A 49-year-old (estimated age) female Aldabra tortoise (*Geochelone gigantea*) was evaluated because of focal necrosis, deep abscess formation, and osteomyelitis affecting the third vertebral carapacial scute and underlying dermal bone. Manual debridement of the necrotic scute with rongeurs was performed under anesthesia and revealed 3 adjacent defects in the carapace encompassing a total area of 14.5 × 11.5 cm with an average depth of 1 to 2 cm (Figure 1). A focal area (1 × 3 × 3 cm) of the central portion of the defect extended 1 to 2 cm deeper into the bone than the remainder of the lesion. A CBC revealed mild leukocytosis (12,000 WBCs/µL; reference range, 1,750 to 9,690 WBCs/µL) attributable to heterophilia (7,920 cells/µL; reference range, 150 to 6,390 cells/µL) and monocytosis (1,560 cells/µL; reference range, 20 to 400 cells/µL). Results of plasma biochemical analyses were within reference ranges. Aerobic bacterial culture of wound swab specimens yielded *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Pseudomonas* spp. Susceptibility testing indicated that the *Pseudomonas* isolate was moderately resistant to most antimicrobials, but all organisms were susceptible to gentamicin and enrofloxacin. Fungal cultures revealed low growth of *Paecilomyces* spp and moderate growth of *Candida tropicalis*.

Initial management of the wound included application of wet-to-dry bandages and systemic administration of amikacin (2.5 mg/kg [1.1 mg/lb], IM, q 72 h for 5 doses). As the appearance of the wound improved, topical treatment with dilute chlorhexidine lavage followed by application of 1% silver sulfadiazine cream was initiated. Following 23 days of treating...
ment, deep infection of the wound appeared to be resolving, and a thin layer of healthy, pink granulation tissue was visible over 60% to 70% of the wound. The remainder of the wound was covered by a layer of yellow, proteinaceous material where local surface infection appeared to still be present. Laboratory testing at this time revealed resolution of the leukocytosis (5,000 WBCs/μL) and no other clinically important changes.

To aid in wound healing and control microbial contamination, a VAC system was applied to the wound. A foam pad was cut to fit the shape of the wound and covered with an occlusive, clear-plastic adhesive bandage. The bandage was attached via an adapter and suction tubing to the VAC system, which was set to provide continuous negative pressure of 125 mm Hg. The VAC system pump was suspended above the animal, allowing the animal free movement throughout the holding area. Wound dressings were changed every other day, despite a lack of appreciable fluid removal from the wound. Following 10 days of treatment with the VAC system, the deeper central portion of the wound developed a greenish discoloration and exudate. Portions of the wound that had previously been covered with healthy appearing granulation tissue had developed a yellow discoloration, similar to the discoloration initially seen in the nonhealing areas. The VAC system was removed, and the wound was lavaged with dilute chlorhexidine. The following day, bone underlying the wound appeared avascular.

Deterioration of the wound was assumed to be related to a combination of local infection and avascular bone. The animal was anesthetized for reevaluation, and the wound was prepared for reapplication of the VAC system. The avascular bone was removed, and the entire wound was extensively debrided with rongeurs and a handheld rotary tool equipped with a high-speed cutting burr. The 3 defects were connected into a single confluent lesion, and the wound margins were beveled outwards to eliminate undermined edges. Tissue was removed over the entire wound surface until healthy bleeding bone was encountered. Following debridement, the surface of the entire wound bed was etched with the rotary tool to increase the surface area of exposed bleeding bone (Figure 2). Heat generated from the rotary tool was dissipated by constant irrigation with sterile saline (0.9% NaCl) solution. The VAC system was reapplied to the wound (day 0) with a continuous negative pressure of 125 mm Hg. Treatment with ceftazidime (18 mg/kg [8.2 mg/lb], IM, q 72 h) was initiated, and analgesia was provided with ketoprofen (1.8 mg/kg [0.8 mg/lb], IM, prn) and buprenorphine (0.008 mg/kg [0.0036 mg/lb], IM, prn).

The foam bandage was changed daily for the next 4 days (days 1 through 4). Initially, approximately 150 mL of blood and serosanguinous transudate was recovered from the wound each day, but this volume progressively decreased until, after 4 days, the wound only produced enough fluid each day to saturate the foam pad. The wound was alternately lavaged with sterile saline solution and dilute chlorhexidine during bandage changes, and granulation tissue was visible by day 4. After day 4, the bandage was not changed again until day 9, when 75 mL of a proteinaceous, yellow fluid was obtained from the wound overnight. The fluid had a slightly putrid odor, and aerobic bacterial culture yielded Enterobacter agglomerans. Antimicrobial treatment was changed on the basis of results of susceptibility testing to enrofloxacin (5 mg/kg [2.3 mg/lb], IM, q 24 h for 9 days). No gross necrosis was present, and microbial growth was suspected to be restricted to the fluid accumulated in the foam pad and superficial wound contamination. The granulation bed continued to appear healthy and was largely complete at this time, although much of the granulation tissue was now tan (Figure 3). Hard pinpoint spicules were present within the granulation tissue, representing new bone formation or keratinized tissue.

The bandage was changed every other day for the next 23 days (days 10 through 33). Beginning on day 19, a silver-coated, nonadherent polyethylene mesh was placed over the granulation bed, under the foam pad, to decrease surface contamination and microbial growth in the foam pad. Three days later, there was no longer an odor associated with the foam pad. The remaining pink granulation tissue was gradually replaced with tan tissue, and spicule formation continued to progress. A dried proteinaceous transudate covered large areas of the wound, and the underlying tissue bled easily if this layer was disturbed. A silver-impregnated foam pad was substituted for the silver-coated mesh on day 37, and the frequency of bandage changes was reduced to once every 4 days. By this time, the wound was noticeably more shallow and smooth.

After 55 days, use of the VAC system was discontinued and the wound was considered healed. Smooth, palpable carapacial bone was present beneath the entire wound. A layer of dried transudate covered much of the epidermis covering the wound surface. The epidermal tissue showed variable keratinization at this time, with progressing areas of normal pigmentation. The surface of the wound was gently scrubbed 2 to 3 times a week...
for the following several weeks with dilute povidone iodine or chlorhexidine scrub to loosen the dried transudate. Lidocaine ointment (5%) was topically applied to the wound, as the tortoise would occasionally react to the scrubbing. Keratin continued to develop and was considered normal in thickness by day 122, with large areas having normal pigmentation (Figure 3).

Discussion

We report a case of deep shell infection and associated osteomyelitis in an Aldabra tortoise that was treated with VAC and silver-containing bandage materials. Treatment in this case resulted in quick wound healing and a marked decrease in wound healing time, compared with traditional methods, suggesting that VAC with silver-containing bandage materials may represent a more effective and practical treatment for shell wounds than what has been previously assumed. However, additional research is needed.

The chelonian shell is a dynamic, metabolically active structure composed of approximately 60 dermal bones of membranous origin covered with keratinized epidermal plates known as scutes. Scute margins do not correspond with dermal bone margins, and this overlap contributes to the strength of the shell. Traumatic injuries, burns, and bacterial and fungal infections can all damage the integrity of the shell. Superficial lesions result in ulceration of the keratinized epidermal layer; progression of these lesions can cause abscess formation and osteomyelitis in the underlying bone. Deep shell lesions are not well described in the clinical literature, but such cases are commonly encountered and can be difficult to manage. The initial cause of the lesion in the case described in the present report was not known.

Management of open wounds and deep shell abscesses in chelonians has generally consisted of repeated wound debridement to the level of healthy bleeding bone; topical and systemic administration of antimicrobials; and application of wet-to-dry bandages covered with a semipermeable, self-adhesive dressing. However, sealing a site with any remaining infection can have disastrous consequences in terms of osteomyelitis and cellulitis related to the lack of drainage. Because obtaining complete microbial con-
control is challenging, this approach has begun to fall out of favor as the treatment of choice,3,8 being replaced by open wound management with long-term bandaging. Definitive rates of healing associated with traditional methods have not been established, but complete healing may take 1 to 2 years.3,6,7 In contrast, findings for the tortoise described in the present report suggested that VAC may represent an effective way to increase the rate of wound healing and decrease the healing time.

Vacuum-assisted closure is a well-established method of NPWT in humans and has been effectively used to accelerate wound healing.8-11 In general terms, VAC involves applying an open-cell polyurethane foam either alone with pore size ranging from 400 to 600 µm to the wound bed. The foam is cut to approximate the shape of the wound, and bridges of foam can be used to connect adjacent wounds. The open-cell nature of the foam permits equal distribution of applied suction.10,11 The foam is covered by an air-occlusive, plastic, adherent dressing and attached via suction tubing to a control unit that regulates the amount of negative pressure applied and collects fluid removed from the wound (Figure 4). Proper functioning and an airtight seal can be visually confirmed by compression of the foam as negative pressure is established.

Maintaining negative pressure across a wound positively influences wound healing in multiple ways. The vacuum progressively reapproximates pliable soft tissue, pulling it together until it closes. The mechanical stress that is exerted at a cellular level is believed to increase the formation of granulation tissue by promoting cell division, angiogenesis, and local elaboration of growth factors.12 By draining away accumulated fluid and drawing tissue fluid through the wound, NPWT appears to exert a cleansing and stimulating effect on the wound bed. Removal of factors such as metalloproteases that inhibit wound healing may allow local growth factors to function more efficiently.11 Also, NPWT may directly decrease the bacterial burden in infected wounds,13 although more recent data refute the idea that bacterial clearance is enhanced with VAC.14 Granulation tissue formation is limited by available vascularity, and VAC has been shown to enhance perfusion and increase microvascular blood supply to wounds through various mechanisms.13,15,16

Various controlled studies and clinical observations10,11,17 have demonstrated that wounds granulate and heal significantly faster with VAC than with traditional dressing regimens. The use of VAC in the tortoise described in the present report resulted in healing of the carapacial wound at a faster rate than what would be expected with traditional methods. Granulation of the wound appeared complete only 9 days after extensive debridement and reapplication of the VAC system. Epithelialization of the granulation bed progressed quickly, and a complete layer of epidermal tissue with progressing keratinization was present on day 55, when the VAC system was removed. Keratinization progressed steadily without complications following removal of the VAC system, and by day 122, the keratinized epidermis was of normal thickness. This rate of wound healing was quicker than that described in a recent report18 of a similar lesion in a tortoise, in which VAC was used for 161 days and the wound was not completely closed until day 210. Our experience indicated that a shorter application of VAC may be possible in some cases, making this treatment a practical possibility for the routine management of infected shell wounds.

In humans, serial debridement combined with NPWT has been shown to result in consistent decreases in wound volume across a wide variety of wounds.19 The debridement approach used prior to reapplication of the VAC system in the tortoise described in the present report was believed to contribute considerably to the increased rate of healing. Creating a single confluent wound with wide margins and thorough removal of all compromised tissue provided a healthy wound environment. Etching the wound surface with the rotary tool increased surface area and vascular supply, providing a better local environment for granulation tissue to form. New tissue growth and ossification were evident both from the margins of the defect and directly from the wound surface. In a similar case,18 wound healing was reported to occur only from the edges of the wound, which may have partially accounted for the longer healing time.

The use of silver-impregnated bandages has been found to be beneficial in human wound care and was successful in the present case in controlling wound odor and microbial contamination of the wound surface. One of the contemporary hypotheses for delayed healing of wounds is bacterial imbalance, whereby the bioburden of excessive bacteria in the wound produces a chronic reaction that impedes healing.20 The maintenance of a healthy wound environment in chelonian shell lesions covered with traditional bandage materials can be challenging. Excessive bacterial bioburden may represent one factor contributing to the slow healing times typically observed in chelonians. Local antimicrobial dressings, such as those containing silver, decrease the number of bacteria in the wound and may augment healing.21 Although care must be taken to not extrapolate too much from a single case, we subjectively found that wound healing appeared to progress more rapidly following incorporation of silver-containing bandage materials. In our experience, the silver-impregnated foam pad was easier to use than the nonadherent silver-coated mesh, although the mesh provided a higher concentration of silver.

The monitoring and alarm functions of the VAC system protect against air leaks in the system, which can lead to deterioration of wounds, presumably through desiccation and necrosis.22 Commercially available VAC systems also allow for control of the pressure settings. Intermittent, cyclic application of negative pressure (generally 5 minutes of suction followed by 2 minutes without suction) has been suggested to be superior to continuous application of negative pressure in achieving peak blood flow to experimentally created wounds,13,18 although controlled clinical data are not available and continuous suction has been used effectively in many human settings.23 A study22 in swine found that the regulated use of 125 mm Hg of negative pressure was superior to higher and lower negative pressures in accelerating wound healing.

Following use of the VAC system in the present case, the healed carapace had a smooth appearance,
with no pitting or defects. Normal pigmentation quickly returned to the healed lesion. The surface of the healed wound remained slightly depressed, compared with the remainder of the carapace, but additional keratin deposition over the following 6 months made this difference less noticeable. Traditional approaches to shell healing often result in deep, irregular scars that remain for years or even permanently. Although additional cases would be necessary to evaluate the appearance of healed wounds, results for the present case and for a previously reported case suggest that VAC may be appropriate in situations where a cosmetic repair of the shell is highly desirable.

Despite success in the human medical field, the application of VAC in veterinary medicine has been limited. A recent retrospective study concluded VAC was an effective wound management approach for the treatment of traumatic distal extremity wounds in dogs. In that study, VAC increased the rate of wound healing and provided an effective method for securing skin grafts over the wound bed. Although controlled studies are needed, VAC has reportedly been successfully used to manage a variety of wounds in dogs. Case reports have also described the successful use of VAC in treating soft tissue wounds in a horse and a tiger. Reports of nonmammalian applications are scarce, but VAC was suggested to result in improved healing time and management of traumatic shell defects in chelonians, in which lung or other tissues were pulled away from the shell. A VAC system can be applied over any type of tissue or material, including dermis, fat, fascia, tendon, muscle, bone, grafts, and hardware. Care must be taken when applying NPWT near exposed vessels because of the risk of bleeding. Wounds must be thoroughly debrided, free of all grossly necrotic tissue, and well vascularized or additional necrosis is likely to occur. Use of VAC in areas containing necrotic or ischemic tissue is contraindicated, as it may lead to further necrosis. Necrotic and infected tissues are frequently encountered beneath healthy appearing scutes in chelonians. Although not grossly apparent, necrotic and avascular tissue may have persisted following the first debridement in the tortoise described in the present report, leading to the deterioration of the wound bed following the initial application of the VAC system. A more aggressive second debridement thoroughly eliminated any remaining pockets of necrosis. In addition, connecting the 3 smaller lesions into a single confluent lesion helped eliminate potential pockets of necrosis.

Bandage changes are generally recommended every 24 to 72 hours during VAC of wounds in humans. In the tortoise described in the present report, daily bandage changes were necessary during the first 4 days following application of the VAC system because of the amount of fluid being removed. Following a natural decrease in the volume of fluid removed from the wound on day 4, an early attempt was made to decrease the frequency of bandage changes to once every 5 days on the basis of findings in a previous report. This resulted in a minor setback as a result of surface microbial growth. Resumption of every-other-day bandage changes and incorporation of silver-containing bandage materials on day 19 corrected the problem. In humans, ingrowth of granulation tissue into the foam pad necessitates frequent bandage changes. The slower rate of wound healing in chelonians may allow for less frequent bandage changes, especially if secondary measures (eg, silver-containing bandage materials) are used to limit microbial growth on the wound surface and in the foam pad. As wound healing progressed in the present case, the frequency of bandage changes was successfully decreased to once every 4 days. A total of only 21 bandage changes were necessary over 55 days to achieve complete wound healing.

Wound management with VAC in humans is associated with increases in range of motion and comfort. Human patients most frequently complain of discomfort only during bandage changes, particularly if the dressing has become adhered to the healing tissues. Thus, most patients prefer the less frequent dressing changes associated with NPWT, compared with standard wound management regimens. We found bandage changes with the VAC system to be quick, efficient, and less distressing to the tortoise than with the use of traditional wet-to-dry bandages. The tortoise reacted when negative pressure was first established following a bandage change, but otherwise did not appear disturbed by the VAC system. The intensity of the initial suction applied by the VAC unit was adjustable (allowing the time required for the unit to achieve the set pressure of 125 mm Hg to be increased) and the tortoise reacted less when the initial suction intensity was decreased. Suspension of the unit from the ceiling provided constant electrical supply to the unit, alleviating the need to recharge the unit’s battery supply and allowing the tortoise to move around and access a pool for soaking. Throughout treatment, the tortoise was active and alert with a normal appetite. The adhesive dressing applied to the carapace provided a seal for several days, even if the shell was exposed to water. No air leaks were encountered during treatment, and the bandage never became dislodged.

Although associated bandage materials are more expensive, VAC has been shown to have clear economic savings in human medicine when compared with traditional approaches for wound management. In the present case, dressings were easily applied to the wound, minimizing the staff time necessary for bandage changes, when compared with traditional wet-to-dry bandages. The low number of bandage changes and short hospitalization time also made the treatment more cost-effective. The application of VAC in veterinary medicine is still new, but the overall cost of wound management with VAC in dogs is lower than the cost of traditional treatments because of shorter hospitalization times and lower numbers of bandage changes. The technology for VAC can also be easily adapted to a variety of veterinary settings. Foam pads are available in various shapes and sizes, and substitution of off-the-shelf components for commercially available VAC components has been reported, although it is not widely recommended. Treatment on an outpatient basis should also be possible, as human patients are routinely cared for on an outpatient basis with a VAC system in place.

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A recognized limitation of the present case report is that wound healing times can be influenced by individual variation and a host of outside factors. Nevertheless, the present case illustrates that VAC can effectively be used to manage deep carapacial wounds with osteomyelitis. The decrease in wound healing time for this case, compared with that reported for a similar previous case, suggests that the extensive debridement, including etching of exposed carapacial bone, and incorporation of silver-impregnated bandage materials may have further accelerated wound healing. However, clinical studies are needed to draw firm conclusions on healing rates and optimal treatment regimens.

**References**