Clinical Techniques in
Equine
Practice

Management of Avulsion Wounds with Exposed Bone

R. Reid Hanson, DVM, Diplomate ACVS

Lacerations and degloving injuries are common in horses. Because of the small amount of soft tissue covering the bones of the distal extremities, lacerated tendons, joint capsules, and exposed bone are a common sequella to traumatic wounds. Further, more wounds in this region are often associated with extensive soft tissue loss, crush injury, and may be severely contaminated leading to the necessity for open wound management and second intention healing. Exposed bone in open wounds can delay second intention healing indirectly and directly. Desiccation of the superficial layers of bone may lead to infectious osteitis and sequestrum formation. The rigid nature of bone indirectly inhibits contraction of granulation tissue and can prolong the inflammatory phase of wound healing. Skin grafts can be applied to fresh wounds that are vascular enough to produce granulation tissue rapidly, but graft survival is poor over areas of exposed bone because revascularization is slow or absent. Therefore, a healthy, uniform granulation tissue bed over exposed bone is required before skin grafting procedures can be utilized.
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Wounds of the distal limbs are usually caused by wire fences, sheet metal, or other sharp objects in the horse's environment, entrapment between two immovable objects, or during transport. These wounds are often associated with extensive soft tissue loss, crush injury, and severe contamination leading to the necessity for open wound management and second intention healing.

Exposed bone is defined as bone denuded of periosteum, which in an open wound can delay second intention healing indirectly and directly.[1-7] The rigid nature of bone indirectly inhibits contraction of granulation tissue and can prolong the inflammatory phase of wound healing.[1,2] Prolonged periods of time may be necessary for extensive wounds of the distal extremity in horses with denuded bone and tendon to become covered with a healthy, uniform bed of granulation tissue.[8] 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.[9] Rapid coverage of exposed bone with granulation tissue can decrease healing time and prevent desiccation of exposed bone. Exposed bone in wounds of the distal limb of horses can result in extensive periosteal new bone growth that can lead to increased wound size and an enlarged limb even after healing is complete.[10,11] Cortical fenestration of exposed bone has 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.[1,11-14]

Skin grafting procedures are commonly used for distal limb wounds in horses.[15-17] 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 is slow or absent.[6] Therefore, a healthy, uniform granulation tissue bed over exposed bone is required before skin grafting procedures can be utilized.[7]

Numerous studies have been performed to evaluate various aspects of wound healing of the distal aspect of the limb in horses.[8,11,18-30] Most of the studies of wound healing of the distal portion of the limb have been full-thickness cutaneous wounds of varying size without excision of any appreciable amount of subcutaneous tissue or periosteum. There have been only two studies of wounds of the distal extremity of horses, to the author's knowledge, that examined the effect of denuded bone in wound healing.[11-14]

Healing of the Distal Limb Wounds

Avulsion wounds with exposed bone on the distal limb increase in size for approximately 14 to 21 days. Wound expansion is due primarily to the distraction forces applied across the wound during the inflammatory and debridement

Department of Clinical Sciences, College of Veterinary Medicine, Auburn University, Auburn, AL.
Address reprint requests to: R. Reid Hanson, DVM, Dip ACVS, ACVECC, Department of Clinical Sciences, JT Vaughan Hall, 1500 Wire Road, Auburn University, Auburn, AL 36849. E-mail: hansorr@vtmed.auburn.edu

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Figure 1 Extensive degloving injury of the dorsal metatarsus with exposed bone denuded of periosteum. Excessive mobility of the limb under the wound, lack of periosteal coverage of the exposed bone with delay in granulation tissue formation can lead to difficulty in achieving appropriate contraction of the wound with suitable epithelial coverage.

stages of wound healing and the lack of a granulation tissue bed in the center of the wound to counteract tensile forces exerted on the wound margins from the surrounding skin. Wounds with a smaller amount of exposed bone or wounds without 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 and subsequently wound contraction is delayed[2] (Fig. 1).

The ability of any tissue to produce granulation tissue is directly related to the vascularity of that tissue.[9] Tissue with abundant blood supply, such as muscle, can rapidly produce granulation tissue. Less vascular tissue, such as bone, slowly produces granulation tissue resulting in a delay in wound healing.[9]

Wound contraction is the inward or central movement of the wound edges due to 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.[31] Skin, which is attached to the granulation tissue, is moved toward the center of the wound as the granulation tissue contracts. The exact role of the myofibroblast is poorly understood because it has been shown that in rats wounds without myofibroblasts can contract.[32] Myofibroblasts may form and serve to counteract tensile forces on the skin during wound healing.[31,33]

Second intention healing of the distal aspect of the limb of horses can be lengthy and complicated. Wounds of the distal extremity in horses heal slower than wounds on the trunk because of comparatively slower rates of epithelialization and contraction.[11,18] There are also differences in wound healing between horses and ponies.[11,19,20] Similar wounds on the dorsal aspect of the metatarsal region heal slower in horses compared with ponies because wound contraction in ponies occurs to a greater extent than in horses.[11,19] Histological analyses of the wounds showed a prolonged inflammatory phase in the horse, as well as less organization of the myofibroblasts compared with ponies.[11,19] The slower rates of epithelialization have been attributed to inhibition of cell migration and inhibition of mitotic activity by exuberant granulation tissue.[18,19]

As healthy granulation tissue develops, there is a rapid decline in total wound area.[11,23,25,26] The use of pressure bandages may decrease the amount of limb edema (Fig. 2). Exuberant granulation tissue can enlarge a wound by "pushing" the wound edges apart. For injuries associated with exposed

Figure 2 Pressure bandages with comfortable absorptive dressing provides protection from wound contamination, assists in wound debridement, absorption of exudates and reduction in limb swelling.

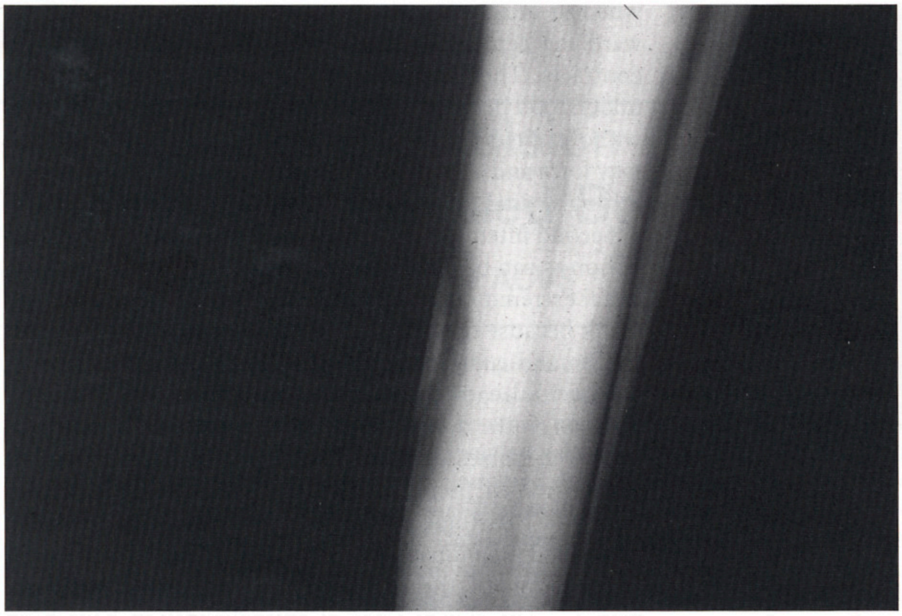

Figure 3 Lateral medial radiograph of a degloving injury involving MT3 with sequestrum formation of the dorsal aspect of MT3 secondary to a degloving injury 26 days earlier. The necrotic portion of bone incites an inflammatory response with accumulation of exudates and eventual drainage.

bone, excessive periosteal new bone growth may contribute to prolonged time of wound expansion.[11]

Sequestrum development can be a sequella to traumatic wounds and is a common cause of delayed wound healing of the distal limbs of horses.[3-5] 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.[9] Afferent vessels from the periosteum and medullary cavity provides blood flow to the compact portion of long bones. Haversian 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 level. 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 after it has been injured.[34] Ischemia of the superficial layers of the cortex leads to necrosis of the affected area[3] (Fig. 3). The necrotic portion of bone incites an inflammatory response with accumulation of exudates and eventual draining tract formation in wounds where the skin has healed over the area.[9] Most reports suggest that infection is required for sequestrum formation, but others suggest infection is not necessary for sequestrum development.[3,5,9,35] Sequestra can delay wound healing by serving as foci of continued inflammation and/or infection.

A rapid reduction in wound area, because of contraction and epithelialization, following an initial period of wound expansion has been reported in several studies.[11,14,20,36] 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[37] (Fig. 4). Persistent swelling of the limb associated with inflammation of the wound increases the total circumference of the limb, and therefore, increases the

Figure 4 Exuberant granulation tissue of dorsal MT3. 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.

area measurements for each wound. Also, the large amount of periosteal new bone growth beneath the wound may contribute to increased total wound area measurements.

Healing of Avulsion Wounds with Exposed Bone

Wounds of the distal aspect of the limb are commonly complicated with exposed or denuded bone.[38] 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.[3-5,13] The presence of denuded bone in wounds can delay wound healing by prolonging the inflammatory and repair phases of wound healing.[1] Exposed bone within a wound can delay wound healing directly if the bone becomes infected, or indirectly because its rigid structure can delay the formation of granulation tissue and wound contraction.[2]

Injuries involving bones in horses stimulate more periosteal new bone growth than similar wounds in other species and ponies.[10,11] Periosteal insults from blunt trauma, tendon/joint capsule strain, surgical manipulation, or laceration/degloving injuries may result in extensive periosteal exostosis[10,11,39] (Fig. 5). More extensive periosteal reaction in young compared with adult horses has been attributed to a more active osteoblastic activity of the periosteum in young horses.[39] The extensive periosteal new bone growth seen in adult horses is poorly understood. Delayed collagen lysis compared with other species may be a contributing factor.[10] The more extensive periosteal new bone formation in horses, compared with ponies was believed to be the result of a slower onset and longer duration of the periosteal response and prolonged extensive limb swelling in horses as compared with ponies.[11] Discoloration of exposed bone is not a reliable indicator of sequestrum formation as not all discolored bone develops sequestra.[4]

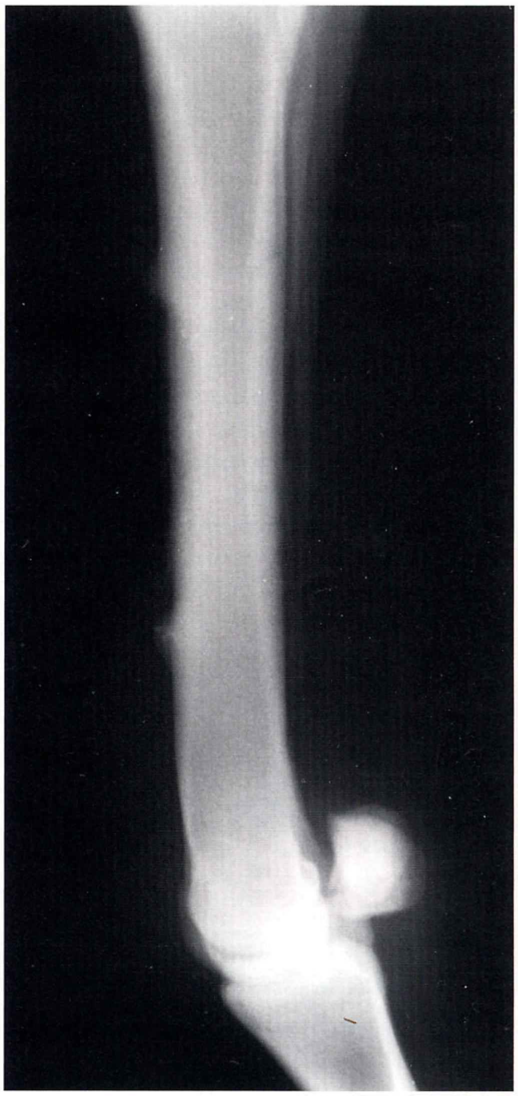

Figure 5 Lateral medial radiograph of a degloving injury involving MT3 four weeks earlier in a 2-year-old horse showing extensive periosteal new bone growth and cortical irregularity. More extensive periosteal reaction in young compared with adult horses has been attributed to a more active osteoblastic activity of the periosteum in young horses.

Despite the common occurrence of exposed bone associated with trauma to the distal aspect of the limb there has been little investigation into methods of stimulating coverage of granulation tissue over exposed bone in horses. 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. Healthy granulation tissue is resistant to infection and provides a moist surface for epithelialization. The delay in wound healing caused by 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 results in exposed bone of the cranium.[13,40] 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.[12,13,41] Like-wise exposed cortices of long bones in humans has been fenestrated with drill holes to promote granulation tissue formation.[1] It has been suggested 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."[42] Cortical fenestration combined with drugs that promote topical granulation tissue may accelerate granulation tissue coverage compared with control wounds, but further investigation is needed (Fig. 6).

Drilling holes in the cortex of the second metacarpal bone in experimentally created wounds in dogs resulted in clot formation over the bone that promoted granulation tissue formation and may have protected the bone's outer layers from desiccation.[43] The effects of cortical fenestration were evaluated in experimentally created wounds of the distal aspect of the limb of horses.[14] Cortical fenestrated wounds became covered with granulation tissue earlier than control wounds and fenestration had no significant effect on sequestrum formation. The granulation tissue growing directly from the bone surface also contributed to granulation tissue formation (Fig. 7). If the wounds are not large (<6 × 6 cm) it may be difficult to realize a significant contribution from the granulation tissue growing from the cortical fenestration sites alone. Cortical fenestration may also be beneficial if it is used with other methods of promoting granulation tissue.[14]

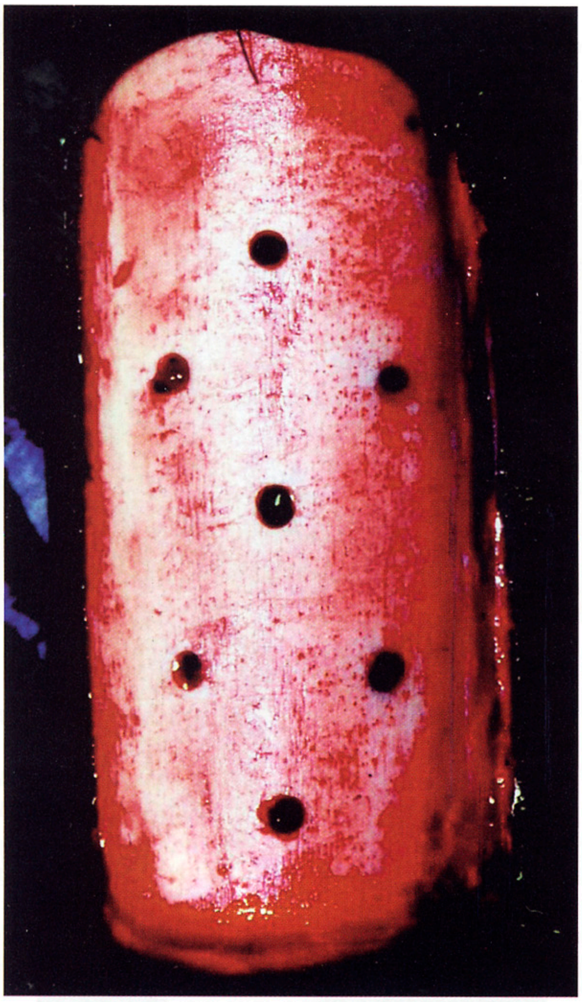

Figure 6 Cortical fenestration of the dorsal aspect of MC3 in a diamond shaped pattern utilizing a 4.5 mm drill. The granulation tissue growing directly from the cortical fenestration sites serves as an extra source for granulation tissue production.

Treatment

A thorough physical examination of the limb will reveal the extent of damage. 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. The surrounding skin should be clipped and cleaned carefully to expose the full extent of the wound. The wound should be flushed, using low pressure (10-14 PSI) lavage with sterile normal saline utilizing and/or a diluted (0.5%) chlorhexidine solution. Any obvious debris should be removed. Following this, the wound should be explored digitally with sterile gloves to establish the extent of the injury and the degree of periosteal damage. Injury to adjacent synovial structures, tendons, and ligaments should be noted. Examination of the wound should also determine the presence of any bony fragments or palpable foreign bodies.

Surgical debridement remains the technique of choice for removal of devitalized tissues and minimizes the incidence of wound infection. Proper debridement removes tissues heavily contaminated by dirt and bacteria and also removes devitalized tissues which act as impediments to wound healing. Debridement of small relatively clean wounds can be done with the wound anesthetized in the standing horse. Larger chronic/infected wounds are often best handled with the patient under general anesthesia.

The wound is sharply debrided until only healthy tissue remains. The base of the flap and a percentage of degloved skin can often be sutured using a far–near, near–far pattern of a monofilament suture.[38] That part of the wound that cannot be covered by the skin flap is allowed to heal by second intention. After debridement and suturing are completed, a hydrogel dressing is applied to the region of the wound that remains open by application of a conformable absorptive dressing (eg, "Tegagel dressing," 3 mol/L). Hydrogels are gels made of 95% water consisting predominantly of a polymer or copolymer. Hydrogels are able to donate moisture to dehydrated tissue and absorb some moisture from an exudating wound. These dressings are particularly useful for rehydrating necrotic tissue and enhancing autolytic debridement. The dressing is applied to the wound bed followed by application of a conformable absorptive dressing. A firm cotton bandage is used to provide warmth and support.

Bone distortion suggests a concurrent fracture, and open fractures carry a poor prognosis. Radiographs are indicated to assess the amount of bone involved, including the possibility of partial, complete or nondisplaced fractures and the possibility of joint involvement. If there is no fracture, the limb should be bandaged as just described. If there is a possibility

Figure 7 Granulation tissue production from a cortical fenestration site as well as the cortical bone in an 11-day-old degloving injury of dorsal MC3. Wounds larger that 6x6 cm in diameter can realize a significant contribution of granulation tissue from cortical fenestration sites.

of a fracture or tendon laceration or joint involvement, a splint should be incorporated in the bandage.

Initially after wounding, the horse should be treated with systemic antibiotics and tetanus prophylaxis. Nonsteroidal antiinflammatory drugs may be administered to decrease pain and inflammation. Systemic antibiotics are indicated during the initial exudative course of the 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 course of antibiotic therapy would be recommended for large avulsion injuries with exposed bone and injuries of the bone that have had the exposed cortex fenestrated. If the wound is severely contaminated or if a synovial cavity has been penetrated, intravenous broad spectrum antibiotics and regional limb perfusion should be initiated (Fig. 8). In one study evaluating synovial fluid concentrations and pharmacokinetics of amikacin in the equine limb distal to the carpus following intraosseus and intravenous regional perfusion, both techniques produced mean peak concentrations ranging from 5 to 50 times that of recommended peak serum concentrations for therapeutic efficacy.[44] For more information the reader is referred to J. Orsini's article, "Management of Severely Infected Wounds in the Equine Patient" in this issue.

Rapid coverage of extensive wounds of the distal limb with granulation tissue prevents desiccation of the exposed tissue.[8] Early in wounding, before the formation of granulation tissues, hydrogel and a comfortable supportive bandage (eg, Steriroll, 16 × 42 inches) provides protection from wound contamination, assists in wound debridement, absorption of exudates, and reduction in limb swelling.[44-47]

The bandage is changed every other day during the exudative period and an antiseptic or antibiotic such as betadine ointment or silver sulfadiazine (eg, Betadine, The Purdue Frederick Company; Silver sulfadiazine, Par Pharmaceutical, Inc, Spring Valley, NY) may be applied to the wound, since they do not delay wound healing. Furacin (Furacin ointment, Phoenix pharmaceuticals, Inc., St. Joseph, MO) should not be used as it has been shown to delay wound contraction, and epithelialization and slow wound healing overall. Alternatively an antimicrobial dressing (eg, Kerlix Antimicrobial Dressing, Tyco Health Care Kendall) may be applied. For more information the reader is referred to T. Stashak's article, "Update on Wound Dressings" in this issue.

Phenylbutazone is continued at 4.4 mg/kg every other day during the initial 2 week 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, nonadherent semiocclusive bandages provide absorption of exudates and keep the surface moist for maximal epithelial migration (Fig. 9). Petrolatum-based mesh with 3% bismuth tribromphenate dressings provide for early, rapid contraction and exudate absorption, but epithelialization is impaired (eg, Xeroform petroleum gauze, Tyco Kendal Health Care).[51] Once a granulation bed has formed, bandaging and protection from contamination may not be necessary if the horse is housed in a clean environment. For lower limb wounds, further, bandaging may promote excessive granulation tissue formation and surface infection and may delay healing by providing a warm moist environment.[44,47,52] Ideally, bandaging is discontinued once granulation tissue has filled the wound bed. This change in the wound environment should suppress exuberant granulation tissue formation, and the scab that forms should provide a moist environment underneath for epithelial migration, although epithelialization is slower under a scab than that seen in wounds bandaged with a semiocculsive dressing.[50]

Topical administration of antibiotics is warranted if surface infection seems to delay wound healing or if infection is spreading to surrounding tissues.[33,37,47,52] 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.[53] Nitrofurazone ointment significantly suppresses epithelialization and wound contraction.[50,53]

Products that promote angiogenesis, collagen deposition, and/or fibroblast migration or proliferation promote the formation of granulation tissue. Topically applied platelet-derived growth factor and transforming growth factor beta have been shown to increase the fibroblast and collagen content of experimentally created wounds in laboratory animals.[53] Acemannan, a water soluble polysaccharide, enhances the monocyte release of interleukin-I macrophages which, in turn, stimulate angiogenesis.[43] Live yeast cell derivative, as a component of hemorrhoid medication, has been used to increase collagen synthesis, and thus granulation tissue formation, in wounds of horses.[22] Occlusive dressings were found

Figure 8 Intravenous regional limb perfusion of the LH. Intravenous regional limb perfusion can provide concentrations of antibiotic 5 to 50 times the recommended peak serum concentrations for therapeutic efficiency.

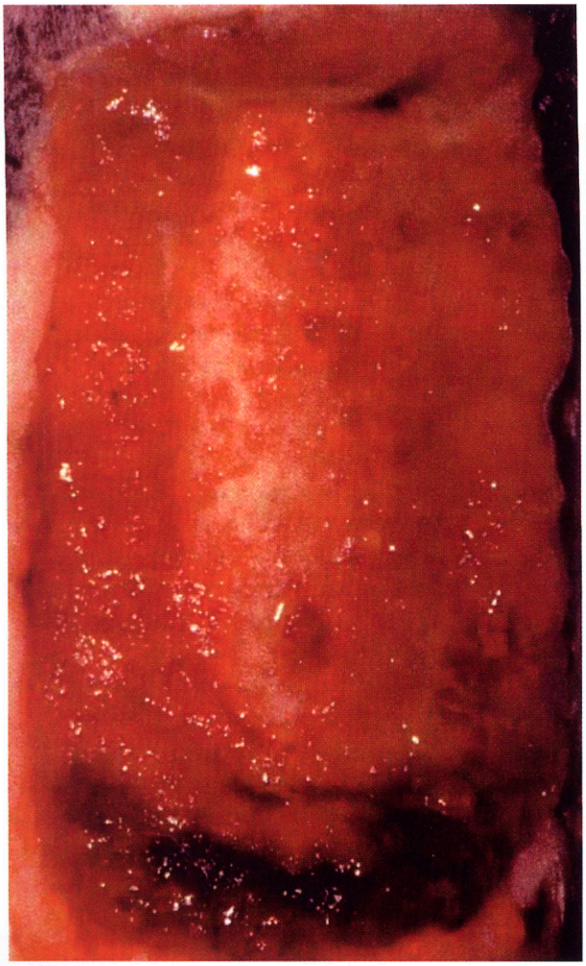

Figure 9 Early formation of granulation tissue on the cortical surface of the dorsal radius denuded of periosteum from a traumatic injury.

to increase the formation of granulation tissue in humans and horses.[8,21] Reduced ambient oxygen tension and reduced local pH produced by the occlusive dressing may increase the formation of granulation tissue.[21] In a study evaluating the effects of a flexible hydroactive dressing on horses in a clinical setting, rapid production of uniform granulation tissue occurred in wounds that are notoriously difficult to cover with granulation tissue.[8,45] For more information on products that stimulate granulation tissue formation the reader is referred to C. Theoret's article, "Wound Repair in the Horses: Problems and Proposed Innovative Solutions" in this issue.

Surgical resection of granulation tissue is a simple and effective method to control exuberant granulation tissue. The procedure is performed with the horse standing, since granulation tissue is not innervated[37] (Fig. 10). Strips of granulation tissue can be shaved from the wound bed from distal to proximal to produce a flat surface level with surrounding wound edges. The epithelial margin should be preserved to allow continued healing. A pressure bandage is usually necessary to control hemorrhage after excision.[17]

In lower limb wounds of horses, this technique has been successful in allowing second intention healing that has been delayed because of exuberant 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 and preserves the epithelial margin for continued healing. As with any technique to remove granulation tissue, healing by contraction and epithelialization must be supported, or the excessive granulation tissue will recur.

Application of a cast on lower limb wounds of horses provides maximal immobilization. Wounds over joints or wounds involving extensor tendons or flexor tendons may require immobilization to aid in closure of these wounds. Frequently the hock or carpus is involved in these types of compound injuries. If the limb is mechanically stable, treatment of the wound with bandages for a few days after wounding, then proceeding with cast application, may allow for better wound debridement and a better-fitting cast due to reduced limb edema. Casts minimize exuberant granulation tissue due to wound immobility. Casts should be maintained no longer than necessary, however, in lower limb wounds for reason similar to those for bandages and the danger of cast sores. Skin grafts can be incorporated after cast removal to facilitate coverage of the wound. A splint bandage is continued during this period.[54]

Wound healing is delayed during sequestrum formation. Removal of sequestra either naturally or surgically is necessary before a wound can completely heal. Radiographs will only show the presence of the developing sequestrum 2 to 4 weeks after a wound is incurred. Once confirmed, the sequestrum is located and removed by excising the overlying

Figure 10 Fully granulated wound on the dorsal surface of MT 3. Surgical resection of granulation tissue is a simple and effective method to control exuberant granulation tissue. Shaving the wound bed from a distal to proximal direction allows for more ideal visualization of the wound margins during debridement.

Figure 11 Sequestrum formation of the distal medial radius underneath a central area of the wound margin devoid of granulation tissue. The sequestrum is located and removed by excising any overlying granulation tissue and the area is curetted to eliminate any residual infected tissue.

granulation tissue and the area is curetted to eliminate any residually infected tissue within the involucrum (Fig. 11). It is unwise to try to dislodge a developing sequestrum by chiseling the bone surface. This technique can increase the risk of fracture either during surgery or during recovery. After removal of sequestra the horse should be recovered from general anesthesia using a rigid splint to avoid possible complications.[54] Many sequestra, however, can be removed while the horse is standing with local anesthesia and sedation. Regular follow-up radiographs should be taken at 2 to 3 week intervals.

Skin Grafting

Skin grafting of lower limb wounds should be considered to cover the granulating wound bed if contraction has ceased and the wound bed is large. Skin grafts have been shown to decrease healing time, by preventing the formation of exuberant granulation tissue.[55,56] Also skin grafting is one of the best techniques for covering a wound that has been chronically affected by exuberant granulation tissue. Additionally, a large wound may be more economically treated with a skin graft than by a lengthy period of bandaging.

Healthy granulation tissue capable of accepting a graft is firm, red, vascular, and free of purulent discharge (Fig. 12). The presence of growing epithelium at the wound margin is a good indication of the beds' health and the probable success of graft acceptance. Acute wounds require five or more days before a healthy bed of granulation tissue covers the wound. Because new granulation tissue is highly vascular, it readily accepts grafts.[17]

Frequently, however, wounds in horses are treated for several weeks before the decision is made to try skin grafting. By this time, granulation tissue is mature and fibrous and has less of a blood supply than newly formed granulation tissue.[57] Consequently, its ability to accept a graft is decreased. Therefore, chronic wounds often require surgical debridement of granulation tissue to a level below the skin surface or down to healthy granulation tissue.[55]

Surgical excision of the granulation bed should be performed at least 24 hours before grafting. Early excision allows for the control of hemorrhage, obtaining healthy granulation tissue at a desired level, judging of the horse's willingness to be bandaged, and assessment of stabling facilities for the horse during the wound healing period.[17] Biopsy, culture, and sensitivity testing of the wound can be performed if the granulation tissue appears abnormal or if an excessive exudate is present. After debridement, the wound should be covered with a non adhesive pad and a well-padded bandage. Wounds over highly movable sites should be stabilized with a splint incorporated into the bandage. The success of the graft acceptance is highly influenced by appropriate bandages that prevent graft movement yet prevent bruising of the delicate granulation tissue.[17]

Figure 12 Granulating wound along the dorsal medial aspect of MT 3. Healthy granulation tissue capable of accepting a graft is firm, red, vascular, and free of purulent discharge. The presence of growing epithelium at the margin of the wound is a good indication of the beds' health and the probable success of graft acceptance.

Figure 13 Pinch grafts placed 4 days earlier in a granulating wound bed of the dorsal MC3. The superficial necrosis of each individual graft does not interfere with the overall graft bed uptake.

For graft acceptance, wound bacteria must be minimized. Beta-hemolytic *Streptococcus spp.*, *Proteus spp.*, and *Pseudomonas spp.* are capable of producing destructive proteolytic enzymes which breakdown fibrinous attachments between the graft and recipient bed. These bacteria can also produce excessive purulent discharge which forces the graft from the bed.[58]

A range of antibiotics are available in topical form. They are potentially hazardous and not always absorbed into the wound. Because of varied barriers to diffusion in the wound, such as necrosis and pus, topical antibiotics often do not reach infection deep in the wound. There is considerable risk to the patient of sensitization and the development of resistant organisms, especially when used routinely over prolonged periods in uninfected wounds. This risk is compounded by the practice of concocting topical mixtures of different topical and, in some cases, crushed or powdered systemic antibiotics. Furthermore, certain topical antibiotics impair proliferation and epithelialization of wounds. For these reasons the topical use of antibiotics has become controversial and is no longer recommended. Currently, topically applied antiseptics creams/ointments or dressings are recommended. Systemic administration of antibiotics is indicated, however, if the deep tissue within or surrounding the wound is infected or a septic osteitis is present.

Povidone–iodine solutions are commonly used to lavage wounds because of their broad antimicrobial spectrum.[59] Iodine compounds have the broadest spectrum of all topical antiinfectives, with action against bacteria, fungi, viruses, spores, protozoa, and yeasts. The free iodine, which gives the solution its antimicrobial activity, is complexed with polyvinyl pyrrolidone to increase its stability and to reduce its irritating effect and staining properties. Povidone iodine solutions between 0.1 and 0.2% (10 to 20 mL/1000 mL) concentrations are best for wound lavage as greater concentrations are cytotoxic to neutrophils. A dilute chlorhexidine solution (0.05%) (1:40 dilution) can also be used daily to cleanse granulated wounds.[60] Povidone iodine does not maintain an adequate, residual or cumulative disinfectant action, especially in the presence of blood. In this situation significant bacterial regrowth has been observed with povidone iodine but not with chlorhexidine preparations. In addition, the activity of chlorhexidine is not significantly reduced by the presence of other organic matter.[33] Chlorhexidine solutions of 0.5%, however, slow granulation tissue formation.[37]

Before skin grafting, the bone underlying the wound should be examined using radiography. Large wounds often develop healthy granulation tissue around their perimeter before the sequestrum completely defines itself. Graft taken at the periphery of a wound is often moderate. More grafts can be applied once the sequestrum is removed and healthy granulation tissue develops.

Donor site selection is influenced by the method of grafting, color and texture of the donor hair, cosmesis of the donor site and ease of obtaining skin. Skin is safely and easily taken from the pectoral or the dorsal neck regions after injection of local anesthetic solution. Other donor sites include the ventral midline, ventral lateral abdomen caudal to the cinch area, sternal region-caudal to the girth path, and perineum. Regardless of the area, the donor site should be prepared aseptically. Hair at the donor site should be clipped before obtaining the graft, rather than shaved to prevent damage to the epithelium.[17,55]

Grafting Techniques

The basic surgical techniques for successful skin grafting in the horse are not complicated and are easily learned with minimal investment in equipment.[61]

Pinch Grafts

Pinch grafts are distinct pieces of skin (3 mm diameters) produced by excising an elevated cone of skin. Pinch grafting is easily performed in the sedated horse, with the donor site desensitized by injection of a local anesthetic. Because the donor sites are small and are not full-thickness defects, they are left to heal by second intention.[17,54]

The grafts are retrieved by elevating the skin with forceps or a bent needle tip and making a split-thickness cut in the skin at a right angle. The center of these grafts is nearly full-thickness, which provides some hair follicles. Once retrieved, the skin disk is implanted into pockets created in the granulation tissue with either a No. 15 or No. 11 scalpel blade. To create pockets, the blade is inserted obliquely distad (downward) 2 mm below the surface into the granulation bed. Generally, the pockets are created in parallel rows at 1 cm intervals. Insertion of grafts in the pockets is tedious, but it is best done using small forceps or a blunted needle. Immediately after insertion, a moderate amount of pressure is

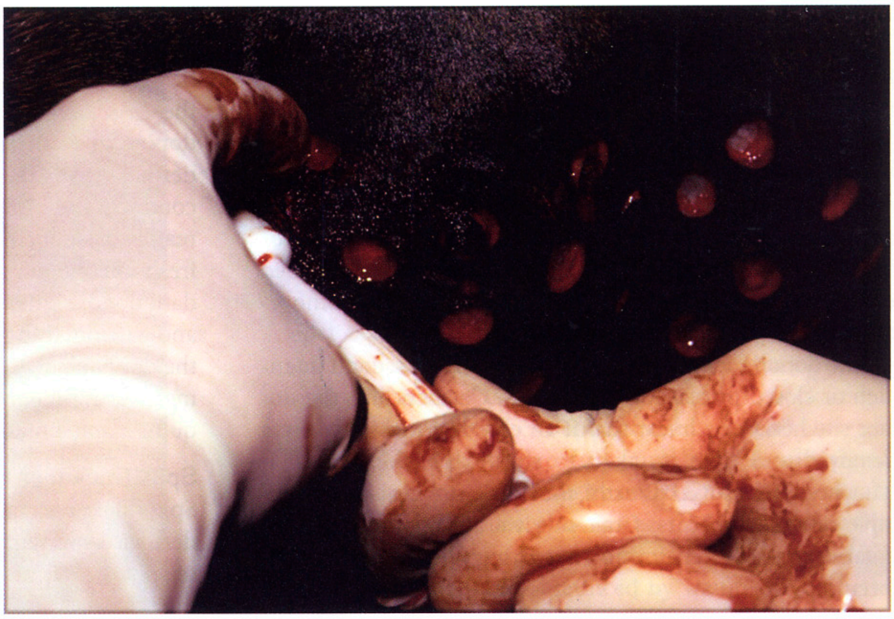

Figure 14 Eight mm punch grafts obtained from the dorsal pectoral area. With punch grafting, circular plugs of skin are directly removed from the locally anesthetized donor site or by obtaining biopsies from an excised elliptical area of skin.

necessary to control hemorrhage and maintain the grafts in the pockets.

To better control hemorrhage, portions of large wounds are best grafted and bandaged before proceeding to grafting other portions of the wound. Starting at the most distal extent of the granulation tissue bed, pockets are created and grafts implanted. Once completed, the wound grafted section is bandaged with a nonadherent pad and sterile gauze roll before proceeding to the next proximal section. Segmental bandaging prevents further loss of grafts if the horse moves or bleeding becomes excessive. Graft acceptance is as high as 75% using pinch grafts.[17] This may be due in part to pockets which hold the graft in contact with the granulation tissue (Fig. 13). Necrotic spots along the top of these granulation pockets normally occur during healing, after which the graft epithelializes circumferentially. Because pinch grafts are small, complete epithelialization of the wound often requires >70 days.[17,54]

Improper orientation of the hair direction can be minimized by accurately grasping the skin for retrieval of the graft and systematically holding it during placement in the pockets. Despite this, hair growth may occur in multiple directions. Divergent hair growth, however, may help to cover the scar since hair tends to be sparse. Once healed, the recipient site is often characterized by a cobblestone appearance, while there are pinpoint scars at the donor site. For show horses, appearance of pinch grafted wounds may not be cosmetically acceptable.

Punch Grafts

With punch grafting, circular plugs of skin are directly removed from the locally anesthetized donor site or by obtaining biopsies from an excised elliptical piece of skin (Fig. 14). This procedure can be readily performed on the standing horse. Punch grafts are full thickness and therefore must have subcutaneous tissue and fascia removed from the dermis with a blade before implanting. Doing this will increase graft acceptance. While recipient beds are created punch grafts can be placed on a saline soaked sponge for short periods until implantation.[55,62]

A biopsy punch, of a size smaller than that used to obtain the donor graft, is used to create recipient sites for the punch biopsies. Eight mm and 6 mm biopsy punches for the donor and recipient sites are used. Regardless of the size used, biopsy holes are placed at 5 to 15 mm intervals. Once the biopsy holes recipient site are made in the granulation tissue,

Figure 15 Recipient graft bed of the dorsal fetlock. Once the 6 mm biopsy incisions are made in the granulation tissue, cotton-tipped applicators are placed into each site to control hemorrhage until donor grafts are implanted.

cotton-tipped applicators are placed into the holes to control hemorrhage until donor grafts are implanted (Fig. 15). Because a moderate amount of hair follicles are present in these full-thickness grafts, orienting the grafts with the hair all going in the same direction as the surrounding skin hair is beneficial for cosmesis. Orienting the grafts is often difficult with the donor hair clipped. If the wound is large, staged sections of punch grafting and bandaging, as described for pinch grafting, may help maintain grafts in the recipient bed and prevent their loss from excessive hemorrhage or movement of the horse (Fig. 16).

The donor sites may be left open to heal by second intention or closed primarily with sutures. Cosmetically, the donor site heals in a linear scar if an elliptical piece of skin is removed and time is taken to suture the skin edges. If punches are removed directly, the donor site heals with multiple star-shaped scars. Graft survival as high as 95% with total wound epithelialization occurring within 47 days has been reported.[62]

Tunnel Grafts

Tunnel grafting requires harvesting of full-thickness or split-thickness strips of skin. Strips are 2 to 5 mm wide and slightly longer than the length of the wound to allow suturing of the graft to the wound's edges. If full-thickness strips are used, the subcutaneous fascia and fat are removed from the dermis using a scalpel blade or sharp scissors. Doing this will improve graft acceptance. The donor site can then be primarily closed to minimize scarring.

Tunnels are made in granulation tissue that has been allowed to develop 4 to 8 mm above skin level. These tunnels can be created using a cutting needle, flattened K-wire with a trocar point, or malleable alligator forceps. Tunnel grafts should not be placed closer than 2 cm apart to prevent excessive necrosis of granulation tissue.[62]

Tunnel grafts can be performed in most sedated horses standing that remain still. Since movement may destroy the tunnel creation, general anesthesia may be required in some cases. The graft is harvested and stored on a saline-soaked sponge. Six to 10 days after graft implantation the granulation tissue overlying the graft is removed to improve success of graft implantation.

Since tunnel grafts are held in position by the overlying granulation tissue, the graft is useful for hard to bandage regions such as the dorsal surface of the hock (Fig. 17). Graft survival rates up to 80% have been reported with excellent cosmetic results.[62] Most failures are attributable to accidental removal of the graft during removal of the granulation tissue or failure to expose the graft. Exposure of the graft may be facilitated by placing malleable probes or wires through the tunnels to cut through the overlying granulation tissue.[62]

Sheet Grafts

Sheet grafts may be applied as full thickness or split thickness grafts either as a sheet or expanded before transplantation. The full thickness sheet graft is the most cosmetic type of free graft because it contains all the properties of the surrounding skin, provides maximum piliation, and can withstand pressure and friction. Like pinch, punch and tunnel grafting, full thickness sheet grafting requires no sophisticated equipment for harvesting, and the procedure can often be performed in the standing sedated patient using local anesthesia.[17] Since full thickness skin transplants undergo primary shrinkage after they are excised because of recoil of elastic fibers in the deep dermal layers, the graft should be cut slightly larger than the template. The full thickness graft should be sutured to the donor site with some tension to prevent occlusion of the dermal vessels that may occur if the graft is allowed to fully contract. Full thickness sheet grafts are not accepted as readily as split thickness grafts and are usually reserved for fresh uncontaminated wounds. Because of the lack of abundant donor skin in the horse, the graft often must be meshed and expanded to achieve coverage of the wound larger than the donor area. Adult full thickness skin grafts are difficult to mesh using commercial meshing equipment and often require manual meshing (Fig. 18).

Split Thickness Grafts

Split thickness grafts consist of epidermis and a portion of the dermis. A mechanical dermatome or a free hand knife is used to split the dermis.[15,16] The thickness of these grafts is determined by the amount of dermis included. General anesthesia is necessary since harvesting split-thickness grafts is very painful to the horse. Free hand harvesting is another economical method of obtaining a split thickness graft. The Humby skin grafting knife (eg, Humby Skin Grafting Knife; Downs Surgical Inc.) is fitted with an adjustable roller to control the depth of cut but has a fixed blade. The Braithwaite knife (eg,

Figure 16 Staged punch graft placement in the recipient bed of a dorsal MC3 wound. If the wound is large, serial implantation of sections of punch grafts and bandaging, as described for pinch grafting, may help maintain grafts in the recipient bed and prevent their loss from excessive hemorrhage or movement of the horse.

Figure 17 Tunnel graft on dorsal surface of the tarsus. Tunnel grafts are secured by the overlying granulation tissue. The graft is useful for healing of wounds that are hard to immobilize.

Braithwaite Modified Humby Skin Knife, Downs Surgical Inc.) uses disposable blades and has an adjustable roller.[17] Free hand harvesting to obtain a consistently uniform split thickness graft is easily learned[61] (Fig. 19). The thickness of the graft influences its acceptance by the wound.[63] The thinner the graft the less is the demand for vascularity at the recipient bed. Since blood vessels branch as they become more superficial in the dermis, more vessels are cut and exposed on thinner grafts. The greater the number of exposed vessels, the better the absorption of nutrients will be from the granulation bed. Thus, the thinner the dermis the better the graft acceptance. However grafts less that 0.5 mm thickness in the horse lack strength and durability and have sparse or no hair follicles, or exocrine glands resulting in less sebaceous secretion. Grafts harvested between 0.63 mm and 0.75 mm have moderate to good coverage of hair and greater durability than do thinner grafts.[15,16]

A split thickness sheet graft is more cosmetic than a pinch or punch graft because thickness of the graft and orientation of the hair are uniform and coverage by the graft is more complete. Unlike the full thickness graft, suturing of the donor site is not required, and primary graft contraction is minimal.[16] The split thickness graft is more readily accepted than the full thickness graft, and so may be used to cover granulation beds that are less than ideal.

Meshing a sheet graft expands the graft so that large wounds can be covered with smaller pieces of skin (Fig. 20). Coverage of the wound is not as complete as it is with a nonmeshed sheet graft. Meshing grafts greatly enhances graft acceptance by preventing mechanical disruption of the graft from it vascular supply by exudate. Fenestration of the graft also enables topically applied antimicrobial agents to contact the graft bed and allow for the escape of fluid produced by the wound.[16,63]

Before applying the sheet graft to the recipient bed, excess granulation tissue should be excised to the level of the surrounding skin.[16] If the tissue growth of the granulation tissue is not exuberant, the fibrinous exudate covering the granulation tissue should be removed by rubbing the tissue with a scalpel blade. The graft should be positioned so that the direction of its hair growth conforms to that of the surrounding skin. All hemorrhage must be stopped before the graft is applied so that blood does not accumulate beneath the graft.

The graft can be affixed to the wound in the standing horse without using local anesthesia by overlapping and gluing the graft with cyanoacrylate glue to the skin surrounding the wound[17] (eg, Nexaband liquid; BioNexus, Inc., Raleigh, NC). General anesthesia time is reduced by waiting to apply the grafts to the wound after the horse has recovered and further reduces the possibility of damage to the graft during the recovery process.[16] The graft need only be fixed to the wound margin, except in areas that cannot be easily immobilized with a bandage, such as the hock. If the wound is in an area that is difficult to immobilize, such as the fetlock or hock, the graft can be further secured by suturing the graft to its recipient bed using simple interrupted sutures of catgut (Fig. 21).

Figure 18 Full thickness sheet graft on the medial surface of MT 3 in an acute superficial degloving injury. Full thickness sheet grafts are not accepted as readily as split thickness grafts and are usually reserved for fresh uncontaminated wounds.

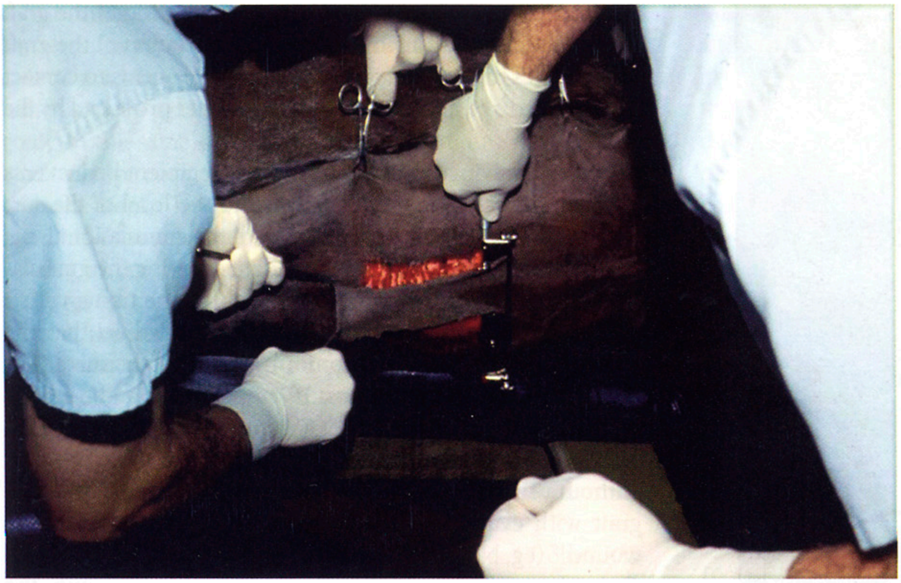

Figure 19 Free hand harvesting of split thickness skin from the ventral abdomen. Free hand harvesting to obtain a consistently uniform split thickness graft is easily learned.

Successful acceptance of the graft depends on attention to postoperative care. Initially a graft is held to the bed by fibrin. Although pale at the outset, because of loss of blood supply due to vessel constrictions and the expulsion of erythrocytes, the graft is nourished by passive imbibing nutrients onto its open vessels from the granulating bed via plasmatic imbibition. During this process the graft may become edematous and pale if not well pigmented. Capillaries from the granulation tissue bed invade preexisting vessels in the grafted skin via inosculation resulting in vascularization of the graft in 4 to 12 days. By the 10th day, a firm complete union of the graft to the bed is achieved. The epidermis might necrose and slough in some regions of the graft, and if so, usually only the superficial areas of the graft have been lost. Closer examination may reveal islands of dermis surrounded by granulation tissue (Fig. 22). The epidermis will regenerate from migration of epithelial cells present in the sebaceous, sweat glands, and hair follicles. Scaliness of split-thickness grafts is usually present for several months until the exocrine glands regenerate.[55]

During vascularization, of the first 4 to 12 days, the grafts are protected from the environment by a snug, well-padded bandage. The grafted wound should be covered with a nonadherent material[17,62] (eg, Release, Johnson and Johnson Products, Inc; Telfa Sterile Pads, The Kendall Co., Hospital Products, Boston, MA; Adaptic, Johnson and Johnson Products, Inc., Fort Dodge, IA).

Because horses have numerous areas that are difficult to bandage, the graft type must be carefully selected based on the intended recipient site. Frequent bandage changes in some cases can be beneficial for graft acceptance. Soaking the inner bandage with sterile saline and then carefully removing it prevents destruction of many grafts. The presence of purulent material on the initial change of bandage does not have a detrimental effect on the acceptance of individual grafts.[17] Any wound discharge can then be gently swabbed, rather than wiped, with an antimicrobial agent.

If the graft is applied to a healthy granulation tissue bed and the grafts have been harvested aseptically, bandage changes can occur every 4 to 7 days. Pinch and punch grafts

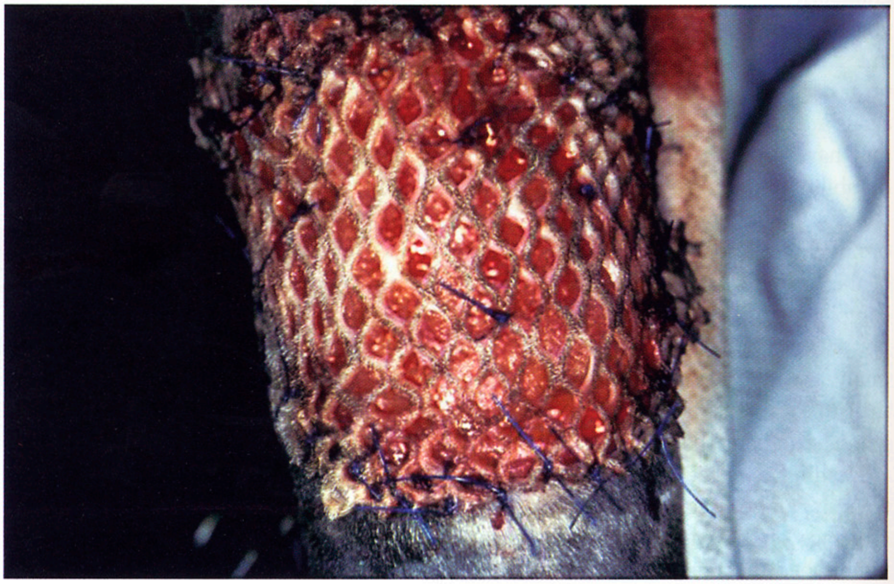

Figure 20 Split thickness mesh graft placed on the dorsal surface of MT3. Meshing grafts before recipient bed implantation greatly enhances graft acceptance by preventing mechanical disruption of the graft from the vascular supply of the bed by exudate.

Figure 21 Suturing a split thickness graft on the dorsal surface of the fetlock. If the wound is in an area that is difficult to immobilize, such as the fetlock or hock, the graft can be further secured by suturing the graft to its recipient bed using simple interrupted sutures or by gluing to the surrounding epithelial margin.

don't require bandage changes for 7 days if a bulky bandage or bandage splint is used. Periodic bandage changes allow for a clean environment and recognition of graft failure.[59] During the infection, the granulation bed can be treated and re-grafted in patches, if necessary. Additional immobilization gained with a cast is usually unnecessary but if the grafted area requires complete immobilization, a bi-valved cast should be used to allow for periodic bandage changes and inspection of the wound for signs of streptococcal or pseudomonas infection. Immobilization splinting is generally not required to facilitate acceptance of grafts after 10 to 14 days; however, continued immobilization may lessen edema and decrease the possibility of self-mutilation.[15,16,55]

Silver sulfadiazine in a 1.0% water-miscible cream is effective against most Gram-positive and Gram-negative organisms and may enhance wound epithelialization. Topical applications of corticosteroids discourage excessive granulation tissue development. Commonly used products to achieve this effect are 0.025% flurocinolone cream. Topical corticosteroid ointments inhibit lysosomal activity and fibroblastic proliferation. Although corticosteroids slow migration of epithelial cells from the graft, they do not significantly interfere with wound healing in horses.[60] Generally only one or two applications of the steroid is needed for the desired effect. Epithelialization of the granulating areas within the graft may be enhanced by application of live yeast cell derivative found in common hemorrhoidal medication[17] (eg, Preparation H; Whitehall Laboratories Inc., New York, NY).

Regardless of the grafting technique utilized, grafting procedures may need to be repeated in partial areas of the wound where graft uptake was unsuccessful. Neck cradles and or antichew products on the bandage should be incorporated to prevent further destruction. For many horses, frequent bandage changes aid in comfort. Persistence in re-grafting on horses that self-mutilate wounds has resulted in satisfactory wound healing in the majority of cases.

Donor sites of split thickness grafts retain a portion of dermis and thus are analogous to deep abrasions. The donor site of split-thickness grafts is very painful to the horse, since many nerve endings are exposed. Split thickness donor sites contract only slightly, since a portion of the dermis remains intact and heal with a scared appearance. Donor sites of full thickness grafts should be sutured. If the suture line dehisces, the wound should be treated as any open wound to optimize second degree healing.

Summary

The goals of wound management of the distal extremity in horses is to protect the wound from further trauma and close the wound in the most efficient and cost effective manner possible. This may require application of a skin graft after a

Figure 22 Split thickness graft applied to the dorsal surface of MT 3 five days earlier. The epidermis has sloughed in some regions of this graft. Only the superficial surface of the graft has been lost. Closer examination may reveal islands of dermis surrounded by granulation tissue.

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 a clean bed 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.

Regardless of the method used for closure of wounds over exposed bone, the formation of healthy granulation tissue in the wound is required. Wound healing over exposed bone relies on the same cellular and humoral interactions present in the healing of other superficial wounds. The inflammatory, debridement, and repair phase 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.

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