Effects of Negative Pressure Wound Therapy on Healing of Open Wounds in Dogs

Marco Demaria¹, DVM, Bryden J. Stanley¹, BVMS, MVetSc, Diplomate ACVS, Joe G. Hauptman¹, DVM, MS, Diplomate ACVS, Barbara A. Steficek², DVM, PhD, Diplomate ACVP, Michele C. Fritz¹, BSc, LVT, John M. Ryan³, MVB, MRCVS, Nathaniel A. Lam¹, DVM, Trevor W. Moore¹, DVM, and Heather S. Hadley¹, DVM

¹Department of Small Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI, ²Diagnostic Center for Population and Animal Health, College of Veterinary Medicine, Michigan State University, East Lansing, MI and ³Royal (Dick) School of Veterinary Studies, University of Edinburgh, Edinburgh, UK

Corresponding Author
Bryden J. Stanley, BVMS, MVetSc, Diplomate ACVS, Department of Small Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824
E-mail: stanle32@cvm.msu.edu

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Objective: To compare the effect of negative pressure wound therapy (NPWT) with standard-of-care management on healing of acute open wounds in dogs.

Study Design: Prospective, controlled, experimental study.

Animals: Adult dogs (n = 10).

Methods: Full-thickness 4 cm x 2 cm wounds were surgically created on each antebrachium and in each dog were randomized to receive either NPWT or standard wound dressings (CON) for 21 days. Dressing changes and wound evaluations were made at 8 time points. First appearance of granulation tissue, smoothness of granulation tissue, exuberance, percent epithelialization, and percent contraction were compared. Biopsies for histopathology were taken, and histologic scores determined, at 5 time points, and aerobic bacterial wound cultures performed at 2 time points.

Results: Granulation tissue appeared significantly earlier, and was smoother and less exuberant in NPWT wounds compared with CON wounds. Percent contraction in NPWT wounds was less than CON wounds after Day 7. Percent epithelialization in NPWT wounds was less than CON wounds on Days 11, 16, 18, and 21. Histologic scores for acute inflammation were higher in NPWT on Day 3, and lower on Day 7, than CON wounds. Bacterial load was higher in NPWT on Day 7.

Conclusion: NPWT accelerated appearance of smooth, nonexuberant granulation tissue; however, prolonged use of NPWT impaired wound contraction and epithelialization.

The management of degloving and shear injuries is a continuous challenge in both human and veterinary medicine. Open wound management until the wound is considered suitable for reconstruction or until it has healed by second intention has been the treatment of choice for centuries. Frequent and painful dressing changes over prolonged periods intensifies overall case management, and may impact treatment costs. Moreover, repeated sedation or short anesthesia are often necessary for dressing changes, discouraging early ambulation and appetite recovery.

Negative pressure wound therapy (NPWT), also known as “vacuum-assisted closure” or “topical negative pressure therapy,” involves the application of subatmospheric pressure to a wound. It was originally developed over a decade ago as an alternative treatment for debilitated patients with chronic wounds.¹-⁴ Treatment involves uniform distribution of negative pressure to all wound tissues enclosed within a sealed environment. Typically, open cell polyurethane ether foam or open weave moistened gauze is placed into the wound bed, and sealed by placing an adhesive, nonpermeable drape over the wound area and adjacent skin to create a closed system. Recent studies have shown equally effective delivery of negative pressure and mechanical deformation with either contact dressing.⁵,⁶ Negative pressure is obtained and maintained by an evacuation tube leading from the contact dressing through a reservoir canister to a programmable vacuum pump.

Several mechanisms of action of NPWT have been investigated, most focused on fluid movement and mechanical application of pressure.²,⁷-¹¹ Application of a controlled vacuum to the wound interface facilitates removal of excess interstitial fluid, resulting in decreased interstitial pressure and wound edema. When interstitial pressure falls below capillary pressure, the capillaries reopen and blood flow to the wound and periwound tissue increases.²,⁵,⁸,¹¹-¹⁴ The mechanical deformation of the cells within and around the wounds stimulates cell division and migration, which is critical for wound healing.
wound, and shear forces acting on the extracellular matrix result in a higher fibroblast mitotic rate and increased production of granulation tissue.10,15 Several studies in pigs examined the physiologic response of different wound types to subatmospheric pressure treatment. There was a significant increase in granulation tissue formation and blood flow to the wound compared with control wounds.1,5,12,16 A reduction in the number of bacteria in infected wounds has also been reported, but not consistently. Proprietal claims of enhanced bacterial clearance in wounds undergoing NPWT remains controversial.2,17–20

NPWT was originally described for chronic wounds in people but applications for a variety of wounds and surgical situations are now reported, mainly in case series and clinical reviews.21 The high rate of clinical success and relative ease of application of NPWT have encouraged adaptation in compromised flaps,22–25 free skin grafts,26–29 postoperative sternal incisional infection and mediastinitis,30–34 perineal, urologic, and gynecologic wounds,35,36 as well as for cytotoxic sloughs,37 abdominal wall defects and drainage,38–41 and burns.42,43 Reduced overall treatment cost and shortened hospitalization have been documented with NPWT.44–48 Trauma and orthopedic surgeons use NPWT to treat orthopedic extremity trauma in people with extensive soft tissue damage.49–53 NPWT is also becoming the first line of treatment in the field for complex wounds of injured soldiers.54–59

There are only 5 case reports and 1 retrospective clinical case series on use of NPWT in the veterinary literature.60–65 To validate any benefit of NPWT in veterinary medicine, randomized, controlled comparisons in companion animals are clearly justified. Our hypothesis, formulated on the basis of our own observations amassed from over 50 clinical cases, was that open wounds treated with NPWT would show superior wound healing compared with wounds treated with a standard wound management protocol. To test our hypothesis, the aim of this study was to compare wound healing variables between wounds treated with NPWT and those undergoing a standard wound management protocol (an absorbent foam dressing until granulation tissue, followed by a nonadherent, semiocclusive dressing), on acute, full-thickness wounds with exposed bone in healthy dogs. Wound healing variables recorded include first appearance of granulation tissue, smoothness of granulation tissue, exudate production, percent wound epithelialization, percent wound contraction, histologic indicators of inflammation and repair, and aerobic bacterial cultures.

**MATERIAL AND METHODS**

Adult purpose-bred male Coonhounds (n = 10), 1 year of age, weighing 20–25 kg with a body score 4–5/9 were studied. Each dog was normal on physical examination, complete blood count, serum biochemical profile and urinalysis.

**Technique**

On Day 0, each dog was administered acepromazine maleate (0.05 mg/kg, intramuscularly [IM]) and morphine sulfate (1 mg/kg IM), and then anesthetized with thiopental (16 mg/kg, intravenously [IV] to effect). After endotracheal intubation, anesthesia was maintained with isoflurane (baseline concentration, 2% delivered in oxygen 30 mL/kg/min). Both thoracic limbs were clipped and prepared for aseptic surgery, from just above the elbows to the proximal phalanges. Strict aseptic surgical technique was maintained throughout the procedure. Using a template, a 4 cm × 2 cm full-thickness skin wound was surgically created on the dorsal aspect of the antebrachium. Antebrachial fascia was removed adjacent the small tendon of the abductor pollicis longus muscle and the distal aspect of the radius exposed. Using a template, a 2 cm × 1 cm area of periosteum was excised to simulate a minor shear injury (Fig 1). Wounds were blotted with saline-moistened sterile gauze until hemostasis was achieved. Initial digital photographs (Sony DSC-T100, Sony Electronics Inc., New York, NY) on macro setting and fine resolution were taken at this time.

Right and left leg wounds were randomized to treatment (NPWT) or controls (CON) based on coin-toss. NPWT dressings consisted of either open cell, polyurethane foam (V.A.C.® GranuFoam®, Kinetic Concepts Inc., San Antonio, TX) or saline-moistened, loose-weave, gauze (Kerlix, Tyco Healthcare Group, Mansfield, MA) applied directly onto the wound bed. Wounds were sealed with an impermeable adhesive drape applied over the NPWT dressing and surrounding skin, through which the evacuation tube exited. The evacuation apparatus consisted of either a flat perforated disc (V.A.C.® T.R.A.C.® Pad, Kinetic Concepts Inc.) or a flat fenestrated drain (Chariker-Jeter Dressing Kit, Smith & Nephew, St. Petersburg, FL) with tubing connected through an in-line 3-way stopcock to coiled tubing (Core SAIV®, International Win, Kennett Square, PA) leading to an overhead bar, and into the vacuum pump (Figs 2, 3). A continuous, negative pressure of −110 to −125 mmHg was applied and maintained throughout the study. These parameters were chosen based on consultation with the manufacturers, and reviewing the appropriate literature in people,1,2,16,21,30,31,54 and dogs.61 Dogs were monitored and negative pressures measured with a transducer (QA-PT Parameter Tester, Metron, Grand Rapids, MI) through the 3-way stopcock every 2–4 hours during the day (8 AM, 10 AM, 12 PM, 4 PM) and every 6 hours overnight (6 PM, 12 AM, 6 AM). This schedule was maintained throughout the study to verify the accuracy of the pump settings with the modified tubing, and the integrity of the vacuum of the dressings (Fig 2).

CON dressings consisted of absorbent hydrophilic foam dressings (Copa Foam Dressing™, Kendall Tyco Healthcare) as the primary layer dressing until granulation tissue was present in the wound, at which time a nonadherent, petroleum-impregnated, semiocclusive dressing (Adaptic, Johnson & Johnson, New Brunswick, NJ) was used as a primary layer. Both legs were bandaged from digits to the elbow with secondary and tertiary layers, which were identical for both wound groups throughout the study. Pain medication was administered before recovery from anesthesia (morphine sulfate 1 mg/kg IM, carprofen, 4 mg/kg subcutaneously) and carprofen was continued.
orally for 7 days (4 mg/kg orally once daily). Elizabethan collars were maintained postoperatively.

On Days 3, 5, 7, 9, 11, 14, 16, 18, and 21, dogs were medicated with acepromazine maleate (0.05 mg/kg, IM) and morphine sulfate (0.7–1.0 mg/kg, IM) for dressing changes. All wounds were evaluated subjectively and then gently cleaned with sterile saline-soaked gauze sponges. Aseptic technique was maintained during all dressing changes. Care was taken not to disrupt the wound bed at these times, but all exudate and dried clots were removed to facilitate accurate wound photography. Although the dressings were changed at Day 5 (Saturday), wounds were not evaluated at this time (because of limited weekend staffing). Wounds were redressed as previously described at each dressing change until study completion. Antibiotics were not administered.

**Quantitative Measurements**

Fine-resolution digital photography with a carefully positioned millimeter measurement scale was performed on Days 0, 3, 7, 9, 11, 14, 16, 18, and 21. Upon study completion, all images were randomized and blinded, and planimetry software (ImageJ®, NIH, http://rsbweb.nih.gov/ij/index.html) was used to calibrate and trace open wound area (defined as the area of pregranulation or granulation tissue), and total wound area (defined as open wound area and the surrounding area of new epithelialization lacking hair follicles). From these 2 measurements, the percent epithelialization of the wound at each time point and the percent contraction with respect to size at Day 0, could be calculated. The following response variables were compared:

1. **Time to first appearance of granulation tissue (days).**
2. **Percent epithelialization (%)** expressed as \( \frac{\text{total wound area Day } n - \text{ open wound area Day } n}{\text{total wound area Day } n} \times 100. \)
3. **Percent contraction (%)** expressed as \( \frac{\text{total wound area Day } 0 - \text{ total wound area Day } n}{\text{total wound area Day } 0} \times 100. \)

**Qualitative Measurements**

At each dressing change, the wound bed appearance, peri-wound status, and discomfort upon dressing removal were evaluated subjectively and recorded (Table 1). Subjective evaluation of the wound bed included the designations: pregranulation tissue or granulation tissue. When granulation tissue was present, it was defined as “smooth” (depth variations estimated to be \( \leq 0.5 \text{ cm} \)), or “irregular” (depth variations estimated to be \( > 0.5 \text{ cm} \)), and the color

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**Figure 1** Intraoperative views showing placement of the 2 × 4 cm sterile template on the dorsal aspect of the distal antebrachium (A), and followed by the creation of a 1 × 2 cm periosteal excision to simulate a mild shear injury (B). Note how retraction of wound skin edges enlarges open wound area.

**Figure 2** Negative pressure wound therapy (NPWT) dressings consisted of either polyurethane ether foam (A) or loose-weave gauze (B). Integrity of the NPWT dressings was checked regularly with a transducer, via a 3-way stopcock at the level of the evacuation tubing.
assigned as red, purple-red, or pale. Exuberant granulation tissue was recorded when the tissue extended above the level of the periwound skin.

**Histologic Evaluation**

A 2 mm strip of the original excised skin was submitted for histopathology (Day 0). Additional biopsy specimens (2 mm diameter) were taken from the wounds on Days 3, 7, 14, and 21, in identical locations along the wound edges of all wounds using a disposable 2 mm dermal biopsy punch. Specimens were placed in 10% neutral buffered formalin and routinely processed for light microscopy. Representative sections were stained with hematoxylin and eosin, and with trichrome to more clearly identify collagen. Microscopic evaluation of the samples was performed by a board certified veterinary pathologist (B.A.S.) who was unaware of the sample grouping.

The concentration of neutrophilic cellular infiltration and the degree of edema, hemorrhage, and necrosis were evaluated and scored: 0 = none, 1 = minimal, 2 = moderate, and 3 = marked. The criteria used to define the concentration of cellular infiltrates were as follows: 0 = within normal histologic limits, 1 = scattered, 2 = clustered or nodular, and 3 = diffuse. Histologic evaluation of tissue edema was based primarily on distribution within the sections, with 0 = none, 1 = focal, 2 = localized (regional), and 3 = diffuse. The degree or extent of hemorrhage within the tissue sections was subjectively and comparatively designated as 0 = none, 1 = mild, 2 = moderate, and 3 = severe. The necrosis component was evaluated utilizing the following histopathologic criteria: 0 = none, 1 = focal, 2 = nodular/regional, and 3 = diffuse (tracking along fascial planes). These 4 histologic features were weighted equally and plotted at each time point to check for any graphical interaction of each composite by group, before being summed to formulate a histologic acute inflammation score (HAIS; range 0–12).

Fibroblast proliferation was designated, histologically, by pattern and degree of tissue involvement. Scoring criteria were as follows: 0 = none, 1 = focal (loose), 2 = locally extensive, and 3 = effacing normal tissue architecture. Microscopic interpretation of collagen density was based on intensity and depth of distribution within tissue sections. Scoring values were defined as 0 = none, 1 = superficial dermal, 2 = superficial to mid-dermal, and 3 = superficial dermal to subcutaneous. Similar to fibroblast proliferation, the neovascularization component was scored on histologic pattern and degree of tissue involvement: 0 = none, 1 = focal (loose), 2 = transdermal, and 3 = effacing normal tissue architecture. These 3 histologic features were weighted equally and plotted at each time point to check for any graphical interaction of each composite by group, before being summed to formulate a histologic repair score (HRS; range 0–9).

**Aerobic Bacterial Cultures**

On Days 7 and 14, after the dressings were removed but before cleansing of the wounds, a sterile culture swab was rolled over the entire wound surface, no more than once. The sample was stored at 4°C and plated within 4 hours of retrieval onto 5% enriched Sheep-blood agar, CNA agar, and MacConkey agar. All cultures were held for 72 hours before being regarded as negative. Bacterial isolates were enumerated and identified following this institution’s Standard Operating Procedures for Wound Cultures. Species and number of colony-forming units (CFU) were recorded, and an aerobic bacterial load defined as follows: no growth or isolated from broth culture only = 0, < 50 CFU = 1, 50–100 CFU = 2, and > 100 CFU = 3.
at each time point (Days 7 and 14), the aerobic bacterial loads of all isolates were summed for each wound.

Statistical Analysis

First appearance of granulation was analyzed by means of the Wilcoxon signed-rank test, and presented as median and range. The occurrence of “smooth” and “exuberant” granulation tissue designations in each group were compared by means of a McNemar’s test of equality at each time point after Day 7 (i.e., time points when granulation tissue was present in all wounds). The response variables of % epithelialization, % contraction, HAIS, and HRS may have been affected by the following factors: (a) treatment group (NPWT, CON); (b) time, (c) dog. This was a paired design, with each dog serving as its own control, and each dog being repeatedly measured over time. The data were analyzed by means of a 3-factor ANOVA with the fixed factors of treatment group and time, and the random factor of dog (SAS PROC MIXED, SAS, Cary, NC). Aerobic cultures were analyzed by means of a Wilcoxon’s signed-rank test. P < .05 was considered significant for all statistical analyses.

RESULTS

All dogs tolerated surgery, their bandages and NPWT well. Minor line separation caused loss of vacuum in 1 dog early in the study (Day 1), which was corrected at the next check by simple equipment replacement. Because of the scheduled checks, the maximum time negative pressure could have been lost in this dog was 4 hours. Dogs did not display any abnormal vocalization, shivering, tachypnea, tachycardia, lameness, reluctance to move, inappetence, lethargy, or absence of tail wag while in their enclosures. At the first bandage change (Day 3), mild discomfort was noted in 9 dogs upon removal of NPWT dressings; and in 2 dogs upon removal of the CON dressings. Moderate pain (flinching) was noted in 4 dogs upon removal of the NPWT dressings on Days 7, 9, and 11. At several of these times granulation tissue appeared to be proliferating into the interstices of the foam dressings (Fig 4). Periwound skin erythema was evident around 7/10 of NPWT wounds in after Day 11, but only around 1/10 of the CON wounds. Before Day 11, only 2 dogs had periwound irritation (both NPWT wounds). The secondary layer of the bandage was always “Dry & Clean” in the NPWT wounds, and either “Dry & Stained” or “Moist & Stained” in the CON wounds. All wound fluid evaluations were serous or serosanguinous, and no maceration or desiccation was noted in any wound.

Granulation tissue appeared in NPWT wounds significantly earlier (median, Day 3; range, 3–3) than the CON wounds (median, Day 7; range, 3–9). “Smooth” granulation tissue (compared with “irregular”) was more frequent in NPWT wounds than CON wounds, reaching significance on Days 14, 16, and 18 (Fig 5). Exuberant granulation tissue was observed significantly more frequently in CON wounds on Days 9, 11, 16, 18, and 21 (Fig 6).

All open wound areas initially increased during the first week following wound creation. By Day 7, retraction was greater in the NPWT wounds compared with CON wounds. Subsequently, at every time point until study completion, percentage contraction was significantly less in the

![Figure 4](image-url) Granulation tissue can be seen growing into the interstices of this foam dressing at Day 9, causing mild disruption of the vascular tissue and some minor hemorrhage.
affected by the presence of periwound erythema. The duration of the study. Aerobic bacterial load was not clinically evident in any of the wounds for Staphylococcus aureus, the most common isolates, followed by Streptococcus intermedius and β-hemolytic Streptococcus species and were the most common isolates, followed by Staphylococcus aureus, with occasional other isolates (Table 2). There were no clinical signs of wound infection in any of the wounds at any time point (Fig 11).

**Microbiology**

Bacteriologic cultures taken on Days 7 and 14 from each wound yielded 40 samples (10 dogs × 2 wounds × 2 time points); 33 were positive (17 NPWT, 16 CON). The aerobic bacterial load (as previously defined) was significantly higher in NPWT wounds than in the CON wounds on Day 7 (Table 2). Although both wound groups increased their bacterial loads over time (from Days 7 to 14), this was significantly different only in the CON wounds. Staphylococcus intermedius and β-hemolytic Streptococcus species were the most common isolates, followed by Staphylococcus aureus, with occasional other isolates (Table 2). There were no clinical signs of wound infection in any of the wounds for the duration of the study. Aerobic bacterial load was not affected by the presence of periwound erythema.

**DISCUSSION**

Our results show both advantages as well as drawbacks to continuous NPWT in acute open wounds in dogs. It is clear that granulation tissue appears earlier in acute wounds when NPWT is applied. This finding is in accordance with previous studies in swine, and clinical reports in people, as well as our (B.J.S., M.G.D.) clinical observations in over 50 cases. Although the precise mechanisms by which fibroplasia and angiogenesis are enhanced with NPWT are not fully understood, it has been postulated that the microdeformation of cells under applied force stimulates division and ongoing proliferation. Additionally, one of the mechanisms thought to be acting to facilitate angiogenesis and fibroplasia when applying a controlled negative pressure to the wound interface is the removal of excess interstitial fluid resulting in a decrease in interstitial pressure. When the interstitial pressure falls below capillary pressure, capillary blood flow to the wound and periwound tissue is increased, increasing oxygen tension. Studies on swine and rabbits showed that the application of subatmospheric pressure to wounds reduced localized edema that compresses blood and lymphatic microvasculature, and resulted in an increase in local perfusion and microvascular blood flow. In addition to its early appearance, the smoothness of the granulation tissue was quite notably superior when NPWT was applied (Fig 6). Unfortunately, we could not accurately assess alignment of collagen fibers histologically to support the macroscopic findings. The reason for this may have been because of our failure to orientate the small (2 mm) biopsies within the paraffin blocks, resulting in variability in angle of the cut sections. This could be addressed in future studies by using larger (4 mm) biopsies, inking the superficial surface of the biopsy sample and careful embedding technique.

Granulation tissue was markedly less exuberant when NPWT was applied (Fig 6), and this may be a direct mechanical effect of the NPWT pressing on the wound rather than an applied vacuum per se. The ability of the NPWT modality to produce a smooth, vascular bed of granulation tissue within a few days of wounding could be of great value when a reconstructive effort is being contemplated. The reason for the superior quality of granulation tissue production with NPWT is not fully understood. The physiologic effects of mechanical force on tissues, called mechanical transduction, is well known by plastic and orthopedic surgeons, since it is the basis of tissue expansion and osteogenic distraction. Viscoelastic tissue will deform slowly over time with applied mechanical forces. It has been shown that these same applied forces result in an increase in the mitotic rate of the stretched cells. The applied mechanical shear forces also deform the extracellular matrix in the wound, and thus deform the cells anchored to it. It is postulated that these forces could also result in a wide variety of molecular responses, including activation and stimulation of growth factor pathways, but precise mechanisms have not been elucidated. The deformation of cells occurs also in tissues distant to the wound dressing interface, and this distant stretching may additionally enhance the formation of new periwound tissue.

All wounds initially retracted after wounding which is an expected characteristic, and can be attributed to the inherent viscoelastic properties of skin. Interestingly, the NPWT wounds retracted more than the CON wounds, and...
subsequently failed to demonstrate any evidence of superior contraction throughout the remaining study period. Looking at the slopes of the percent contraction graphs (Fig 7), the rate of contraction that occurs after initial retraction appears similar between the 2 groups. The reason for the increased initial retraction may be because of the mechanical effects of the NPWT dressing on the wound, physically holding the wound edges apart, or the anatomic location of the wound on the extremity.21 The presence of a possibly larger wound at 1 week when using NPWT would need to be weighed against the advantages of having an early, smooth granulation tissue bed available for reconstruction. The difference in epithelialization between the 2 wound treatments was less marked clinically, although

Figure 6 Representative of different dogs’ control (CON) and negative pressure wound therapy (NPWT) paired wounds at various time points. Note the generally smooth appearance to the granulation tissue beds in the NPWT wounds. In addition to being more irregular, the granulation tissue in the CON wounds also demonstrates more exuberance (extending above the level of the periwound skin).
statistically significant. Epithelialization appeared to be retarded when NPWT was used, and this difference became greater as wound healing progressed (Fig 9). Indeed, taking into account both the contraction and epithelialization responses to NPWT, as well as the granulation tissue proliferating into the foam in the second week, there seems to be no benefit in continuing NPWT beyond the appearance of a smooth granulation tissue bed. Although not part of the formal study, it was noted that once NPWT was removed from the wounds at Day 21, contraction and epithelialization proceeded rapidly.

In the published case series reporting the use of NPWT in 15 dogs with traumatic wounds, the authors perceived early granulation formation and also suspected a reduction in tissue edema with the use of NPWT.61 Epithelialization and contraction were not discussed by the authors, possibly because the average duration of NPWT was 9.7 days, with all dogs subsequently undergoing successful cutaneous reconstruction.

As measured by the HAIS, the acute inflammatory period appeared to peak earlier (Day 3) in the NPWT wounds compared with CON wounds (Day 7; Fig 11). Negative pressure therapy has been shown to cause earlier peaking of interleukin-10 and higher levels of interleukin-6 compared with control wounds, but no early differences in other cytokines was noted in a short-term swine study.75 It would be useful to determine levels of inflammatory cytokines over a 14-day period in a comparison study. Possibly as acute inflammation subsided earlier in the NPWT wounds, fibroplasia could become more readily established, although this was not reflected in the HRS scores, which were similar in both groups. A more accurate histologic comparison of inflammatory and repair processes could have been made if biopsies were taken daily or every other day. However, the process of daily biopsy collection itself would possibly affect other variables being compared, such as contraction and epithelialization.

Although both NPWT and CON wounds showed increasing polymicrobial contamination over time, no wounds had clinical infection during the study period. This is not surprising, as the wounds were created in healthy, young animals under strict aseptic conditions. It is interesting to note however, that contrary to some studies,2 NPWT did not appear to enhance bacterial clearance from these wounds and in fact NPWT wounds carried a
significantly higher bacterial load at Day 7. This is in agreement with more recent controlled studies.\textsuperscript{17,18,20} In the absence of obvious signs of infection or susceptibility studies, the clinical significance of this is not known. It seems prudent, however, that heavily contaminated or dirty wounds be adequately cleansed, debrided, and lavaged before NPWT is applied.\textsuperscript{54} Systemic antibiotics are usually used for the duration of therapy in the clinical setting.\textsuperscript{61} Further investigations comparing the effect on bacterial load of impregnated NPWT dressings (such as chlorhexidine, Manuka honey, or silver) could be undertaken.

It should be noted that loss of negative pressure for prolonged periods (e.g., overnight), would convert the wound to an occlusive environment and lead to wound maceration and bacterial proliferation. Regular monitoring of negative pressure settings, either by nursing personnel or owners, is required for this therapy.

In this study NPWT was easily applied, caused minimal morbidity and was well tolerated by all dogs. Periwound erythema developed in most dogs with prolonged use of NPWT, but was not associated with observable morbidity or an increase in aerobic bacterial load. In some dogs, possibly those with sensitive skin, periwound skin erythema occurred in the first 10 days. This has been reported in people and in dogs, and has been attributed to the irritating effects of the adhesive used to ensure integrity of the negative pressure environment.\textsuperscript{61,78} This occurrence could be avoided by shortening the total NPWT experience to 7–10 days.

There is definitely an initial learning curve when using this modality, and we had some issues with the boisterous nature of our healthy dogs, which are unlike our wounded clinical patients. Although we briefly lost dressing integrity in 1 dog early in the study, we are confident that the loss of negative pressure for this period did not influence the study outcome. Maintenance of the NPWT was greatly facilitated in this study by the incorporation of the extensible coiled drip tubing, mounted at the top center of each enclosure (Fig 3). This modification allowed freedom of movement for each dog in its 6’ x 4’ enclosure whilst constantly connected to the vacuum pump, and minimized the chances of accidental line disconnection, tangling or chewing. We were satisfied that this modified evacuation tubing did not influence the pressure at the wound bed, as we checked wound pressures against the vacuum pump settings with the transducer every 2–6 hours.

One advantage of NPWT in open wound management is the longer time interval between dressing changes. Typically, once the NPWT dressing has been properly applied and vacuum established, minimal care is required and dressing changes need only be performed every 2–3

### Table 2

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<th>Species</th>
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<th>CON Day 7</th>
<th>NPWT Day 14</th>
<th>CON Day 14</th>
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Aerobic bacterial load is defined as no growth or isolated from broth culture only = 0, < 50 colony-forming units = 1, 50–100 colony-forming units = 2, and > 100 colony-forming units = 3.

NPWT, negative pressure wound therapy; CON, control.
days. Although periodic checks are required to assure proper machine function and dressing integrity, this lower intensity of care reduces the need of specialized supervision, and theoretically could be managed by committed owners on an outpatient basis. In comparison, a wet-to-dry dressing requires bandage changes under deep sedation every 12–24 hours, with increased risk of strike-through, especially with the highly exudative wounds found in the immediate postwounding period. In this study we used both foam and gauze dressings as the primary contact layer. Recent studies in swine suggest that both dressings incite similar effects on mechanical deformation, wound edge blood flow, and wound edge contraction, and are equally effective in the application of negative pressure.\textsuperscript{5,6,79} However, these dressings should be compared in companion animals and novel dressings developed and tested. Further studies exploring different clinical applications of negative pressure therapy in companion animals are also indicated, as well as determining the ideal negative pressure settings and the differing effects of continuous, intermittent, and variably applied negative pressure therapy. There is some evidence demonstrating that the blood flow alterations resulting from intermittently and variably applied NPWT may stimulate angiogenesis and granulation tissue formation even more readily than continuously applied negative pressure.\textsuperscript{30}

Summarily, we found in this controlled study that NPWT is a valuable mechanical adjunct to early wound healing in healthy dogs, most beneficial in the development of a healthy granulation tissue bed, thus shortening the time to reconstruction. Additionally, when allowing a wound to heal by second intention, NPWT can be used to rapidly establish smooth granulation tissue, creating a wound bed conducive to epithelialization and contraction. Because of the effects on epithelialization and contraction, there seems to be little benefit in continuing this modality for longer than 10 days, unless suppression of exuberant granulation tissue is indicated.

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