, cleansed, debrided, and lavaged. The periwound skin should be clipped and prepped with margins of 3 to 5 cm, to ensure adequate contact area for the adhesive drape. The last cleanse of the periwound skin should be with alcohol, which is an effective defatting and drying agent.

Ensure the periwound skin is completely dry, because any moisture weakens adhesion of the drape. A hairdryer on a low setting can be used (Fig. 4).

Note that the foam must be porous (open-cell or reticulated), with every air pocket communicating. Closed-cell foam mattress material is contraindicated; it does not apply an effective vacuum to the wound surface and simply becomes an occlusive dressing, leading to wound maceration.

NPWT is typically applied to the wound when the animal is under general anesthesia, although reapplication can often be undertaken with just sedation. Aseptic technique should be maintained throughout the dressing application.

There is a learning curve associated with this modality. Once the team becomes adept at placing the dressing and managing the vacuum pump controls, complications with dressing leakage or pump alarms will decrease.

Fig. 5. All the required equipment should be gathered before applying NPWT dressings. This equipment includes, from left to right, the vacuum pump, the tubing and canister, the foam dressing, adhesive drapes, and specialized pad with tubing.

Fig. 6. The reservoir canister with the canister tubing should be firmly attached to the vacuum pump.
Application of Negative Pressure Wound Therapy

1. Ensure that the battery of the NPWT machine is charged and that all required equipment is gathered together (Fig. 5).
2. Place the reservoir canister with the canister tubing onto the vacuum pump (Fig. 6).
3. Check again that the skin around the wound is closely shaved or clipped, and absolutely dry. Any oozing of blood or wound fluid onto the periwound skin should immediately be swabbed from the skin with sterile gauze. Apply a thin coating of liquid skin adhesive to the skin for about 3 to 5 cm around the wound, allowing it to dry for a few minutes. If there are uneven surfaces, such as between the digits or in skin folds, stoma paste or hydrocolloid gels can be molded into a dam to help secure an airtight seal (Fig. 7).
4. Cut the foam dressing to the shape of the wound and place it into the wound bed. The dressing should fit just inside the wound edge to avoid compression of the wound edge and adjacent periwound skin. If the wound is large and/or irregular, the foam dressing can be roughly secured to the wound edge with a few skin staples or cut strips of adhesive drape to prevent dislodgement while the adhesive drape is applied (Fig. 8).

Fig. 7. (A) Liquid skin adhesive is applied sparingly to the periwound skin. (B) In areas where the periwound skin is uneven, such as in between the digits of this dog, stoma paste or hydrocolloid gels can be molded to help attain an airtight seal.

Fig. 8. (A) The foam is being cut to the shape of the open wound. (B) In larger, complex wounds the foam can be preventing from dislodgement by stapling to the skin edges.
5. Seal the whole wound area with the impermeable, adhesive drapes. These drapes typically come sandwiched between 2 layers to facilitate handling and placement. Avoid wrinkles or folds in the drape when possible, because they can track air from the environment and compromise the integrity of the dressing (Fig. 9).

6. Cut a 2-cm round hole in the sheet exposing a small area of the foam dressing. Place the proprietary adhesive fenestrated disc with associated evacuation tubing over the hole (Fig. 10).

7. Immediately connect the evacuation tubing to the tubing on the reservoir canister of the programmable vacuum pump and set either continuous or intermittent negative pressure to the sealed wound, between −80 and −125 mm Hg. Once powered on, the dressing should contract noticeably, become very firm and raisinlike to the touch (Fig. 11, Video 1). As the pump approaches the preset vacuum level, it becomes quiet and only activates on an intermittent basis, to maintain the vacuum. Listen closely to the dressing for sounds of leakage (a low, moist, whistling sound); more adhesive draping may be required.

8. If the wound is on a limb, the NPWT dressing can be covered with a soft, padded bandage, coiling a length of the evacuation tubing into the bandage layers. It is useful to create a window in the bandage so that the foam dressing can be palpated, and to obtain confirmation that it is still firm and raisinlike (Fig. 12). With trunk wounds, the dressing can be left unbandaged. Allow adequate tubing to extend from the bandage to the patient’s dorsum throughout a full range of motion if the

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Fig. 9. (A, B) The wound and foam are sealed by applying the adhesive drapes and peeling off the layers as instructed. Try to avoid wrinkles in the drapes.

Fig. 10. (A) A 2-cm hole has been cut in the drape, exposing the foam. (B) The specialized adhesive pad with the evacuation tubing is placed over the hole.
patient is ambulatory. However, do not allow too much slack so that the patient could become tangled. With large dogs, the pump can be inserted into a vest and worn; with small dogs and cats, it should reside immediately outside the cage, and be transported with the dog when ambulating (Fig. 13).

9. Dressing integrity and machine function should be checked regularly during the period of deployment. The animal should be either continually monitored in an intensive care unit or checked every 2 hours. If the vacuum is lost for more than several hours, the dressing will become occlusive and wound maceration will result.

**MANAGEMENT AND COMPLICATIONS**

- NPWT is redressed every 48 to 72 hours; an acute traumatic wound typically requires only 1 to 3 dressing changes before a healthy bed of granulation tissue is

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**Fig. 11.** NPWT has been activated and the foam dressing shrinks and becomes firm to the touch.

**Fig. 12.** The limb has been bandaged over the NPWT dressing, incorporating a coil of the evacuation tubing within its layers. A window has been cut in this bandage over the NPWT dressing. This window allows the carer to check that the dressing is still contracted down and firm to the touch.
evident. It is important not to leave the dressing on for longer than 72 hours, especially in young dogs, because granulation tissue can develop quickly and may grow into the interstices of the foam.

- Dressing changes take approximately 15 minutes and are usually performed under sedation or brief anesthesia. The entire dressing and adhesive drapes can be removed or just the portion of the dressing over the wound. In the latter case, the drape at the foam edge is sharply incised and just the foam and drape covering the foam are removed. Following wound cleansing, and placement of the new foam dressing, the adhesive drapes are placed over foam and also cover the original drapes on the periwound skin (Fig. 14).

- Pumps are designed to alarm with loss of pressure caused by disruption of the occlusive dressing. In this case, either reinforce the dressing with more adhesive drapes or change the dressing as soon as possible (within 2–4 hours) to prevent wound maceration. To prevent leakage of the dressing, be meticulous during original dressing placement.

Fig. 13. Many pumps come with their own carrying satchel to facilitate ambulating with the patient.

Fig. 14. The NPWT dressing is being replaced. Only the adhesive drape over the foam has been removed. Following cleansing, new foam will be placed in the wound and the adhesive drape placed, covering the original adhesive drape.
Pumps are also designed to alarm when obstructed. This problem does not occur often because of the low viscosity of wound exudate in companion animals, and the regular venting of the tubing in some commercial systems. Obstruction can also be cleared by flushing and stripping the tubing.

Intermittent therapy (5 minutes on, 2 minutes off) may lead to an increased risk of loss of dressing integrity caused by the lack of vacuum in the off mode. Dogs tolerate both intermittent and continuous therapy modes well, but cats sometimes seem to resent the restarting of the vacuum in intermittent mode.81 For these reasons, NPWT is mostly used in continuous mode.

**SUMMARY**

NPWT is increasingly playing a beneficial role in wound care, and the modality has now been validated in several applications in veterinary medicine. Advantages of NPWT include early appearance and improved quality of granulation tissue, decreased frequency of dressing changes, elimination of strike-through (because all exudate is collected in the canister), and an earlier time to reconstruction. Further investigations are indicated to determine optimal protocols for the different indications and in different species.

**SUPPLEMENTARY DATA**

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.cvsm.2017.06.006.

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