Exposed bone
Exposed or denuded bone is a common complication of wounds of the distal aspect of the limb. Exposed cortical bone in which the periosteum has been removed, is prone to desiccation of the superficial layers of the cortex, which may result in infectious superficial osteitis and sequestrum formation. 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.

Distal limb avulsion wounds with exposed bone increase in wound size for 14 to 21 days. Wound expansion is due predominantly to the distraction forces applied across the wound during the inflammatory and debridement stages of wound healing, and the lack of a granulation tissue bed in the center of the wound to neutralize the tensile forces exerted on the wound margins from the surrounding skin. Wounds with a small amount of exposed bone, or wounds without exposed bone, expand for a shorter period because less time is required for granulation tissue to seal the wound. Larger wounds with exposed bone take longer to form a granulation bed and subsequently wound contraction is postponed.

Periosteal insults from blunt trauma, tendon/joint capsule strain, surgical manipulation, or laceration/degloving injuries may result in extensive periosteal exostosis. Injuries involving bones in horses stimulate more periosteal new bone growth than similar wounds in other species and ponies. More extensive periosteal reaction in young compared to adult horses has been attributed to a more active osteoblastic activity of the periosteum in young horses. The extensive periosteal new bone growth seen in adult horses is poorly understood. Deferred collagen lysis compared to other species may be a contributing factor. The more extensive periosteal new bone formation in horses compared to ponies is alleged to be the result of a slower onset and longer duration of the periosteal response and prolonged extensive limb swelling in horses, as compared to ponies.

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 development is 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 prompted the search for different methods to promote granulation tissue coverage of bone in other species.

Head trauma, thermal injury, and surgical oncology often results in exposed bone of the cranium in humans. In these cases the outer cortex of the uncovered portion of the cranium is fenestrated with drill holes, burrs, or lasers to expose the medullary cavity from which granulation tissue grows to cover the exposed bone. Similarly, exposed cortices of long bones in humans have been fenestrated with drill holes to promote granulation tissue formation. It has been suggested that the drill holes promote healing by allowing osteogenic factors from the medullary cavity access to the wound, or by the enhancement of healing of bone and soft tissue by a nonspecific response known as “the regional acceleratory phenomenon”. Cortical fenestration combined with drugs that promote topical granulation tissue may accelerate granulation tissue coverage compared to control wounds, but further investigation is needed.

Cortical fenestration of 1.6 mm drill 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. The effects of cortical fenestration with 3.2 mm drill holes were evaluated in experimentally created wounds of the distal aspect of the limb of horses. 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. If the wounds are not large (≤ 6 x 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 advantageous if it is used with other methods of promoting granulation tissue. Splinting of the limb is usually not necessary for the recovery from general anesthesia unless there are associated traumatic injuries to the limb that would suggest instability.

Degloving injuries
Degloving or avulsion injuries are not uncommon in equine practice, and their management can be challenging because of prolonged treatment, cost, and sometimes unknown outcome. The body that becomes entrapped in hazards or a limb that becomes intertwined in fencing or can quickly sustain tissue damage. The most common sites for this type of trauma are the hemi thorax, dorsal aspect of the metacarpus and/or metatarsus and the cranial aspect of the tarsus. Vascular, soft tissue and bone damage is directly proportional to the length of time and effort the horse uses to free itself. Some injuries that seem to be superficial and innocuous on the surface may involve vital structures surrounding the wound and/or later develop cutaneous and internal abscesses and/or ulcerative cellulitis. Local
wound care should be an integral part of the initial treatment. The severity and duration and location of the laceration determines the best approach to the treatment of degloving injuries as healing of wounds involving the distal limb is often delayed when compared with other areas of the body, further complicating the healing process.

Primary repair of the wound is the preferred treatment for wounds that involve detachment of skin with maintenance of an intact blood supply. Complications such as sequestrum formation are lessened and healing is improved when the exposed bone and tendons are covered with skin and soft tissue in the immediate post trauma period. Closing as much of the wound as possible improves the cosmetic and functional outcome and lessens the amount of healing having to occur by second intention.

Delayed closure of a degloving injury is preferred when there is significant contamination, swelling and trauma of the wound without loss of skin. Initial treatment for the first 2-3 days after injury include debridement and lavage of the wound followed by wet to dry bandages to facilitate further debridement. Pressure bandaging is indicated to remove edema associated with the injury. Debridement of the wound edges and appropriately applied tension sutures facilitate closure of the wound as skin retraction is a complication of delayed closure.

Second intention healing is indicated for degloving injuries in which there is a considerable loss of skin immediately at the time of injury or in which a closed degloving injury has developed avascular necrosis of the skin with subsequent sloughage. The wound is sharply debrided until only healthy tissue remains. A hydrogel Carradress®, Carrington, Irving, TX) dressing is applied to the region of the wound that remains open. These dressings are able to contribute moisture to dehydrated tissue, augment autolytic debridement and absorb some moisture from an exuding wound. The dressing is applied to the wound bed followed by application of a conformable absorptive dressing (Kerlix®, Kendall, Mansfield, MA). A firm cotton bandage is used to provide warmth, support and to minimize excessive movement of the limb and associated wound area. Depending on the size and location of the wound, skin grafting may be indicated to facilitate complete healing. Grafting should be delayed to permit maximum wound contraction which, depending on the location and size of the wound, may be 4-8 weeks after injury.

Dorsal knuckling of the fetlock and an inability to extend the digit is a common complication of distal limb wounds that is usually associated the loss of the extensor tendon of the distal limb. Supporting the dorsal aspect of the limb to counteract the pull of the flexor tendons on the palmar and/or plantar aspect of the limb is the premise for management of extensor tendon disruption. The wound and extensor tendon laceration is managed by second intention healing without suturing the extensor tendon. A rigid polyvinyl chloride (PVC) splint is applied to the dorsal or palmar and/or plantar aspect of the distal limb after wound bandaging. The bandage and splint, which maintains the limb in extension and prevents dorsal knuckling of the fetlock, are retained until normal limb function returns which may vary from 7 days to 6 weeks.

**Excessive skin tension**

Skin sutured with excessive tension is likely to have complications of healing due to local ischemia with pressure necrosis of the surrounding skin and the pull through of sutures at the skin edge with subsequent wound disruption. Undermining the surrounding skin, relief incisions, and appropriately applied tension sutures are the most common methods that can be used to lessen tension along the skin margins.

The surrounding skin can be undermined up to 4 cm from the wound edge without associated complications. Relief incisions can be closed after the primary incision is closed or left to heal by second intention.

In order not to interrupt the blood supply to the primary suture line, tension sutures are positioned well away from the wound margin. Once the tension suture is in place, the primary incision line is sutured to close the wound edges. Tension suture patterns include vertical mattress, horizontal mattress, far-far-near-near, and far-near-near-far patterns. Vertical mattress sutures with or without skin support to prevent laceration of the wound edges such as polyethylene or rubber tubing, are useful in reducing tension on the primary suture line. This tension suture support method is used in areas that cannot be bandaged well such as the upper limb, body and neck region. It is contraindicated to use tension suture supports under a limb cast or heavy bandage as these supports may cause tissue necrosis and suture line failure. Tension sutures are not effective after 7 to 10 days and should be removed in a staggered fashion with one-half removed initially followed by the remaining sutures later.

**Movement**

The extent of movement of the skin relative to the underlying bed of granulation tissue is usually much higher in the limb regions than in the trunk. This is possibly exacerbated by the relative lack of skin elasticity as well as the obvious proximity of the limb skin to structures with a high degree of motion such as joints and tendons. Trunk wounds have a better available reparative blood supply than those of the distal limb.

An injury to the distal limb metacarpal or metatarsal region of a horse which involves the flexor tendons and/or their sheaths requires healing by the ingress of blood vessels from adjacent structures. However, as healing attempts to progress, repeated tendon contraction and limb movement moves the injury away from the site of the skin wound leaving the damaged tissues with no effective mechanism for healing.
Rigid limb casting of a distal limb wound is very effective in facilitating wound contraction and epithelialization if the tissues are initially sharply debrided and lavaged. The mechanisms for this may be more complex than merely controlling movement. Although movement of the limb and wound is limited, added surrounding pressure applied to the wound may also facilitate the healing process. Warmth, restriction of movement and the presence of a moist healing environment in conjunction with a cast are probably significant factors that contribute to wound healing. Which aspects of the exudate are desirable and enhancing of wound healing and which are inhibitory is not known in the horse. Heat, pain, swelling, or lameness created by the cast indicate attentive reevaluation of the wound and the consideration of cast removal or cast change.

Self-mutilation
Significant self-mutilation of wounds through rubbing, biting, and pawing can occur if the horse is not adequately restrained or medicated. Usually the most intense pruritic episodes occur in the first weeks of wound healing during the inflammatory phase of repair and during eschar sloughing but can be a later complication associated with burn wounds. To prevent extreme self-mutilation, the horse should be cross tied and/or sedated at this time and use of a neck collar may be considered. Delayed healing, poor epithelialization, and complications of second intention healing may limit return of the animal to their previous use.

Skin grafting
Skin grafting decreases healing time and is one of the best techniques for covering a wound that has been chronically affected by exuberant granulation tissue. 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. Frequently, however, wounds in horses are treated for several weeks before skin grafting is initiated. At this point granulation tissue is mature, fibrous and has less of a blood supply than newly formed granulation tissue. Other complications of graft acceptance and healing are wound infection and sequestra formation.

Chronic inflammation, inherently present during second intention healing of wounds on the distal portion of limbs of horses may be at least as important as infection because it reduces the quality of the granulation bed and results in the production of a moderate amount of purulent exudate, both of which negatively influence acceptance of grafts. As a result the ability of a wound bed to accept a graft is lessened. It is therefore imperative that chronic granulating wounds be debrided to a level below the skin surface down to a level of healthy granulation tissue prior to graft application.

To increase the success of graft acceptance wound bacteria must be minimized. Beta hemolytic Streptococcus spp., Proteus spp., and Pseudomonas spp. are capable of producing destructive proteolytic enzymes and excessive purulent discharge which breakdown fibrinous attachments between the graft and recipient bed. Topical antiseptics have better efficacy than antibiotics in reducing bacterial wound load as the latter increase the risk of patient sensitization and the development of resistant organisms especially when used routinely over prolonged periods in uninfected wounds. Infected wounds, however, should be treated with broad-spectrum antibiotics while awaiting culture results. The bone underlying the wound should be radiographed for evidence of sequestra and excessive pericortical dystrophic mineralization. Large wounds often develop healthy granulating tissue around the perimeter before a sequestrum completely defines itself.

Donor site is influenced by the method of grafting, color, and texture of the donor hair, cosmesis of the donor site, and ease of obtaining skin. Common sites for obtaining donor skin include pectoral, dorsal neck region, perineum, ventral midline, ventral lateral abdomen and sternal region caudal to the girth area.

Pinch grafts
Pinch grafts are distinct pieces of skin (3 mm in diameter) produced by excising an elevated cone of skin. Graft acceptance is as high as 75% using pinch grafts partially due to the fact that the pockets of granulation tissue hold the graft in contact with the wound. Complications include necrosis of the graft, slower wound healing, improper orientation of hair, and thin skin coverage of the wound.

Necrotic spots along the top of the granulation pockets normally occur during healing, after which the graft epithelializes circumferentially. Because pinch grafts are small, complete epithelialization of the wound often requires greater than 70 days. Improper orientation of hair growth is a complication of pinch graft application despite repeated efforts to properly align the hair to match that of the recipient area. A cobblestone appearance with thin subcutaneous tissue is sequelae of pinch graft applications that may not be cosmetically acceptable for show horses.

Punch grafts
Punch grafts are circular pieces of skin that are directly removed from the locally anesthetized donor site or by obtaining biopsies from an excised piece of donor skin. Common complications of punch graft failure are incomplete removal of the underlying subcutaneous tissue from the graft, recipient site hemorrhage, and motion.

As punch grafts are full thickness they must have the subcutaneous tissue and fascia removed from the dermis with a surgical blade before implanting as these layers will prevent revascularization and subsequent graft failure. Placing grafts in saline soaked sponge gauze for a short period of time minimizes graft desiccation while recipient beds are created. Accumulation of blood and serum beneath the graft displaces the grafts from the recipient site. Hemorrhage can be avoided by ensuring that it is controlled before grafting. Displacement of the grafts can also be minimized by using a biopsy punch a size smaller than used to obtain donor graft to
ensure a snug fit in the recipient bed. Displacement of the graft by motion can be minimized by securing the wound under a heavy bandage. Displacement of grafted tissue at wrap changes can be reduced by soaking the primary bandage prior to removal. Casting is not indicated for punch graft techniques as punch grafts are not indicated for grafting over moveable areas of the body.

**Tunnel grafts**
Tunnel grafts are useful for healing of wounds that are hard to immobilize or bandage as on the dorsal surface of the hock or fetlock. Graft survival rates of 80% have been reported with excellent cosmetic results. Complications of tunnel grafting include the placement of tunnel grafts too close to one another, failure of the graft to become exposed and accidental removal of the tunnel graft when removing the overlying granulation tissue.

This technique requires harvesting of full-thickness or split-thickness strips of skin 2 to 5 mm wide and slightly longer than the length of the wound’s edges. These grafts are placed 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. The graft is then tunneled approximately 6 mm below the surface of the granulation tissue at the recipient site ensuring that the epidermal side of the graft faces the surface of the wound. Tunnel grafts should not be placed closer than 2 cm apart to prevent excessive necrosis of granulation tissue. The cut ends of the skin strips are sutured to the skin on either side of the granulation bed. A tourniquet may be useful to control hemorrhage and improve visualization of the strips for procedures that involve grafting on a limb.

If placed the correct depth, the granulation tissue overlying the graft should slough in 7 to 10 days. If this does not occur, it should be excised at this time. Adjacent granulation tissue that is raised should be excised at this time. Most tunnel graft failures are attributable to accidental removal of the graft during removal of the overlying granulation tissue or failure of the graft to become exposed. Exposure of the graft if necessary may be facilitated by placing malleable probes or wires through the tunnels to cut through the overlying granulation tissue.

**Full thickness sheet graft**
Full thickness or split thickness grafts can be applied as a sheet or expanded before transplantation. The full thickness sheet graft is the most cosmetic type of free sheet graft as it contains all the properties of the surrounding skin, provides maximum piliation, and can withstand pressure and friction. Full thickness grafts are not as readily accepted because there are less exposed blood vessels available for imbibition of plasma and for insoucilation.

No specialized equipment is needed for harvesting, and the procedure can often be performed in the standing sedated horse using local anesthesia. Donor sites of full thickness grafts should be sutured. The graft should be cut slightly larger than the recipient bed to allow for shrinkage after the graft is excised because of recoil of elastic fibers in the deep dermal layers of the graft. 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.

A high oxygen gradient between the wound and the graft is essential for neovascularization of the graft and graft acceptance. Full-thickness grafts treated with hyperbaric oxygen therapy developed less granulation tissue, edema, and neovascularization, but more inflammation. The superficial portion of these full-thickness grafts was also less viable than the superficial portion of those not treated with hyperbaric oxygen therapy.

Full thickness sheet grafts are often considered compromised because they often require more nourishment than can be supplied by the granulating recipient wound. As a result full thickness grafts are usually reserved for fresh uncontaminated wounds. The upper layers of a full thickness graft are more likely to slough because full thickness grafts require more nourishment and have fewer exposed vessels for this purpose. 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.

**Split thickness grafts**
Split thickness grafts are more readily accepted than full thickness grafts, and may be used to cover granulation beds that are less than ideal. Since blood vessels branch as they become more superficial in the dermis more vessels are cut and exposed with split thickness grafts. The greater the number of exposed vessels the better the absorption of nutrients will be from the granulation bed. A split thickness sheet graft is more cosmetic than a pinch or punch graft because the thickness of the graft and orientation of the hair are uniform and coverage by the graft is more complete.

A mechanical dermatome or a free hand knife (Watson Skin graft knife, Down’s Surgical, Sheffield, England) is used to split the dermis. The latter is preferred as it is easy to use and economical to employ. General anesthesia is necessary to obtain the graft as split thickness donor sites are very painful to the horse, since many nerve endings are exposed. Grafts less than 0.5 mm thickness in the horse lack strength, durability, and have sparse or no hair follicles or exocrine glands which results in less sebaceous secretion. Grafts harvested between 0.63 mm and 0.75 mm have good coverage of hair and greater durability than do thinner grafts. Unlike full thickness grafts suturing of the donor site is not required and primary graft contraction is minimal since a portion of the dermis remains intact and heals with a scarred appearance.

The grafts can be applied to the wound after the horse has recovered from general anesthesia. This reduces anesthesia time and the possibility of damage to the graft during the recovery process. The graft can then be affixed to the wound with the horse standing
without using local anesthesia by overlapping and gluing the graft with cyanoacrylate to the skin surrounding the wound. To increase graft success 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 with simple interrupted absorbable sutures. Meshing grafts greatly enhances graft acceptance by preventing mechanical disruption of the graft from its 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.

Although proper graft bed preparation and grafting techniques are important for successful graft application, successful graft acceptance depends greatly on attention to postoperative care. During the initial 4-10 days the graft may become edematous and pale. These changes are from a loss of blood supply due to vessel constriction and the expulsion of erythrocytes while the graft is nourished by passive imbibing nutrients onto its open vessels from the granulating bed via plasmatic imbibition. By day 10 the graft typically has a complete union to the graft bed. The epidermis might necrose and slough in some regions of the graft. Generally only the superficial areas of the graft have been lost and small areas of dermis surrounded by granulation tissue are present. The epidermis will regenerate from migration of epithelial cells present in the remaining sebaceous glands, sweat glands and hair follicles.

Periodic bandage changes allow for a clean environment and recognition of graft failure. For many horses frequent bandage changes aid in comfort. Soaking the inner bandage with sterile saline for 5 minutes and the carefully removing the bandage prevents destruction of many grafts. The presence of purulent material on the initial bandage change does not have a detrimental effect on acceptance of individual grafts. Silver sulfadiazine in a 1.0% water-miscible cream is effective against most Gram-positive and Gram-negative organisms and may enhance wound epithelialization. Additional immobilization gained with a cast is usually unnecessary to facilitate acceptance of grafts after 10-14 days. Immobilization may, however, lessen edema and decrease the possibility of self-mutilation. Persistence in re-grafting on horses that self-mutilate wounds has resulted in satisfactory wound healing in the majority of cases.

References