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The Use of Vacuum-Assisted Closure Therapy for the Treatment of Distal Extremity Wounds in 15 Dogs

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Objective—To evaluate clinical outcome after vacuum-assisted closure (VAC) therapy in dogs with traumatic wounds located in the distal extremities and report our early experience with VAC.
Study Design—Retrospective study.
Animals—Dogs (n = 15) with traumatic distal extremity wounds.
Methods—Medical records (1999–2003) of dogs with traumatic injuries to the distal extremities managed by VAC were evaluated. Data included signalment, location of wound, time until surgical intervention, wound reconstruction methods, orthopedic procedures, outcome, complications associated with VAC, and length of hospitalization.
Results—The mean number of days until reconstruction was 4.6 days (range, 2–7 days). Reconstructive surgery was successful in all cases. Mean hospitalization was 9.7 days (range, 6–16 days). Complications included dermatitis at the wound margin and loss of vacuum causing wound desiccation.
Conclusion—VAC therapy can be used to achieve adequate management of traumatic distal extremity wounds. VAC provides an effective method of securing skin grafts over the wound bed.
Clinical Relevance—VAC therapy can be used as an ancillary treatment for distal extremity wounds in dogs before surgical repair as well as a method for securing skin grafts to the wound bed.

INTRODUCTION

TRAUMATIC INJURIES causing major soft-tissue damage to the extremities are commonly encountered in animals. Most wounds occur after vehicular trauma. The resultant shear force separates skin and subcutaneous tissue from underlying muscle and fascia. Skin may be completely avulsed from the extremity or produce a tissue flap attached by a pedicle of varying width. Concurrent orthopedic injury (exposed joints, ligamentous and tendinous damage resulting in joint instability, and loss of bone) is often present.[1,2]

After patient stabilization, early wound management includes debridement of devitalized tissues, vigorous wound lavage to reduce contamination, and application of a wet-to-dry bandage reinforced with a splint if there is joint instability. Wet-to-dry bandages are often changed once or twice daily under sedation or general anesthesia if further debridement is necessary, and this process is continued until the wound is sufficiently healthy for soft-tissue repair and orthopedic repair if needed.

Use of vacuum-assisted closure (VAC) therapy is an alternative strategy for wound management in human surgery. VAC therapy is the controlled use of subatmospheric pressure to a wound by intermittent or continuous application of negative pressure to a specialized wound dressing to help promote wound healing.[3–7] VAC use includes decubital ulcers, degloving injuries, distal extremity wounds, securing split thickness skin grafts in anatomically challenging areas, poststernotomy dehiscence after cardiac surgery, open peritonitis, abdominal wound dehiscence, and perineal wounds.

To our knowledge, VAC therapy for treatment of traumatic wounds in dogs has not been reported. Based

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on human literature, we hypothesized that VAC therapy may be useful for the treatment of traumatic injuries of the distal extremities in dogs and may decrease wound healing and hospitalization times. Thus, our purpose was to evaluate clinical experience with VAC therapy in dogs with traumatic distal extremity wounds.

MATERIAL AND METHODS

Criteria for Inclusion

Dogs with traumatic distal extremity wounds (1999–2003) treated with VAC therapy were included. For inclusion, dogs had to have no other major abnormalities beyond their wound based on physical examination, hematologic, serum biochemical, and urinalysis profiles.

Data Retrieved

Data collected included signalment, wound cause and location, time until surgical intervention, reconstructive methods, orthopedic procedures if applicable, outcome, hospitalization time, and complications associated with VAC therapy.

Clinical Management

VAC therapy was initiated after emergency medical and supportive care. Dogs were sedated with propofol (6 mg/kg intravenously [IV], to effect), and the wound was clipped and cleaned, explored, thoroughly debrided of any devitalized tissue (including bone), and thoroughly lavaged with physiologic saline (0.9% NaCl) solution under aseptic conditions. Microbial culture was not performed before initial treatment.

VAC therapy consisted of placing open cell ether foam (V.A.C, KCI USA Inc, San Antonio, TX) precut to the wound shape over the wound. Embedded into the foam was a noncollapsible, side-ported evacuation tube (Fig 1). The foam was positioned on the wound so that the evacuation tube exited in a proximal direction to decrease the likelihood of the tube becoming kinked or dislodged. The surrounding skin was completely cleaned and dried, and clipped of hair to assure good contact with an adhesive drape circumferentially placed over the foam and limb, overlapping the wound margin by $\geq$ 5 cm. The evacuation tube was elevated from the skin, wrapped by the adhesive drape to avoid undue tubing pressure on the skin, and connected to a vacuum pump (V.A.C, KCI USA Inc). The applied pressure was -125 mmHg in a continuous setting,[3] which caused collapse of the foam and an airtight seal. Cefazolin (22 mg/kg, IV, every 8 hours), morphine (0.25 mg/kg, subcutaneously, every 4–6 hours), and IV fluid therapy were administered as needed.

VAC sponges were changed every 24 hours for the first 2 days. After sedation, the wound was inspected, the vacuum pump turned off, and the evacuation tube disconnected, which allowed reexpansion of the foam beneath the adhesive drape. The adhesive drape directly over the sponge was removed leaving the rest of the drape in contact with the skin to hold additional adhesive drapes after foam change. Wounds were inspected and flushed with warmed physiologic saline solution and the skin thoroughly dried. Sterile gloves were used to perform foam changes and apply new adhesive drape, then the evacuation tube was reconnected to the vacuum pump, and continuous suction at -125 mmHg re-established.

Fig 1. Vacuum-assisted closure components, which include the calibrated vacuum pump, open cell ether foam, and the noncollapsible evacuation tube. The pump can be used in a continuous or intermittent vacuum setting.

For dogs where full thickness mesh grafts were applied, VAC therapy was used as a method of immobilizing the graft-wound bed interface immediately after reconstructive surgery. In these dogs, petroleum-impregnated gauze (Adaptic, Johnson & Johnson Medical, Skipton, UK) was applied over the graft before placing the foam and 75 mmHg of continuous suction pressure was used.[7] After 72 hours, the dog was sedated, the adhesive drape removed, and graft viability assessed.

RESULTS

Signalment

Fifteen dogs were included (Table 1). Breed distribution was mixed breed (7), Australian shepherd (3), Labrador retriever (2), German shepherd (1), Weimaraner (1), and Swiss mountain dog (1). Mean age at admission was 3.7 years (range, 8 months—9 years). All injuries were caused by vehicular trauma and dogs were admitted within 48 hours of injury.

Preoperative Evaluation

Wounds were medial tarsal (9 dogs), medial carpal (5), and 1 dog had a tibial and a tarsal wound (Table 1).

Table 1. Summary Data for 15 Dogs with Extensive Traumatic Injuries of the Distal Extremities, Involving the Carpus or Tarsus, Treated with Vacuum-Assisted Closure Therapy

Dog	Age (years)	Sex	Weight (kg)	Wound*	Surgical Procedure	Complication	Days Until Surgery	Outcome	Hospitalization (days)
1	9	FS	12	Tarsus	Type-II ESF/RSCF	Leakage of VAC Dermatitis	3	Flap survived	6
2	1	MC	18	Tarsus	RSCF/Splint	Leakage of VAC Dermatitis	4	Flap survived	7
3	7	FS	32	Tarsus	Type-II ESF/mesh skin graft	None	5	Graft survived	9
4	2	M	30	Tarsus	Full thickness skin graft/Splint	None	5	Graft survived	9
5	0.8	F	16	Tarsus	Type-II ESF/RSCF	None	5	Flap survived	10
6	7	M	32	Tarsus	Full thickness skin graft/Splint	None	6	Graft survived	11
7	3	FS	23	Tarsus	RSCF/Splint	None	2	Flap survived	7
8	1.5	FS	41	Tarsus	RSCF/Splint	None	4	Flap survived	11
9	3	M	31	Tibia and tarsus	Free muscle transfer/Mesh skin graft/Prosthetic ligament	Implant infection	7	Flap survived	16
10	4	MC	31	Caudal-dorsal tarsus	Full thickness skin graft/Splint	None	7	Flap survived	12
11	6	MC	23.8	Carpus	Type-II ESF/Mesh skin graft	None	4	Graft survived	10
12	2	MC	21	Carpus	Full thickness skin graft/Splint	None	4	Graft survived	8
13	7	MC	42	Carpus	Full thickness skin graft/Splint	None	5	Graft survived	11
14	1.5	FS	28	Carpus	Full thickness skin graft/Splint	None	4	Graft survived	10
15	1	F	48	Carpus	Full thickness skin graft/Splint	None	5	Graft survived	9

*All wounds were associated with medial collateral ligament rupture.
FS, female spayed; F, female; MC, male castrated; M, male; ESF, external skeletal fixator; RSCF, reverse saphenous conduit flap.

Concurrent injuries included medial collateral injuries on stress radiographs (tarsal joint—dogs 1–10; carpal joint—dogs 11–15); no fractures were detected.

Initial Management

Dogs had varying degrees of stabilization and emergency wound management before definitive treatment. Emergency measures included wound debridement and wound lavage with sterile saline solution. Cefazolin (20 mg/kg IV every 8 hours) was administered for the duration of VAC therapy, then on hospital discharge cephalexin (22 mg/kg, orally, twice daily for 2 weeks) was administered.

VAC Application

For the initial 2 dogs (dogs 1, 2) the entire adhesive drape was removed from the limb and replaced at each bandage change, thereafter dogs 3–15 had only that portion of the adhesive drape immediately over the foam removed as described above.

Fluid exudate in excess of 100 mL in 48 hours was frequently encountered. Within the first 48 hours after initial VAC application, there was increased deposition of granulation tissue (Fig 2) after which there was no need for further wound debridement. Mean days until reconstruction was 4.6 days (range, 2–7 days).

Surgical Procedure

A reverse saphenous conduit flap was used to repair the skin defect in 5 dogs[8] (dogs 1, 2, 5, 7, 8) whereas 9 dogs had a free skin graft (dogs 3, 4, 6, 10–15). In dog 9, a combined free muscle transfer of the rectus abdominis muscle and a mesh graft were used to cover the skin defect. This dog also required a prosthetic ligament to stabilize the tibial–tarsal joint. Most dogs (2, 4, 6–8, 10, 12–15) required a medial splint to immobilize the affected joint. In dog 5, complete repair of the skin defect could

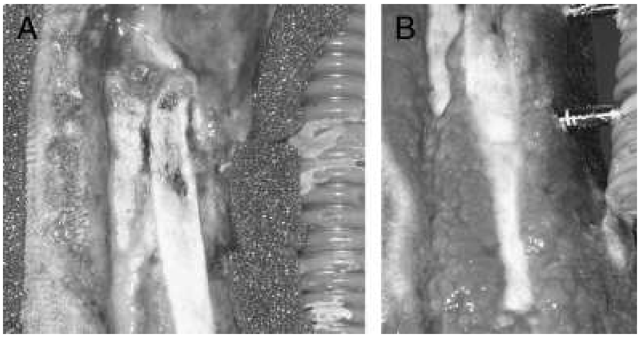

Fig 2. Dog 5. Shearing wound of the tarsus. (A) Wound 3 days after wet-to-dry bandaging. There is bone exposure and limited granulation tissue. (B) 48 hours after VAC therapy. Most of the exposed bone is covered with granulation tissue.

not be established with a reverse saphenous conduit flap and $\sim 1/3$ of the distal portion of the wound remained uncovered. The flap survived, and the remaining exposed wound was subsequently repaired with a mesh skin graft. After suturing the skin graft to the wound bed, VAC therapy was again applied to secure the sutured skin graft to the wound bed.

VAC was removed for graft viability assessment at 72 hours; all grafts survived. Mean VAC time was 9.7 days (range, 6–16 days). The external skeletal fixator in 4 dogs (1, 3, 5, 11) was removed in 4–6 weeks. All splints were removed in 4–6 weeks. The prosthetic ligament implant was removed at 6 weeks because of infection of the implant causing a draining tract.

Hospitalization

Median hospitalization (admission to discharge) was 11 days.

Complications

Complications directly related to VAC were few and largely technical in origin. In dogs 1 and 2, loss of vacuum resulting from incorrect removal of the adhesive drape covering the sponge led to wound desiccation. These 2 dogs developed dermatitis immediately adjacent to the the wound as a result of completely removing the adhesive at each bandage change.

DISCUSSION

Based on clinical experience with conventional wound management techniques, including use of wet-to-dry bandaging,[9,10] we found that VAC therapy promoted early wound healing and granulation tissue formation in dogs with extensive traumatic injuries of the distal extremities. Successful wound healing occurred in 15 dogs with soft-tissue injuries involving the carpus and tarsus with few complications. Tissue edema was notably reduced 2–7 days after VAC use and granulation tissue was typically present within 48 hours. Mean time from start of VAC therapy to use of reconstructive techniques was 4.6 days (range, 2–7 days). It was our impression that VC therapy was also very effective in stabilizing skin grafts used to manage wound healing in these dogs.

Mechanism of VAC Action

Application of subatmospheric pressure causes the foam dressing to collapse and the resultant mechanical forces are transmitted to all wound surfaces in contact with the foam dressing. The applied forces result in an increased mitotic rate and angiogenesis and adjacent tissues are recruited through viscoelastic flow.[3] Negative pressure effectively accelerated granulation tissue formation and subsequent wound shrinkage, necessitating fewer procedures to achieve wound closure.[3] We typically observed granulation tissue formation in our dogs within 48 hours. Previous human[4,5,11] and experimental animal[6] studies report that subatmospheric pressure promoted faster healing and increased granulation tissue formation compared with standard wet-to-dry dressings. Another beneficial action is mechanical stimulation of cells by tensile forces on surrounding tissues caused by collapse of the foam dressing.[12]

Ilizarov bone distraction technique has shown how tissue moves and grows in response to applied mechanical force, with viscoelastic flow increasing mitotic rate and distraction histiogenesis.[12,13] Several in vivo and in vitro studies have shown that mechanical stress applied to cells increases the expression of certain growth factors (e.g., vascular endothelial growth factor and fibroblast growth factor-2) that are known stimulators of angiogenesis and cell proliferation.[14–18] Two broad mechanisms of action have been proposed for VAC effects: removal of fluid and mechanical deformation.[16]

Fluid removal both decreases edema decreasing interstitial pressure and shortening diffusion distances, and removes soluble factors that may slow healing.[16] The effects of mechanical deformation on increased tissue growth are well known from experience with tissue expansion in plastic and reconstructive surgery.[16]With vacuum application to tissue in VAC therapy, there is continuous removal of excess fluid from the interstitium at the wound periphery, resulting in decreased local interstitial pressure and restoration of flow to compressed blood vessels.[17] It has been suggested that wound fluid contains factors, which, when applied to cells in culture, inhibit mitosis, protein synthesis, and collagen synthesis.[18]Active fluid withdrawal from nonhealing or slowly healing wounds should remove these inhibitory factors.[18] Laser Doppler probes incorporated into the foam show a 5-fold increase in skin blood flow with continuous negative pressure (range, 25–500 mmHg) during VAC therapy.[19] VAC also promotes capillary blood flow velocity, increased capillary bed and blood volume, stimulates endothelial proliferation and angiogenesis, narrows endothelial spaces, and restores capillary basement membrane integrity,[17] which collectively should improve blood circulation in wounds. By narrowing endothelial spaces and restoring capillary basement membrane integrity, VAC could decrease vessel permeability and wound edema; however, another report identified relative hypoperfusion close to the wound edge.[20] The hypoperfused zone was larger at high negative pressures and was especially prominent in subcutaneous tissue. VAC therapy also induced a change in microvascular blood flow that is dependent on the pressure applied, the distance from the wound edge, and the tissue type.[20]

Effect of VAC on Cytokines

In pigs, VAC wound therapy resulted in an earlier, and greater, peaking of IL-10 and maintenance of IL-6 levels compared with saline-moistened gauze control wounds, which showed decreased IL-6 values.[21] Increased local release of proinflammatory interleukins (IL-6, IL-8) and angiogenic growth factors in wounds have also been observed after VAC therapy in humans.[22] These mediators may be involved in the accumulation of neutrophils and in development of angiogenesis, which appear to play a crucial role in the accelerated granulation tissue formation after VAC therapy.[22] Increase in local vascularity and tissue oxygen tension enhances resistance to infection, mainly through more effective neutrophil function and decreased potential for anaerobic colonization and growth.[23] VAC therapy decreased bacterial numbers from $\sim 10^7$/gm tissue to 10^2–10^3/gm tissue in humans[3]; however, in a more recent randomized prospective trial in human patients,[24] there was no significant quantitative reduction in bacterial load with either VAC or conventional therapy. These results differ from an earlier rat model clinical study where, using semiquantitative superficial swabs, VAC therapy caused a trend toward reduced bacterial load[25] and a study in pigs where there was a significant decrease in bacterial numbers in tissue biopsies.[6] The observed differences may reflect the animal model used where wounds were deliberately contaminated with bacteria. One explanation for a decrease in non-fermentative Gram-negative rods could be the creation of an external hypoxic environment. Interestingly, an increase in the number of *Staphylococcus aureus* was found in VAC-treated wounds of rats.[25] In another study in there was no consistent effect of VAC on bacterial clearance.[26] We did not perform wound microbial culture.

Securing Skin Grafts

Our experience suggests that VAC therapy can be used as an adjunctive method for securing skin grafts to the wound bed in dogs. With the application of a continuous negative-pressure dressing, uniform distribution of pressure and apposition between the graft and the wound bed is achieved even if the surface contour is irregular.[27] This becomes particularly important in dogs with traumatic injuries that need grafting because grafts are often applied in irregularly contoured regions like the fore and hind limbs. The negative-pressure dressing provides continuous removal of wound fluids preventing hematoma or seroma formation, which contribute to graft loss.[28] The occlusive nature of the VAC dressing maintains a moist environment preventing graft desiccation, which is detrimental to healing.[29] We found that the use of negative-pressure dressing as skin graft reinforcement had advantages including: (1) ease and speed of application; (2) it readily conformed to any surface; (3) achieved wound fluid removal, minimizing seroma or hematoma formation; and (4) it immobilized the graft tissue interface, reducing graft failures because of movement.

In humans, shearing injuries are typically managed by skin replacement as a full thickness or meshed split-thickness graft;[30] however, other techniques, like revascularization of the sheared tissue, and free-flap reconstruction are also advocated.[31,32] Sutures and staples are commonly used to secure grafts[33] but VAC has also been used especially with split-thickness grafts[7,34] and is associated with improved graft survival as measured by reduction in the number of repeated graft attempts.[28,35–37] VAC dressings were also successfully used to secure large, circumferentially sutured skin grafts.[33]

Complications

Complications associated with VAC therapy were minor and largely technical in origin. The first 2 dogs had vacuum loss because we removed the adhesive drape completely. This led to wound desiccation and dermatitis developed immediately adjacent the wound. Changing the bandaging protocol so that only the adhesive tape immediately over the open cell ether foam was removed seemingly resolved this problem, which did not occur in the other 13 dogs.

The most commonly encountered complications in human VAC use include erosion of surrounding tissue because of pressure caused by the evacuation tubing, excessive in-growth of granulation tissue into the foam dressing, and desiccation of the tissue when an inadequate seal is obtained.[3] Excessive tissue in-growth into the foam dressing occurred when time between dressing changes was prolonged. Foam removal is recommended at least every 48 hours and longer intervals can result in the disruption of newly formed capillary beds and cause minor bleeding. We believe that changing the foam dressing every 24 hours for the first 2 days and then every 48 hours reduced the chance of in-growth of granulation tissue into the foam dressing in our dogs.

Erosion of adjacent tissue by the evacuation tube was not observed in our dogs, possibly because we elevated the tube and wrapped it in adhesive drape to minimize skin pressure. When vacuum was applied, the foam collapsed achieving an airtight seal, which would explain why we did not observe tissue desiccation in the other dogs. We selected -125 mmHg pressure based on observations that wounds treated with this negative pressure had a significant increase in granulation tissue formation compared with treatment at -25 or -500 mmHg.[6]

Despite limitations of a retrospective study with relatively low case numbers and a lack of objective measurements of wound healing, based on our clinical experience with other methods of wound management for shearing injuries of the canine carpus and tarsus, we believe that VAC therapy is useful for the treatment of distal extremity wounds. It seemingly promotes early granulation tissue formation and wound closure and effectively stabilizes skin grafts. Although VAC therapy is early in the course of its development and application in veterinary patients, we are encouraged by the outcomes we observed and commend it as a method of wound management that warrants further investigation.

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