8.2 Degloving Injuries

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Introduction

Horses are subject to trauma in relation to their locale, use, and character. Wire fences, sheet metal, or other sharp objects in the environment, as well as entrapment between two immovable objects or during transport, are often the cause of injury. The wounds are commonly associated with extensive soft tissue loss, crush injury, and harsh contamination, which necessitate open wound management and second intention healing. One of the most difficult of these wounds to heal is the degloving injury that exposes bone by avulsion of the skin and subcutaneous tissues overlying it.

Exposed bone is defined as bone denuded of periosteum, which in an open wound can delay second intention healing indirectly and directly.[1] The rigid nature of bone indirectly inhibits contraction of granulation tissue and can prolong the inflammatory phase of repair.[1] Prolonged periods may be required for extensive wounds of the distal extremity with denuded bone and tendon to become covered with a healthy, uniform bed of granulation tissue.[2] Desiccation of the superficial layers of exposed bone can lead to sequestrum formation, which is one of the most common causes for delayed healing of wounds of the distal limb of horses.[3] Rapid coverage of exposed bone with granulation tissue can decrease healing time and prevent desiccation of exposed bone and subsequent sequestrum formation. Exposed bone in distal limb wounds (Figure 8.61) can result in extensive periosteal new bone growth that can lead to increased wound size and result in an enlarged limb, even after healing is complete.[4] Cortical fenestration, curettage, and scraping of exposed bone have been reported in horses, humans, and dogs as a means of promoting granulation tissue formation to enhance second intention healing or provide a vascular bed for skin grafting procedures.[4–7] In one study, drilling holes in the bone produced a greater amount of clot than did scraping the bone. This clot provided an early coverage for the bone and protected it from desiccation. The ingrowth of fibroblasts and capillaries from the bone surface and surrounding tissue into the clot to form granulation tissue was a desired effect.[8]

Skin grafting procedures are commonly used in the management of distal limb wounds in horses.[9] Skin grafts can be applied to fresh wounds that are vascular enough to produce granulation tissue, but graft survival is poor over areas of exposed bone because revascularization of the graft is slow or absent.[10] A healthy and uniform bed of granulation tissue must form over exposed bone before skin grafting procedures can be used.[11]

Figure 8.61. Degloving injury, with extensive loss of soft tissue and periosteum along the dorsal surface of the third metatarsal bone. Larger wounds with exposed bone take longer to form a granulation bed, which subsequently delays wound contraction. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 189, (2004), with permission from Elsevier Saunders.

Numerous studies have been performed to evaluate various aspects of wound healing at the distal aspect of the limb in horses.[2,4,12–20] Most have used models of full-thickness cutaneous wounds of variable size without excision of any appreciable amount of subcutaneous tissue or periosteum. To the author's knowledge, only two studies of wounds of the distal extremity of horses have examined the impact of denuded bone on wound healing.[4,7]

This chapter will review the healing of distal limb wounds and complications related to degloving injuries which expose the underlying bone. Therapies to promote wound healing and control granulation tissue, as well as bandaging methods, will be reviewed. Grafting techniques which could facilitate the healing of distal limb wounds are discussed in Chapter 11.

Healing of Distal Limb Wounds

Vascularity and Granulation

The ability of a tissue to produce granulation tissue is directly related to its vascularity.[3] Tissue with an abundant blood supply, such as muscle, can rapidly produce granulation tissue. Tissue with a poor vascular supply, such as bone, produces granulation tissue slowly, resulting in delayed wound healing.[3] As healthy granulation tissue develops, there is a rapid decrease in total wound area.[4,17] The use of pressure bandages may control the amount of limb edema (Figure 8.62). Exuberant granulation tissue can enlarge a wound by "pushing" its edges apart. For injuries associated with exposed bone, excessive periosteal new bone growth may contribute to a prolonged period of wound expansion.[4]

Figure 8.62. Pressure bandage with comfortable absorptive dressing provides protection from wound contamination and assists in wound debridement, absorption of exudate, and reduction in limb swelling. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 189, (2004), with permission from Elsevier Saunders.

Wound Contraction

Wound contraction is the inward or central movement of the wound edges due to "pulling" forces generated within the wound and is one of the major means of wound closure in second intention healing. Fibroblasts and myofibroblasts are the major cell types that contribute to wound contraction. Reorganization of collagen by fibroblast cell membrane movement causes wound contraction by condensing or "piling up" the collagen into a smaller unit.[21] Skin, which is attached to the granulation tissue, is subsequently moved toward the center of the wound. The exact role of the myofibroblast is poorly understood because it has been shown that rat wounds lacking myofibroblasts can contract.[22] Myofibroblasts may play a passive role by counteracting tensile forces on the skin during wound healing.[21]

Second Intention Healing

Second intention healing of wounds located at the distal aspect of the limb of horses can be lengthy and complicated. Wounds of the distal extremity in horses heal less quickly than those of the trunk because of comparatively slower rates of epithelialization and contraction.[4] There are also differences in wound healing between hor and ponies.[4,12,13] Similar wounds on the dorsal aspect of the metatarsal region heal more slowly in horses, compared to ponies, because wound contraction in ponies occurs to a greater extent than it does in

Histological analyses of these wounds showed a prolonged inflammatory phase in the horse, as well as less organization of the myofibroblasts, compared to ponies.[4,12] The higher TGF-β concentrations present in the wounded tissues of ponies may explain the more intense inflammatory response and greater degree of wound contraction The slower rates of epithelialization have been attributed to inhibition of cell mitotic and migratory activity by exuberant granulation tissue.[12] As a result of this finding, authors have investigated whether intramuscular administration of recombinant equine growth hormone (10 ug/kg daily for 7 days, then 20 ug/kg daily for 49 days) would increase the epithelialization rate by increasing the mitotic and migratory activity of the epithelium. Their finding, however, discovered that the use of equine growth hormone does not appear to have any beneficial clinical effect on healing of equine limb wounds.[24]

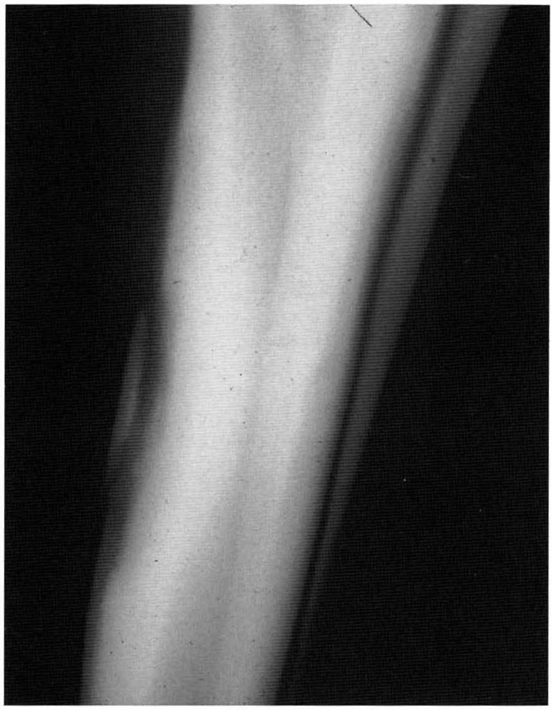

Figure 8.63. Lateral medial radiograph of the third metatarsal bone (MT3) with sequestrum formation of the dorsal aspect of MT3 secondary to a degloving injury 26 days earlier. The sequestrum incites an inflammatory response with accumulation of exudate and eventual wound drainage. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 190, (2004), with permission from Elsevier Saunders.

Sequestra Formation

Sequestra development can be a sequel to trauma and is a common cause of delayed healing of wounds of the distal limbs of horses.[1] Sequestra can result from any insult that interrupts the blood supply to bone. Periosteal trauma may lead to local vascular stasis by reducing venous outflow.[3] Afferent vessels from the periosteum and medullary cavity provide blood flow to the compact portion of long bones. Haversion canals, which are connected by Volkmann canals, contain the capillaries which provide nutrition to compact bone. Outflow, or efferent flow, occurs at the periosteal and endosteal levels. The blood supply in the cortex of equine long bones is sensitive to trauma because the dense mineralized matrix of the bone cortex prevents rapid collateralization of vessels following injury.[25] Ischemia of the superficial layers of the cortex leads to necrosis of the affected area (Figure 8.63).[1] The necrotic portion of bone incites an inflammatory response with accumulation of exudate and can lead to the formation of a draining tract in wounds where the skin has healed over the area.[3] Most reports suggest that infection is required for sequestrum formation, while others counter this hypothesis.[3] Sequestra can delay wound healing by serving as foci of continued inflammation and/or infection, which postpone the ensuing phases of repair.

Impediments to Wound Healing

A rapid reduction in wound area due to contraction and epithelialization, following an initial period of wound expansion, has been reported in several studies.[4,7] Exuberant granulation tissue can decrease the rate of wound contraction and epithelialization by providing a physical barrier that impedes movement of the wound margins and advancing epithelium (Figure 8.64).[26] Persistent swelling, associated with wound inflammation, increases the total circumference of the limb, thereby increasing the surface area of each wound. A large amount of periosteal new bone growth beneath the wound may also contribute to increased total wound area measurements.

Figure 8.64. Exuberant granulation tissue in a wound located on the dorsal aspect of the metatarsus. Exuberant granulation tissue can decrease the rate of wound contraction and epithelialization by providing a physical barrier that impedes movement of the wound margins and advancing epithelium. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 190, (2004), with permission from Elsevier Saunders.

Healing of Degloving Wounds

Trauma to the distal aspect of the limb is frequently complicated by exposed or denuded bone.[27] Exposed cortical bone, denuded of periosteum, is subject to desiccation of the superficial layers of the cortex, which may result in infectious superficial osteitis and sequestrum formation.[1,6] The presence of denuded bone in wounds can delay healing by prolonging the inflammatory and repair phases of wound healing. Exposed bone within a wound can delay healing directly if the bone becomes infected, or indirectly because its rigid structure and the limited blood supply available at its cortical surface can impede the formation of granulation tissue and wound contraction.

Distal limb avulsion wounds with exposed bone increase in size for 14–21 days. Wound expansion is due primarily to the distraction forces applied across the wound during the inflammatory and debridement stages of repair and the absence of a granulation bed in the center of the wound to counteract tensile forces exerted on the wound margins by the surrounding skin. Wounds with little or no exposed bone expand for a shorter period because less time is required for granulation tissue to fill the wound. Larger wounds with exposed bone take longer to form a granulation bed, which subsequently delays wound contraction (Figure 8.61).

Complications Associated with Denuded Bone

Injuries involving bones in horses stimulate more periosteal new bone growth than similar wounds in other species and ponies.[4] Periosteal insults from blunt trauma, tendon/joint capsule strain, surgical manipulation, or laceration/degloving injuries may result in extensive periosteal exostosis.[4,28] More extensive periosteal reaction in young versus adult horses has been attributed to a greater osteoblastic activity of the periosteum in the young horse.[28] The extensive periosteal new bone growth seen in adult horses is poorly understood. A species-related delay in collagen lysis may be a contributing factor.[4] The more extensive periosteal new bone formation in horses compared to ponies is believed to result from a slower onset and longer duration of the periosteal response as well as prolonged extensive limb swelling related to the inefficient resolution of the inflammatory response to injury.[4] Bone sequestration is associated with wound drainage, the formation of unhealthy granulation tissue, and inadequate wound contraction and epithelialization (Figures 8.65a,b). Discoloration of exposed bone is not a reliable indicator of sequestrum formation.[1]

Methods to Stimulate the Growth of Granulation Tissue

Despite the frequent presence of exposed bone associated with trauma to the distal aspect of the limb of horses, there has been little investigation into methods of stimulating coverage by granulation tissue. Granulation tissue plays a very important role in second intention healing because it provides a barrier to infection and mechanical trauma for the underlying tissues. Moreover, healthy granulation tissue provides a moist surface

Figure 8.65. (A) Degloving injury of 3 months duration involving the dorsal metatarsus. Note the linear defect in the granulation tissue which was associated with wound drainage, unhealthy granulation tissue, as well as inadequate wound contraction. These signs are typical of sequestrum formation. The dark spots in the granulation tissue, particularly overlying the fetlock region, are pinch grafts that have been accepted. (B) Lateral radiograph of the third metatarsal bone revealing a linear sequestrum with involucrum formation along the dorsal surface of the bone. Courtesy of Dr. T. Stashak.

for epithelialization. Therefore, the delay in wound healing related to exposed bone has incited the search for different methods to promote granulation tissue coverage of bone in other species.

In humans, head trauma, thermal injury, and surgical oncology often lead to exposed bone of the cranium.[6,29] In these cases the outer cortex of the exposed portion of the cranium is fenestrated with drill holes, burrs, or laser to expose the medullary cavity from which granulation tissue grows to cover the exposed bone.[5,6] Likewise, exposed cortices of long bones in humans have been fenestrated with drill holes to promote granulation tissue formation.[4] It appears that the drill holes promote healing by allowing osteogenic factors from the medullary cavity access to the wound, or they may enhance healing of bone and soft tissue by a nonspecific response known as "the regional acceleratory phenomenon."[30] Cortical fenestration (Figure 8.66) combined with drugs that promote local fibroplasia may accelerate granulation tissue coverage, though further investigation is needed to verify this hypothesis.

Drilling 1.6 mm holes in the cortex of the second metacarpal bone in experimentally created wounds in dogs resulted in clot formation over the bone that promoted the development of granulation tissue and may have protected the bone's outer layers from desiccation.[8] The effects of 3.2 mm cortical fenestrations were evaluated in experimentally created wounds at the distal aspect of the limb of horses.[7] Fenestrated wounds were covered with granulation tissue earlier than were control wounds, because of the formation of granulation tissue directly from the cortical fenestration sites (Figure 8.67); however, fenestration had no significant effect on sequestrum formation. If the wounds are not large (<6 cm × 6 cm), it may be difficult to distinguish a significant

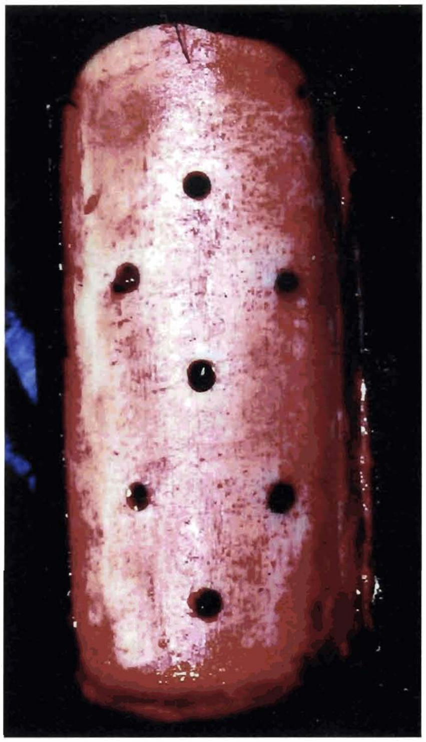

Figure 8.66. Cortical fenestration of the dorsal aspect of the third metatarsal bone in a diamond shaped pattern using a 3.2 mm drill. The cortical fenestration sites allow for the rapid formation of granulation tissue within the drill sites and over the associated exposed bone. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 192, (2004), with permission from Elsevier Saunders.

Figure 8.67. Granulation tissue production from cortical fenestration sites as well as the cortical bone in an 11-day-old degloving injury of dorsal metacarpus. Wounds > 6 cm × 6 cm in diameter can obtain a significant contribution of granulation tissue from cortical fenestration sites. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 192, (2004), with permission from Elsevier Saunders.

additive contribution from the granulation tissue growing directly from the cortical fenestration sites alone. Cortical fenestration may also be beneficial if it is used with other methods of promoting fibroplasia in larger wounds because there may be an additive effect.[7]

Management of Degloving Injuries

Wound Preparation and Evaluation

Because exposed bone stripped of its periosteum is very susceptible to infection, it is important to use aseptic techniques when cleansing and bandaging the wound. In one study, less *S. aureus* adhered to periosteum than to cortical bone, cut cortical bone, and endosteal surfaces.[31] The surrounding skin should be clipped and cleaned carefully to reveal the full extent of the wound. The wound should be flushed with sterile saline to which a diluted antiseptic solution (e.g., 0.5% chlorhexidine or 0.1%–0.2% povidone iodine) is added, using low pressure (10–14 PSI) lavage with a 19-gauge needle (or catheter) and a 35 ml syringe. Any obvious debris must be removed.

Following lavage, the wound should be explored digitally with sterile gloves to establish the extent of injury and degree of periosteal damage. Injury to adjacent synovial structures, tendons, and ligaments should be noted. Examination of the wound should also aim to determine the presence of any bony fragments or palpable foreign bodies. For a more in-depth discussion of wound preparation, see Chapter 2.

Bone distortion suggests a concurrent fracture, and open fractures carry a poor prognosis. In these cases, radiography is indicated to assess the amount of bone involved, including the possibility of partial, complete, or non-displaced fractures and the possibility of joint involvement. If there is no fracture, the limb should be bandaged as described later. When there is the possibility of a fracture, tendon laceration, or joint involvement, a splint should be incorporated into the bandage as described later. For more information regarding bandage splinting, see Chapter 16.

Surgical Management

Surgical debridement remains the technique of choice for removal of devitalized tissues. Proper debridement removes tissues heavily contaminated by dirt and bacteria and also those which impede wound healing. Debridement of small, relatively clean wounds can be done under local anesthesia in the standing horse. Larger chronic/infected wounds are often best handled with the patient under general anesthesia (Figures 8.68a,b).


A


B

Figure 8.68. (A) Contaminated degloving wound with exposed bone present on the distal lateral aspect of the third metatarsus. Dried, necrotic tissue along with soiled debris is present in the wound. (B) Wound after surgical debridement. Surgical debridement remains the technique of choice for removal of devitalized tissues. Proper debridement removes tissues heavily contaminated by dirt and bacteria and also those which impede wound healing. The wound was sharply debrided until only healthy tissue remained. Courtesy of Dr. S. Barber.

The wound is sharply debrided until only healthy tissue remains. See chapters 2 and 4 for more information regarding preparation of a wound to reduce the chances of infection.

If a flap of skin is available, its base and a portion of degloved skin can often be sutured using a far-near, near-far pattern with a monofilament suture.[27] The part of the wound (<6 cm × 6 cm) that cannot be covered by the skin flap is allowed to heal by second intention or the cortex can be drilled to facilitate the formation of granulation tissue over the wound. To achieve this, a 3.2 mm drill is used to make full-thickness drill holes into the medullary portion of the bone. The drill holes should be placed in a diamond shaped pattern allowing 12 mm–15 mm of separation between each drill hole. A bone rasp or curette, although not as effective in stimulating the formation of granulation tissue, can be used in areas where full-thickness drilling of the bone is contraindicated.

Open Wound Management

Systemic Treatments and Antimicrobial Therapy

Following wounding, the horse should receive tetanus prophylaxis and should initially be treated with systemic antibiotics. Nonsteroidal anti-inflammatory drugs may be administered to decrease pain and inflammation. Systemic antibiotics are indicated during the initial exudative response to injury. An initial course of 5 days of intramuscularly administered procaine penicillin can be followed by a prolonged course of trimethoprim sulfur oral powders or paste. This regimen would be recommended for large avulsion wounds with exposed bone and for bone injuries in which the cortical surface is fenestrated.

If the wound is severely contaminated or if a synovial cavity has been penetrated, intravenous and regional perfusion of broad-spectrum antibiotics should be initiated (Figures 8.69, 12.1–12.4). One study evaluating synovial fluid concentrations and pharmacokinetics of amikacin in the equine limb distal to the carpus following intraosseous and intravenous regional perfusion found that both techniques produced mean peak concentrations ranging from 5 to 50 times that of peak serum concentrations required for therapeutic efficacy.[32] See chapters 9 and 12 for more information regarding this.

Antibiotic impregnated polymethylmethacrylate (PMMA) or plaster of paris (POP) beads have been used for the local delivery of biologically active antimicrobials (Figure 12.6). Each method results in the local delivery of a high concentration of a single or multiple antibiotics. Approximately 80% of gentamicin was released in

Figure 8.69. Intravenous regional limb perfusion of the left hind limb. Intravenous regional limb perfusion can provide concentrations of antibiotic 5 to 50 times the peak serum concentrations recommended for therapeutic efficiency.

the first 48 hours in a POP in vitro model while 63% and 79% of gentamicin or metronidazole, respectively, were released from PMMA during the first 24 hours of another in vitro model. Plaster of paris-impregnated beads inhibited the growth of *E. coli* during the 14-day period of the study. The drugs retain their bactericidal activity after ethylene oxide sterilization and storage at room temperature for up to 2 months with PMMA and 5 months with POP. Antibiotic elution is directly related to the amount of antibiotic incorporated into the cement.[33,34] While antibiotic beads may be effective in the short-term management of wounds, they are no substitute for thorough and meticulous debridement at the initial stages of treatment. For more information regarding the treatment of synovial wounds and infected wounds, see chapters 9 and 12, respectively.

Wound Dressings and Topical Agents to Promote Healing

Clean Wounds. Rapid coverage by granulation tissue of extensive wounds of the distal limb prevents desiccation of the exposed tissue.[2] Prior to the formation of granulation tissue, hydrogel dressings are comfortable and supportive, provide protection from further wound contamination, assist in wound debridement, absorb some wound fluid within their polymer matrix, and reduce limb swelling.[32,35–37] These dressings are particularly useful for rehydrating necrotic tissue and enhancing autolytic debridement. Hydrogels (CarraDres™, Carrington Laboratories, Irving, TX) should only be applied to wounds that appear clean and healthy. The dressing is applied to the wound bed, followed by application of a conformable absorptive bandage dressing. A firm cotton bandage is applied as a tertiary layer to provide warmth and support.

Contaminated Wounds. Debridement dressings can be used to accelerate the transition from a heavily contaminated to a clean status. Application of a finely threaded and widely meshed, woven, cotton gauze dressing bandage or an antiseptic gauze dressing (Xeroform™ petroleum gauze, Covidien Animal Health/Kendall, Dublin, OH; Kerlix™ antimicrobial dressing, Covidien Animal Health/Kendall, Dublin, OH) in a wet-to-dry fashion is most commonly used when wound fluids have a high viscosity or when the wound surface is dehydrated and scabs have formed. This approach facilitates wound debridement and drainage and reduces the bacterial load. It is also an excellent dressing for packing deep contaminated wounds associated with the body or upper limbs. When the dressing dries, fibrin adheres it to the wound's surface, achieving debridement. If further debridement is needed, another wet-to-dry dressing is applied. Usually one to three applications of the wet-to-dry dressing are all that are needed to effectively debride most wounds.

Calcium alginate dressings (EquineGinate™, Carrington Laboratories, Irving, TX), which can absorb 20–30 times their weight in wound fluid, are useful in moderate to heavily exudative wounds during the transition from the debridement to repair phases of healing, or in wounds with substantial tissue loss such as degloving injuries. Calcium alginate dressings should be used only in heavily exuding wounds and applied no more than once, or at most, twice because they require moisture to function properly. They are not indicated for dry sloughing wounds or those covered with hard necrotic tissue. See Chapter 3 for more information regarding wound dressings.

During the exudative period an antiseptic or antibiotic such as Betadine ointment (The Purdue Frederick Company, Stamford, CT) or silver sulfadiazine (Par Pharmaceutical, Inc., Spring Valley, NY) may be applied to the wound, because neither delays wound healing. While furacin (Phoenix Pharmaceuticals, Inc., St. Joseph, MO) is an effective antimicrobial against Gram-positive and Gram-negative organisms, it has little effect against *Pseudomonas* spp. Moreover, it has been shown to decrease epithelialization in laboratory animals and humans by 24% and to delay wound contraction in horses.[38] Therefore, the author does not advocate its use in the management of wounds in horses. Silver sulfadiazine has a wide antimicrobial spectrum including *Pseudomonas* spp and fungi. Contrary to what has been noted in other species, it does not decrease the rate of wound contraction in horses.[39]

Honey has many useful properties including a broad-spectrum antimicrobial activity, anti-inflammatory actions, and stimulation of new tissue growth.[40] The stimulatory effect of honey on wound healing may in part be related to the up-regulation of inflammatory cytokines (tumor necrosis factor alpha [TNF-α], interleukin-1 beta [IL-1β], and interleukin-6 [IL-6]) within monocytes.[41] Sugardine is obtained by adding granular sugar to a povidone iodine solution until a workable paste consistency is reached. It is a hypertonic agent that, via osmosis, draws exudate from the wound. A 10% povidone iodine ointment has not been associated with a delay in wound healing.[39]

Neither Betadine ointment nor a topical antibiotic should be applied to the wound concurrently with honey, sugar, silver-coated dressing, or Kerlix AMD (Kerlix™ antimicrobial dressing, Covidien Animal Health/Kendall, Dublin, OH). Gentamicin sulfate has a narrow antimicrobial spectrum but may be applied to wounds with

Gram-negative bacteria, particularly *Pseudomonas aeruginosa*. Application of a 0.1% oil-in-water cream base slowed epithelialization and wound contraction in dogs.[42] Cefazolin is an effective antimicrobial against Gram-positive and some Gram-negative organisms. The powder form provides an appropriate tissue concentration for a longer period than does the solution, which can be used to treat established infections. For more information regarding wound dressings and topical medications, see Chapter 3.

Equine bandages are composed of a primary and secondary layer, as well as a tertiary layer that maintains the dressing in place. The primary bandage (wound dressing) should be selected according to the condition of the wound and the current phase of repair. Depending upon clinician preference the primary dressing is covered with conforming gauze (Kling gauze™, Johnson and Johnson, Inc., New Brunswick, NJ), which is applied circumferentially around the limb to assist in securing the dressing. The principal purpose of the secondary layer is to absorb harmful agents such as serum, blood, exudate, bacteria, and other necrotic debris from a wound (SteriRoll™, The Franklin-Williams Company, Lexington, KY). This layer should be thick enough to collect absorbed moisture, pad the wound against trauma, and splint the wound to prevent excessive motion.

Materials used in the secondary layer are conforming gauze and cotton pads, which must be carefully applied to conform to the shape of the limb. The tertiary layer is usually composed of materials stiffer than those used for the secondary layer. The purpose of this outer layer is to hold the previous layers in place, prevent contamination and trauma, provide pressure to minimize swelling of the limb which will reduce tension at the wound edges, and decrease the range of motion.

The final layer should be porous yet waterproof. Elastic self adhesive bandages (Vet Wrap™, 3M Company, St. Paul, MN) are frequently used as the tertiary layer. The tertiary layer must be applied with constant pressure that is gradually increased as the bandage is wrapped in a distal-to-proximal direction. The most proximal and distal aspects of the cotton pad (secondary layer) are initially left uncovered to avoid pressure points that may affect circulation with intact skin. As a final step, the proximal and distal ends of the bandage are covered with an adhesive bandage (Elasticon™, Johnson and Johnson, Inc., New Brunswick, NJ) that adheres to the outer layer and the skin. This prevents penetration of foreign bodies such as shavings and dirt between the skin and bandages, which may cause skin sores and wound contamination. For more information regarding techniques of bandaging, see Chapter 16.

General Care. Phenylbutazone is continued at 4.4 mg/kg every other day during the initial 5-day period. Alternate-day bandage changes are continued until the wound is covered by a healthy bed of granulation tissue. After early formation of granulation tissue, non-adherent, semi-occlusive bandages provide absorption of exudate and keep the wound surface moist, which favors maximal epithelial migration. A hydrogel-based sheet or gauze dressing provides for early, rapid contraction and exudate absorption (CarraDres™ and CarraGauze™ Carrington Laboratories, Irving, TX). Once granulation tissue has filled the wound bed, bandaging and protection from contamination may no longer be necessary if the horse is housed in a clean environment and there are economic constraints. Indeed, a healthy bed of granulation tissue provides resistance to infection due to improved vascular dynamics and the subsequently superior oxygen delivery.

Control of Granulation Tissue. Ketanserin gel (Vulketan gel™, Janssen Animal Health, Beerse, Belgium) is effective in preventing exuberant granulation tissue formation in equine lower limb wounds. Ketanserin is thought to antagonize the serotonin-induced suppression of wound macrophages and thus allow a strong and effective inflammatory response to occur within wounds. This should translate into a superior control of infection and a better orchestration of the later phase of repair when the cytokines and growth factors released by the activated macrophages play an important role. Ketanserin is 2 to 5 times more likely to result in successful closure by reducing infection and proud flesh formation than antiseptics or desloughing agents.[43]

Silicone gel dressings (Cicacare™, Smith and Nephew, Largo, FL) have been effective in controlling hypertrophic and keloidal scarring in human burn patients by apparently exerting pressure on the microvasculature of the scar and altering levels of various growth factors, notably pro-fibrotic TGF-β.[44] The anoxic fibroblasts are then thought to undergo apoptosis rather than proliferating and secreting extracellular matrix components, which normally contribute to scarring. Silicone gel dressings greatly surpassed a conventional non-adherent absorbent dressing in preventing the formation of exuberant granulation tissue in experimental wounds located on the distal limbs of horses. Contraction and epithelialization progressed faster in the first 2 weeks of repair, possibly as a result of healthier granulation tissue. Furthermore, tissue quality exceeded that of wounds treated conventionally, which may translate into superior tissue strength.[45,46]

Topical administration of antibiotics is warranted if surface infection seems to delay wound healing or if infection spreads to surrounding tissues.[26,37,47] Topically administered gentamicin ointment can significantly suppress bacterial counts in wounds. Triple antibiotic (bacitracin, neomycin, polymixin) and silver sulfadiazine ointments promote healing and do not appear to suppress epithelialization, while nitrofurazone ointment significantly suppresses epithelialization and wound contraction.[48]

Products that promote angiogenesis, fibroblast migration or proliferation, and/or collagen deposition promote the formation of granulation tissue. Topically applied platelet-derived growth factor (PDGF) and TGF-β have been shown to increase fibroblast number and collagen content in experimentally created wounds in laboratory animals.[49] Acemannan, a water soluble polysaccharide, enhances the release of IL-1 from macrophages, which in turn stimulates angiogenesis.[8] Live yeast cell derivative, a component of hemorrhoid medication, has been used to increase collagen synthesis and thus granulation tissue formation in wounds of horses.[15]

Occlusive dressings have likewise been shown to enhance the formation of granulation tissue in humans and horses,[2,14] possibly by lowering the ambient oxygen tension and reducing the local tissue pH.[14] In an equine study evaluating the effects of a flexible hydroactive dressing in a clinical setting, rapid and uniform fibroplasia occurred in wounds that are notoriously difficult to cover with granulation tissue.[2,35] The use of occlusive dressings should be discontinued once granulation tissue fills the wound bed, prior to it becoming exuberant.

Surgical resection is a simple and effective method to control exuberant granulation tissue. The procedure is performed with the horse standing because granulation tissue is not innervated (Figure 8.70).[26] Strips of granulation tissue can be shaved from the wound bed in a distal to proximal direction to produce a flat surface level with or slightly (~2 mm) below the surrounding wound edges. The epithelial margin should be preserved to allow continued healing. A pressure bandage is usually necessary to control hemorrhage after excision.[9] In lower limb wounds of horses this technique has been successful in enhancing second intention healing that was delayed because of protruding granulation tissue. This technique is preferred for the removal of exuberant granulation tissue over other methods such as application of caustic drugs because it is easy to perform, provides tissue for histological evaluation (if needed), and preserves the epithelial margin for continued healing. As with any alternate technique, healing by contraction and epithelialization must subsequently be supported or excessive granulation will recur.

Corticosteroids may be applied topically to curb the early formation of exuberant granulation tissue, hence facilitating epithelialization and wound repair.[50] The ability of some corticosteroids to suppress the formation of exuberant granulation tissue in the early phases of healing may be related to their ability to selectively

Figure 8.70. Fully granulated wound on the dorsal surface of the third metatarsus. Surgical resection of granulation tissue, as in this case, is a simple and effective method to control exuberant granulation tissue. Shaving the wound bed in a distal to proximal direction allows for better visualization of the wound margins during debridement. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 194, (2004), with permission from Elsevier Saunders.

decrease the release of pro-fibrotic TGF-β from monocytes and macrophages, therefore inhibiting lysosomal activity and fibroblastic proliferation.[51] Corticosteroids are generally applied at the earliest signs of formation of exuberant granulation tissue; one or two applications are all that are needed to achieve the desired effect. Continued applications are not recommended because this may exert negative effects on wound contraction, epithelialization, and angiogenesis.[52] Corticosteroids should not be applied to an infected wound because they inhibit the inflammatory response required to eliminate micro-organisms. More information on the treatment of exuberant granulation tissue is provided later in this chapter.

Immobilization of the Wound

Bandaging Methods

One of the most challenging areas to bandage on a horse is the hock. The conformation and the combination of forces that allow flexion and extension (e.g., reciprocal apparatus) impose some important considerations when applying a bandage to this region. Horses are reluctant to accept any restriction to movement in this region and frequently disrupt the bandages as a result of exaggerated flexion. The primary and secondary layers should be applied, avoiding excessive pressure over the point of the hock (calcaneal tuberosity), using the same technique as for the carpus. For the tertiary layer, a figure-8 bandage is applied starting with circumferential wraps around the distal aspect of the tibia and continuing down with figure-8 wraps below and above the hock. Applying a length of 10 cm wide, low-stretch adhesive tape (Elasticon™, Johnson and Johnson, Inc., New Brunswick, NJ) longitudinally along the plantar aspect and incorporating it at the proximal and distal end of the bandage assists in preventing slippage of the bandage (Figure 16.7a–c).

In addition the author uses a thick cotton bandage as a secondary layer on the distal aspect of the limb from the coronary band to the most proximal aspect of the metatarsus (Figure 16.8b). This also helps to prevent slippage of the hock bandage, and by decreasing the range of motion of the fetlock, restricts movement of the hock. A rigid bandage or splint applied to the distal limb with the fetlock in partial flexion greatly decreases the range of motion of the hock, thereby increasing longevity of the bandage and allowing optimal wound healing. For more information regarding bandage application and splinting techniques, see Chapter 16.

Casting

Application of a cast to a lower-limb wound provides maximal immobilization. Wounds over joints and/or tendons may require immobilization because continued movement disrupts healing. Frequently the hock or carpus is involved in these types of compound injuries. When the limb is mechanically stable, the wound should be bandaged for a few days prior to applying a cast to allow superior wound debridement and permit dissipation of edema, which will ensure a better-fitting cast. Casts minimize the formation of exuberant granulation tissue by reducing motion. Casts should be maintained no longer than necessary over lower-limb wounds for reasons similar to those mentioned for bandages and to minimize the development of cast sores. Generally casts over wounds should be changed every 3 to 10 days but this will depend on the nature and location of the wound and the temperament of the horse. Skin grafts can be used after cast removal to facilitate wound coverage. A splint bandage is continued during this period.[53] For more information regarding splint bandage and cast application, see Chapter 16.

Management of Sequestra

Removal of bony sequestra, either naturally or surgically, is required for a wound to heal completely. Radiographs will identify the presence of the developing sequestrum 2 to 4 weeks after trauma (Figures 8.63 and 8.65b). Once its presence has been confirmed the sequestrum is located and removed by excising the overlying granulation tissue and the area is curetted to eliminate any residually infected tissue from within the involucrum (Figure 8.71). It is unwise to try to dislodge a developing sequestrum by chiseling the bone surface, which could increase the risk of fracture during surgery or recovery. After removal of sequestra, the horse should be recovered from general anesthesia wearing a rigid splint to avoid possible complications such as fracture.[53] Many sequestra, however, can be removed under local anesthesia and sedation while the horse is standing (Figure 8.72a,b). Regular follow-up radiographs should be taken at 2–3 week intervals. For

Figure 8.71. Sequestrum formation of the distal medial radius beneath a central area of the wound devoid of granulation tissue. The sequestrum was located and removed by excising overlying granulation tissue and the area was curetted to eliminate any residual infected tissue. Reprinted from *Clinical Techniques in Equine Practice*, Vol 3, R. Reid Hanson, Management of avulsion wounds with exposed bone, p. 195, (2004), with permission from Elsevier Saunders.

more information regarding management of sequestra, see Management of Wounds of the Distal Extremities, in the first section of this chapter.

Skin Grafting

The goals of managing wounds of the distal extremities in horses are to protect the wounds from further trauma and heal the wounds in the most efficient, cost-effective manner possible. This may require application of a skin graft after a suitable bed of granulation tissue has formed. Skin grafts may be applied to fresh wounds that are vascular enough to rapidly produce granulation tissue or on wounds with clean, healthy appearing beds of granulation tissue. Survival of grafts over exposed bone is poor because vascularization occurs slowly. Skin grafting is usually employed following a period of open wound management and after granulation tissue formation. The granulation tissue bed to be grafted should appear red to pink, smooth, and free of any defects. For more information regarding the methods used for skin grafting, see Chapter 11.

Conclusion

Regardless of the methods used to heal wounds over exposed bone, the formation of healthy granulation tissue in the wound is required. Wound healing over exposed bone relies upon the same cellular and humoral elements that contribute to healing of other superficial wounds. The inflammatory, debridement, and repair phases work in concert to prepare the wound bed for granulation tissue formation, contraction, epithelialization, and maturation, but the presence of exposed bone in wounds may directly or indirectly delay healing.

Wounds that expose bone that are fenestrated with 3.2 mm drill holes are covered with granulation tissue earlier than control wounds, because of the formation of granulation tissue directly from the cortical fenestration sites. Cortical fenestration may also be beneficial if it is used with other methods of promoting fibroplasia in larger wounds because there may be an additive effect. Prior to the formation of granulation tissue, hydrogel dressings are comfortable and supportive, provide protection from further wound contamination, assist in

A B

Figure 8.72. Same horse as in Figure 8.77. (A) Sequestra was removed on the standing horse following local anesthesia and sedation. A periosteal elevator was used to elevate the sequestrum from the associated involucrum. (B) Excised sequestra. Courtesy of Dr. T. Stashak.

wound debridement, absorb some wound fluid within their polymer matrix, and reduce limb swelling. Debridement dressings can be used to accelerate the transition from a heavily contaminated to a clean status. This approach facilitates wound debridement and drainage and reduces the bacterial load. This chapter has attempted to provide the reader with the most current methods to enhance the healing of degloving wounds in the horse.

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