EQUINE WOUND HEALING

Normal Wound Healing

from https://thehorse.com/115825/how-horse-wounds-heal/

The Inflammatory Phase

The horse's body begins reacting as soon as an injury occurs with the inflammatory phase, Welker said. The skin around the wound begins retracting due to tension; immobilizing the wound can help reduce this effect, he said. Skin retraction can continue for up to 15 days post-injury, he said. Within five to 10 minutes after the horse sustains a wound, Welker said, a vessel response occurs. During this response, "intense vasoconstriction" (narrowing of the blood vessels) occurs at the wound site, followed by vasodilation. It's during this response that fibrin—an insoluble protein that forms the nucleus of a blood clot—arrives at the wound site.

Within 30 minutes of injury, the body's cellular response kicks in, Welker said. Blood platelets and leukocytes (white blood cells) "line up" at the wound site to begin cleaning it. These cells are required for healing, he said, and their presence activates the fibrin, allowing clotting to begin. And finally, within an hour of injury, the localization response takes place. At this point, a fibrin clot has localized damage to just the affected area; the clot also prevents contaminants from getting into the horse's bloodstream or surrounding undamaged tissues, Welker said, and forms the framework needed to repair the defect. Unfortunately, the localization response comes with a downside, Welker said. Because the contaminants have been localized to one central area, inflammation (including swelling, redness, heat, and pain) develops. Excessive inflammation delays healing, Welker said, and can lead to pressure necrosis, pain, scarring, and bacteria development.

The Debridement Phase

The next phase is debridement, which is critical for all wounds and injury healing, Welker said: "Healing cannot proceed without the completion of this stage," he said. The debridement phase takes place when neutrophils (a type of white blood cell capable of engulfing and destroying bacteria and other disease agents, immune complexes, and cell debris) enter the wound defect and kill bacteria, break down debris, and enhance the inflammatory response; unfortunately, when too many neutrophils enter the wound, the healing process slows, Welker said. At that point, pus develops, which further slows the healing process by breaking down fibrin working to fill the defect. To prevent excessive neutrophils from inhibiting healing, he said, keep the wound clean and administer antibiotics.

Some inflammation is good, Welker added, but excessive inflammation slows healing. Epithelialization—which Welker described as the first sign of defect repair—begins between eight and 10 hours after a wound occurs. During this stage epithelial cells "migrate" under the scab at a rate of 0.2 millimeters per day on the horse's upper body

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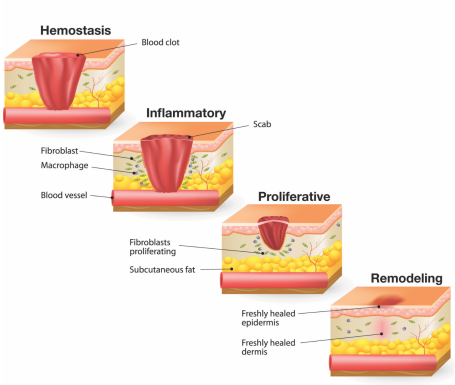
and 0.09 millimeters per day on the animal's limbs or lower body, Welker said. Factors that inhibit or delay epithelialization, he said, include infection, excessive granulation tissue (commonly known as proud flesh), repeated bandage changes, extreme hypothermia, and dessication (the wound drying out).

The Repair Phase

By the fourth or fifth day after a wound occur, fibroblasts (cells responsible for forming connective tissues) move into the area and begin tying the wound edges together to fill the defect. The fibroblasts will continue moving over the defect until they contact other fibroblasts. Welker explained that fibroblasts produce a substance that enhances the fibrin matrix before producing collagen, which essentially serves as a glue holding the layers of skin (or in this case, new epithelial tissue) together.
In the third to sixth day post-injury, Welker said, granulation tissue begins to form and subsequently allows wound contraction to occur (more on that in a moment). Welker said granulation tissue is an important part of wound healing: It provides a surface for the epithelial cells to migrate over, it's resistant to infection, wound contraction centers around it, and it carries the fibroblasts responsible for collagen formation. But granulation tissue can cause problems in some cases.
"Horses are overachievers and can keep producing excessive granulation tissue," Welker said. "This is when it becomes a problem."
He said he considers granulation tissue that rises above the skin level to be excessive.
Next, Welker discussed wound contraction, the process by which open skin wounds reduce in size due to the movement of surrounding full-thickness skin. Welker said special cells on the surface of the granulation tissue bed–modified fibroblasts called myofibroblasts–draw the full-thickness skin toward the center of the wound.
"Wound contraction works best in areas where the skin is relatively loose (upper body), but where skin is relatively tight (lower limb) contraction is much less efficient and will result in wider scars," Welker said.

The Maturation Stage

The final stage in wound healing is maturation, Welker said, and it can last for months to a year or more, depending on wound severity. In this phase, the number of fibroblasts in the area decreases while collagen production and lysis (decomposition) continue, he said. Also in this phase, the wound's tensile strength increases. Welker cautioned that once a wound heals fully, the defect's tensile strength will always be 15-20% weaker than the surrounding areas..



Complications

- healing of equine wounds is complicated by numerous environmental and physical factors
- The following contribute to complications of and challenges to wound healing in the horse

- **Infection**
- presence of foreign bodies, debris, soil and environment can exacerbate
- Longer time taken to assess and clean wound can increase chance of infection
- Reduce by proper wound preparation (cleaning, lavage, debridement)
- Antibiotics (systemic (use broad spectrum, bactericidal) or topical - in lavage or cream/ointment)

- **Movement** - movement is the enemy of wound healing! - Dr White

- **Management** - proper general management will hinder or help healing
- how fast is wound assessed?
- Golden period - 6-8 hrs after injury —> better prognosis, less chance of infection
- Management, treatment and dressing
- For horse: distance and physical exam, check for other injuries, first aid (immobilization + haemostasis), tetanus shot
- Assess extent of wound & contamination, check tissue deficit by assessing skin flap
- For lavage: saline is a good option and wound must be lavage $\geq$ 7 psi to adequately remove material and bacteria. Tap water or dilute antiseptic if heavily contaminated
- Pressure test to check for joint involvement

- Debridement: local anaestheitc + sedated animal, alpha 2 agonist, will still kick you! Excise dead tissue. Use of sterile fly larvae is possible
- Drains - large dead space may result in accumulation of fluid. Keep sterile and remove after 24-48 hrs
- Closure of wound: appropriate suture material (synthetic monofilamenrs like nylon or PDS). Wound closure will cause wound to heal by primary intention which results in a smaller scar. Secondary closure occurs after development of normal granulation tissue, occurs in wounds with large tissue deficit such as proximal limbs, body, neck.
- Dressing: provide optimal healing conditions. Absorbs exudate. Maintains moist environment, protection, increase temp and CO2, O2 to site of wound by circulation

(*From Dr White's lecture)*
1º or contact layer – create moist environment, absorb exudate, gas permeable
2º layer – absorb & protect
3º layer – secure & protect other layers

- **Granulation tissue**

- Otherwise known as proud flesh, 'exuberant granulation tissue' is most common in horses and prolongs the normal healing process.

https://www.horseandhound.co.uk/horse-care/vet-advice/proud-flesh-horses-treatment-60332

- **Extent of trauma** - wounds containing a foreign body or debris will not heal until it has been removed. Check for involvement of synovial structures, obody cavity, fracture, or affecting tendon
- reduce trauma by debridement, haemostasis and management of surgical trauma
- Ensure good drainage!

- **Location of the wound** - trunk vs distal limb wounds in particular. Trunk wounds generally have a better prognosis

HEAD WOUNDS

- The head has an excellent blood supply that helps with rapid healing, but there is little extra skin over the bones of the face. Thus, wounds with significant skin loss take a long time to heal. If there is skin loss involved in a new wound, a veterinarian may be able to save lots of healing time by repairing it if the skin is still viable.
- Head wounds often result in loose flaps of skin. A veterinarian should repair these wounds as soon as possible. Suturing these wounds saves months of healing time and results in improved cosmetic appearance.

- Head wounds often involve bone, which is just under the skin in most places. Thus, a common complication of head wounds is damaged and infected bone. This may require surgical removal immediately or at a later date.
- The sinuses are air-filled cavities within the skull that communicate with the upper respiratory tract. Wounds fracturing the facial bones and entering into these cavities can result in their infection, which can be a chronic and severe problem. Signs of sinus infection are yellow or whitish nasal discharge (often with a foul odor), and chronic swelling or drainage at the wound site.
- A severe wound of the head or neck requires assessment of the whole horse to ensure that their brain and spinal cord have not been injured.

BODY/TRUNK WOUNDS

Body wounds are common and most heal quickly. As was discussed with head wounds, the critical question is whether the wound involves deeper structures or penetrates into the abdominal cavity

A wound that penetrates into the abdominal cavity or chest introduces life-threatening infection into the cavity and results in severe illness within hours.

Severe abdominal wound, before and after treatment. The wood splinters (shown on the far right) penetrated into the abdominal cavity, introducing life-threatening infection. Prompt and aggressive treatment was required to save the horse.

Wounds along the top-line lack the ability to drain, and so pose more problems healing

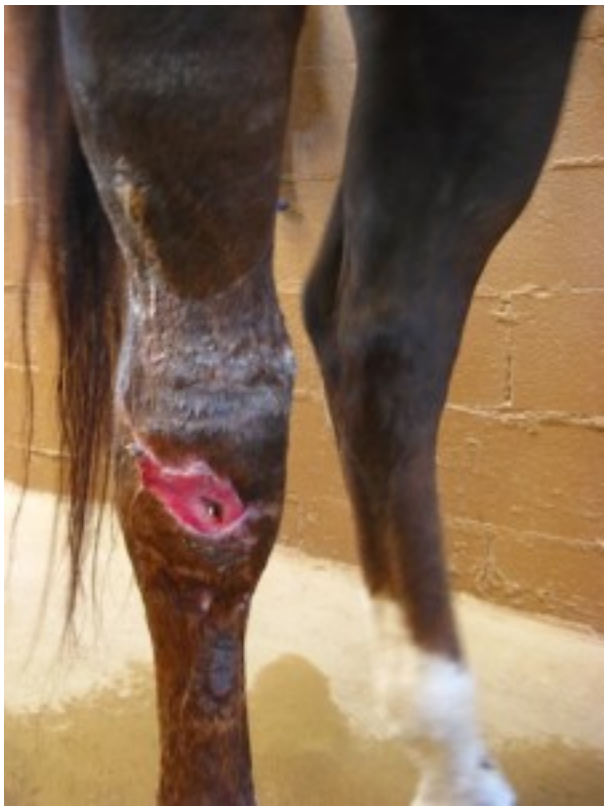
Wounds to the underside of the body are common and generally heal well as long as there is no forei



gn body and the wound does not penetrate body cavities.

Uncomplicated body wounds (especially chest wounds) left open often heal very well by wound contraction.

LOWER LIMB WOUNDS



- Lower limb equine wounds can be serious, even life-threatening, if vital structures are involved.
- Vital structures like joints, tendon sheaths, ligaments and bone are just a few millimeters from the skin surface. If these structures are involved, life threatening or chronic lameness may result. Excellent veterinary management of these injuries from the beginning is the key to successful outcomes.
- Excessive movement, little loose tissue for contraction, and a poor blood supply in the lower limb results in difficult and slow wound healing.
- Overgrowth of healing tissue (proud flesh) is common in lower limb wounds of the horse. Proud flesh is excessive healing tissue that accumulates to a level above the wound bed or surrounding skin surface. It inhibits healing by preventing the skin from migrating over the wound bed. It must be removed and managed. Proper wound care controls the formation of proud flesh.

- Suturing of selected lower limb wounds is usually accompanied by careful bandaging or casting, and long-term confinement. A properly applied cast can result in a quick, cosmetic and functional outcome in what otherwise would be a slow and difficult healing process.

UPPER LIMB WOUNDS

- Upper limb wounds are common and generally heal rapidly.
- There is much more musculature in the horse's upper limb than in the lower limb, so bone and vital structures are generally less often involved.
- There is a better blood supply here than in the lower limb, which aids wound healing. The additional tissue mass means wound contraction can aid healing more than in the lower limb.
- Severe wounds to the upper limb can result in tremendous muscle loss but usually this does not reduce function much.
- Cared for properly, most of these wounds with extensive muscle loss heal well and result in acceptable function of the limb.
- Veterinarians sometimes choose to repair these wounds by suturing, but often recommend treatment leaving the wound open.

SKIN GRAFTS IN THE EQUINE

General Classification of skin grafts
https://pdfs.semanticscholar.org/0321/00db011b7e843bd24e2e35bb45947efa59fc.pdf

https://thehorse.com/16908/skin-grafting-options-for-horse-wounds/

- A skin graft involves the removal and transfer of a healthy piece of skin from a donor site on the horse's body to the wound. The graft attaches to the wound bed naturally with the help of fibrin—a protein involved in blood clotting. In successful procedures, within 48 hours capillaries connect the pieces of skin, by Day 4 or 5 the graft has a blood supply, and by Day 10 it's attached firmly to the wound.
- fluid accumulation, movement, and infection can lead to failure

- three types of free (meaning the skin has been detached completely from the donor site) skin grafts used on horses: Island grafts, which are implanted into the wound, and full-thickness (containing all skin layers) or split-thickness (just the epidermis and a portion of the dermis) sheet grafts, which are applied as a sheet to the surface of the wound.

Island Grafts

- simplest method of skin grafting is island grafting
- small pieces of full-thickness (containing all skin layers) or partial-thickness (the epidermis and only a portion of the dermis) skin are implanted into a granulating (filling with healthy red tissue) wound for the

purpose of increasing the area of skin from which epithelial cells can migrate to cover the wound

- wounds healed with these grafts do not have very cosmetically appealing outcomes.
- Island grafts are subdivided into punch, pinch, and tunnel grafts:
  - Punch: The veterinarian takes these small, full-thickness plugs of skin, about 1 centimeter apart, from the horse's abdomen, pectoral region, perineum, or neck under the mane, with or without suturing the site. Can be tedious - must excise the subcutaneous tissue from each plug to expose the underlying blood vessels before implanting it into the wound. A less tedious version of this method is to harvest a section of skin no more than 10-by-4 centimeters, excise the tissue from it, and then cut out the plugs.
  - the veterinarian punches recipient holes in the wound and inserts the grafts into those holes, then covers the area with a dressing and bandage. After about three weeks a healthy red ring of epithelium should surround each plug. Two-thirds to three-fourths of the grafts survive.
  - Pinch: small discs of skin, 3 millimeters or less in diameter, that are implanted into shallow, shirtlike pockets created in granulation tissue.
  - The veterinarian harvests them from the same donor sites as the punch grafts. After implantation, the grafts first appear as dark spots on the wound's surface, but by Week 3, each disc should sport a red ring around it.
  - Tunnel: veterinarian harvests 2-3-millimeter-wide strips of skin from the flank or neck under the mane and embeds them about 2 centimeters apart in the wound. Schumacher recommends these for helping heal wounds in areas where it might be difficult to immobilize a sheet graft, such as over a hock or knee.

- requires little expertise and no expensive equipment and can nearly always be performed without anesthetizing the horse. Is tedious and usually reserved for small wounds
- scarring at the donor site is a cosmetic drawback

Full-Thickness Sheet Grafting

- doesn't require sophisticated equipment

- can be harvested from the standing horse
- offers the best resulting appearance and function of all methods.
- Use skin of the horse's pectoral region as it is mobile and heals quickly and cosmetically after suturing.
- The veterinarian attaches the graft to the wound using staples, sutures, or glue.
- usually reserved only for fresh, clean wounds (such as surgical wounds that can't be sutured) because full-thickness grafts require more nourishment

Split-Thickness Sheet Grafting

- ideal for wounds too large to be covered by an island or full-thickness graft
- sheet of skin harvested is fairly large (up to 4 inches wide), sites used include the underside of the abdomen or thorax.
- a specialized power-driven or free-hand knife is used to harvest the very precise split-thickness skin graft.
- requires more expensive equipment and skill than the other methods
- split-thickness sheet graft covers the wound more completely and offers a more cosmetic result than island grafting
- less cosmetic than full-thickness grafting
- cons include scarring at the donor site and the need for general anesthesia, which poses its own set of risks and expenses.
- mesh is also utilized and most grafts are meshed (cut staggered, parallel rows of openings in the skin) - mesh allows graft to cover an area much larger than the graft itself, and it tolerates movement better than a nonmeshed graft

MORE TECHNIQUES + PREP OF SITES

https://pdfs.semanticscholar.org/0321/00db011b7e843bd24e2e35bb45947efa59fc.pdf

Grafts that are classified by blood supply are the free graft and the pedicle graft. A free graft is devoid of blood supply; a pedicle graft maintains its own blood supply.[2,5] Because pedicle grafting requires general anesthesia to isolate the required nutrient arterial vessel, free grafting is more practical for use in the field.[2]

Free grafts are further classified as island grafts (e.g., pinch, punch, and tunnel grafts) and sheet grafts. Sheet grafts can be split-thickness or full-thickness and can be applied as solid or meshed sheets. Pinch, punch, tunnel, and sheet grafting can be applied in the field, with the horse standing or recumbent, using short-acting general anesthesia. Sheet grafts provide more complete dermal coverage of the wound; island grafts provide dermal tissue only at the graft site and provide epithelial coverage in between. Grafts help to control infection, provide dermal coverage of the wound, and stimulate epithelialization from the epithelial edges of the wound and graft.[2,9]

HEALING OF GRAFTS

The success of grafting is based on four events: (1) fibrinous adherence of the graft to its bed, (2) plasmatic imbibition (passive absorption of nutrients by the vessels of the graft), (3) revascularization of the graft, and (4) organization of the grafted wound with collagen-secreting fibroblasts.[5] The graft adheres within minutes of implantation.[2,6] Fibrin, formed from fibrinogen, is brought into the recipient site by the surrounding vessels and attaches the graft to its bed.[10] For the first few days after grafting, the delicate fibrinous attachment is the sole method of adhesion.[6] Early immobilization to protect this delicate attachment thus is critical to the acceptance of the graft.[11]

Before the graft is revascularized, it must survive by plasmatic imbibition. This is the process by which the graft bed provides an oxygen-rich, plasmalike nutrient fluid for absorption into the dilated vessels of the graft.[11,12] The duration of plasmatic imbibition depends on the quality of the recipient site bed. The more vascular the recipient bed, the faster the graft is revascularized and the less it must rely on plasmatic imbibition.[10,12]

The graft revascularizes by two processes: (1) vascular anastomoses through a direct connection of graft and host vessels (inosculation) and (2) ingrowth of host vessels into the dermis of the graft.[11,13] Inosculation usually begins during the first 2 days, restoring circulation to the graft by the fourth to seventh day.[10,13,14] Revascularization by invasion of new vessels begins at 4 to 12 days.[2] When revascularization is well established, the fibrinous attachment of the graft is infiltrated with fibroblasts. These cells secrete collagen and ground substance into the wound, increasing the tensile strength of the attachment of the graft.[10,15]

PREPARATION OF THE RECIPIENT SITE

Sheet grafts are best applied to fresh wounds that have no granulation tissue, but such grafts also can be applied to granulating wounds. Island grafts, however, can be applied only to granulating wounds. The granulation tissue to which grafts are applied should be newly formed, richly vascular, firm, and free of purulent discharge.[10,16,17] The presence of advancing epithelium at the margin of the wound is generally a good indicator of the bed's health and capacity to accept a graft.[10,17] Formation of a healthy bed of granulation tissue requires at least 5 days after injury.[10]

Because wounds in horses are frequently treated for weeks before the decision to graft is made, the granulation tissue is often mature and contains more fibrous tissue and a poorer blood supply than would a fresh bed of granulation tissue. Consequently, the ability to accept a graft is less than optimum.[1] Before the graft is applied, the mature granulation tissue must be excised to below the skin surface to allow development of a healthier, more vascular granulation tissue bed. Because of the lack of innervation, granulation tissue can be excised with the horse standing.[17] Deep crevices and depressions in the tissue should be excised so that the wound is smooth, allowing better contact with and thus better acceptance of the graft.[3]

Studies indicate that trimming granulation tissue as much as 4 days before skin grafting may increase acceptance of grafts.[4,18] Because of the significant amount of hemorrhage that results from such trimming, the bed should be trimmed no less than 24 hours before grafting. Wounds that are apparently infected can be cultured for bacterial identification and antimicrobial sensitivity testing.[18]

After debridement, the wound should be covered with a nonadhesive pad and a well-padded bandage. If the wound is at a highly mobile site (e.g., the metacarpophalangeal joint), the site should be stabilized by a splint incorporated into the bandage before grafting to accustom the horse to the decreased range of motion of the joint.[17] The acceptance of the graft is positively influenced by the use of appropriate bandages that prevent movement between the graft and the recipient bed and that help protect the delicate granulation tissue from bruising.[3,4]

For grafts to be accepted, the concentration of bacteria in the wound must be minimized.[19] β-hemolytic *Streptococcus*, *Proteus*, and *Pseudomonas* species are capable of producing destructive proteolytic enzymes that

degrade fibrinous attachments between the graft and recipient bed.[2,3,6,18,19] These bacteria also produce copious purulent discharge that can separate the graft from its bed.[2,3,6,18,19]

Topical treatment of infected granulating wounds with appropriate antimicrobial drugs is more effective than systemic treatment.[17,20] Systemically administered antimicrobial drugs are often incapable of achieving therapeutic concentrations in the granulation tissue because fibrin in the wound prevents penetration of the drug to the surface of the wound.[17,20] Systemic antibiotic therapy may be indicated if infection of the deep tissues is suspected.[18] Dilute chlorhexidine solution (0.05%) can be used daily to cleanse wounds; it is minimally cytotoxic and more bactericidal in the presence of cellular debris than is povidone–iodine solution.[21] Prolonged contact of a stronger solution of chlorhexidine (0.5%) has been demonstrated to slow formation of granulation tissue and to hinder tissue healing.[22]

Before grafting, bone beneath deep wounds should be examined radiographically for the presence of osteitis (which must be resolved) or sequestra (which must be removed). A large wound often develops healthy granulation tissue along its periphery before a sequestrum is visible radiographically. In our experience, grafting can be performed successfully along the periphery of such wounds. A second grafting procedure can then be performed in the center of the wound after the sequestrum is removed and healthy granulation tissue has developed.

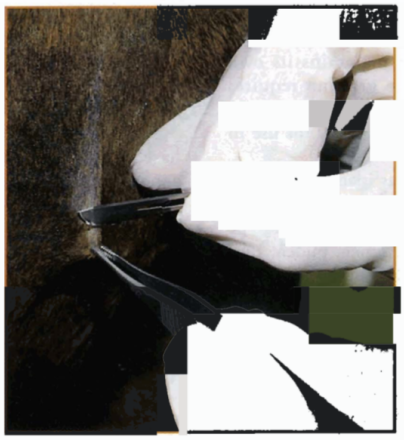


Figure 1—Harvesting pinch grafts from a donor site. The split-thickness graft is harvested by severing the elevated cone of skin under the needle.

Figure 2—Implantation of pinch grafts into pockets (created by a No. 15 blade) in the granulation tissue of the recipient bed.

PREPARATION OF THE DONOR SITE

Selection of the donor site is dictated by the grafting technique to be used. A donor site should be easily accessible for procuring the graft or grafts. The most cosmetic sites for graft procurement may be regions of the neck covered by the mane, the ventral abdomen, or the ventral pectoral region. Other donor sites include the sternal region, the region caudal to the girth path, and the perineum.[17,18] Cosmesis of the wound is best when the donor hair (color and texture) matches that adjacent to the graft site. Local anesthesia of the skin and possibly sedation of the horse are necessary for safe retrieval of the full-thickness donor skin.

Skin for island grafting can be obtained from the perineum after caudal epidural anesthesia.[18] This donor site is particularly convenient for grafting a wound on a rear limb. Split-thickness grafts can only be harvested safely when the horse is anesthetized.

Regardless of the donor site chosen, it should be clipped (rather than shaved) to prevent damage to the epithelium. The site should be prepared with an antimicrobial scrub.[18]

TECHNIQUES

Pinch Grafting

Pinch grafting is the technique of implanting small disks of skin (3 mm in diameter) into the granulation tissue of a wound.[2,18,23] Pinch grafting is easily performed in the field. Grafts are procured by elevating the skin with forceps or a needle with a bent point and severing the elevated cone of skin at its base (Figure 1). The center of such a graft is nearly full-thickness and contains some hair follicles.

The graft is implanted into a pocket created in the granulation tissue by means of a No. 15 or No. 11 scalpel blade (Figure 2). The granulation tissue is stabbed obliquely with the blade to create a pocket 2 mm below the surface such that the opening of the pocket is proximodorsal. The pockets are usually created in parallel rows at 1-cm intervals. Digital pressure should be applied to the pocket for 15 to 30 seconds to control hemorrhage, which may dislodge the grafts.

Insertion of grafts into the pockets can be tedious. A small thumb forceps, a blunted needle, or a No. 15 blade helps in implanting the grafts into the pockets. Grafts can be placed on a saline-soaked sterile sponge, or four to five grafts can be placed on the wound (where they are maintained by hydoscopic pressure) as the pockets are being created. This speeds implantation by minimizing repetitive steps. Immediately after insertion, moderate digital pressure for 15 to 30 seconds may be necessary to control hemorrhage and maintain the grafts in the pockets.

Because of hemorrhage, pocket creation and grafting of a wound should commence distally and progress proximally. Large wounds of the limb are best divided into proximal to distal thirds. Starting with the most distal section, pockets are created and grafts are implanted. After the distal section of the wound is grafted, that section is bandaged with a sterile nonadherent pad and sterile gauze roll before the next (more proximal) section is treated. Staged bandaging prevents loss of grafts if the horse moves or there is excessive hemorrhage. Although the bandage becomes blood-soaked, this technique helps prevent loss of grafts.

Figure 3—Advanced stage of epithelialization after pinch-graft implantation. The cobblestone appearance of divergent, sparse hair growth is cosmetically unacceptable to some clients.

Figure 4—Punch grafts obtained directly from the donor site (with the horse standing). Because this is a full-thickness graft, the subcutaneous tissue should be sharply excised before graft implantation.

For pinch grafts, a 75% acceptance rate can be expected.[17] This percentage is good and may be partially related to the pockets, which hold the graft in contact with the granulation tissue. The surface of the granulation pocket normally necroses during healing; epithelialization then proceeds circumferentially from the graft. Because pinch grafts are small, complete epithelialization may take a long time, especially if few grafts were implanted or there is a high percentage of graft loss.[1]

An advantage of this grafting technique is that the donor-site defects are small and not completely full-thickness. They are thus usually left open to heal by second intention.

One disadvantage of pinch grafting is the difficulty in orienting the direction of hair growth because of the small donor-graft size. Because wounds heal primarily by epithelialization and the amount of hair follicles that survive is small, it may not be worthwhile to try to maintain the orientation of hair. Nevertheless, systematic grasping of the graft and maintaining it in this orientation while it is placed in its pockets may allow appropriate direction of hairs. If the hairs are directed proximally, they help to stabilize the graft and make it easier to insert into the recipient bed. Despite careful orientation, hair growth may occur in multiple directions. This divergence of hair can help to cover the epithelial scar that develops between the islands of skin.

Once they are healed, wounds often have a cobblestone appearance (Figure 3). For owners of show horses, this may not be cosmetically acceptable.[18]

Punch Grafting

Punch grafting is similar to pinch grafting and can be readily performed in the field with the horse standing. Using a skin biopsy punch, circular plugs of skin are removed directly from the anesthetized donor site (Figure 4) or punched from a piece of skin that has been removed from the donor site (Figure 5). During harvesting from the ventral pectoral region, punch grafts are best placed on a saline-soaked sponge.[18] Because punch grafts are full-thickness, subcutaneous tissue and fascia must be removed with a blade before the grafts are implanted.[20] It is easier to remove subcutaneous tissue from a section of skin before punches are harvested because removal from individual plugs is tedious.

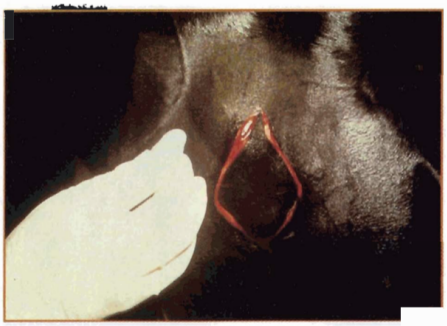


Figure 5—An elliptic piece of skin removed from the chest to create punch or tunnel grafts.

A biopsy punch, usually 2 mm smaller than that used to obtain the donor graft, is used to create recipient sites for the punch biopsies.[2] We use 8-mm biopsy punches for harvesting and 6-mm punches to create the recipient sites (Figure 6). Biopsy holes in the granulation tissue are placed at 5- to 15-mm intervals. Cotton-tipped applicators can be placed in a hole to aid in identifying the hole in the granulation tissue, which rapidly becomes obscured by hemorrhage[6] (Figure 7).

A second approach to controlling hemorrhage after placement of punch sites is to bandage the recipient site for several hours. The grafts can be applied directly from the donor site or can be stored in a refrigerator on saline-soaked gauzes during this period. Because some hair follicles are present, it may be beneficial to orient the graft so that hair growth is in a proper direction. If the wound is large, staged bandaging during the implantation process (as described for pinch grafting) may prevent loss of grafts by precluding excessive hemorrhage or movement of the graft.

Figure 6—Creation of the recipient sites for donor punch grafts using a 6-mm skin biopsy punch.

Figure 7—Sterile applicators placed in the recipient-site pouches to facilitate hemostasis and identification of the site (which is obscured by blood) in the granulation tissue.

The donor graft sites can be closed with sutures or staples or can be left open to heal by second intention. If an elliptic piece of skin is removed to obtain the punch grafts, the donor site should be sutured.[17] If punches are removed directly, the donor sites heal with multiple stellate scars.[17] As with pinch grafting, the recipient site may develop an uncosmetic cobblestone appearance. Nevertheless, hair coverage is more prominent with this technique.[13,17,18] Studies have reported graft survival as high as 95% and epithelialization of the entire wound within 47 days.[1,7,19,24–26]

Tunnel Grafting

Tunnel grafting requires

harvesting of full-thickness or split-thickness strips of skin that are 2 to 5 mm wide and slightly longer than the wound[3,4,6,17,18,27] (Figure 8). Full-thickness skin is often used in field situations because split-thickness skin grafts are difficult to obtain without special equipment (e.g., free-hand knives or motorized dermatomes) and general anesthesia.[18] To improve acceptance of the graft, subcutaneous fascia and fat should be sharply dissected from full-thickness donor skin.[20] Often, the easiest method of obtaining tunnel grafts is to remove a sheet of skin from the donor site. Strips of skin are then easily cut from the stretched and stabilized sheet[18] (Figure 5). To minimize scarring, the donor site is sutured by primary closure.[18]

The grafts are implanted in tunnels created in the granulation tissue, which has been allowed to develop 4 to 8 mm above skin level.[4] These tunnels are created via a cutting needle, a flattened Kirschner wire with a trocar point, a straight teat blade, or a malleable alligator forceps.[3,4,14,27,28] An alligator forceps or a small tendon forceps is then used to grasp and pull the skin strip into the bed[4] (Figure 9). To prevent vascular compromise of the granulation tissue, tunnel grafts should be placed no less than 1 cm apart.[4]

In one popular method used to implant tunnel grafts, adhesive tape (slightly longer than the graft) is placed on the haired side of the graft to minimize graft rotation.[3,28] The graft and tape are then threaded through the eye of a 10- to 12-cm, half-curved or straight cutting needle.[4] The needle and graft are inserted through the granulation tissue 5 mm below the surface. The haired side should be facing outward, and the hair should be oriented in the proper direction.[4]

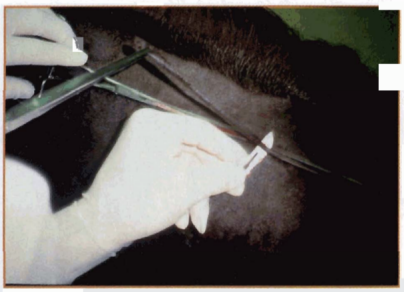


Figure 8—Creation of a tunnel graft from skin along the neck.

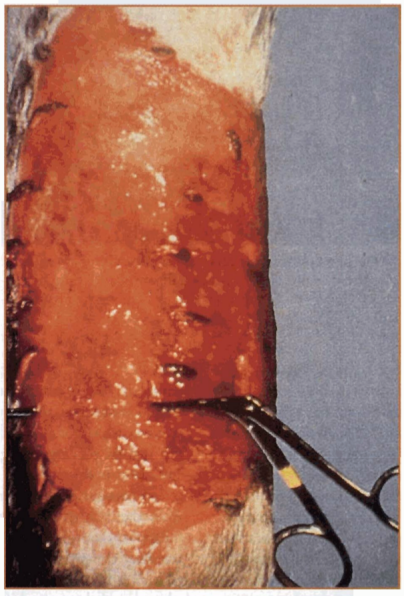


Figure 9—Creation of a tunnel in the recipient granulation tissue and implantation of a tunnel graft using a tendon forceps to pull the grafted tissue through the wound bed.

Because the needle is often smaller than the wound length, multiple small strips of grafts are used or a longer graft is placed over the width of the wound by a two- or three-step passage of the needle.[17] The needle reenters the point of exit for the second and third bite. Tunnel grafts inserted into a wound on a limb should be placed circumferentially because of the increased difficulty in placing the grafts in the proximodistal direction.

When tape is used to facilitate implantation of the graft, the graft may become dislodged, especially if the tape is removed immediately after insertion or later with excision of overlying granulation tissue.[3,28] Attaching the tape to the graft can be tedious and can increase surgical time.[28] Such attachment is unnecessary if an alligator forceps is used.[17]

In some cases, tunnels can be created with the horse standing; however, because slight movement may destroy the tunnel, short-term general anesthesia may be required.[18] In our opinion, general anesthesia facilitates placement of grafts.

To minimize anesthesia time, a full-thickness sheet of tissue can be harvested while the horse is standing. The sheet is cut into strips, stored on sponges soaked with physiologic saline, and then placed into the granulation bed after the horse is anesthetized. The ends of

graft.[20,30,33–35] Full-thickness grafting, however, gives the healed wound a better cosmetic appearance because the graft contains all of the properties of the surrounding skin, provides maximum hair growth, and can withstand pressure and friction.[17]

Mesh Grafting

Mesh grafts are multiple, uniform fenestrations that are created by hand- or mesh-grafting instruments. These grafts allow fluid to drain, topically applied medication to reach the granulation bed, and the graft to conform better to irregular surfaces[17,18,36,37] (Figure 11). The meshing of grafts may improve acceptance and allow a small piece of skin to be expanded to cover a large recipient site.[2]

Meshing a large graft by hand is tedious. Meshing can be facilitated by wrapping the graft several times around a flat strip of sterilized cardboard, x-ray film, or plastic.[2,17,18] Straight cuts are then made with sharp scissors at regular intervals halfway through the skin and cardboard on both sides.[38]

Figure 11—A full-thickness, hand-meshed sheet graft attached with sutures to a wound on a limb.

The time required for the wound to epithelialize completely depends on the expansion ratio of the graft. A graft with a ratio of 9:1 can cover a wound that is nine times larger than the original width of the graft; however, the large areas of the wound within the fenestrations must heal by epithelialization, which increases the time of healing and scar formation. A graft with a 3:1 expansion ratio allows more rapid healing; less epithelialization is necessary to heal the wound.[6,17,36]

POSTOPERATIVE CARE

Acceptance of a graft depends on strict attention to the postoperative care of the wound. Grafts fail when revascularization is obstructed, infection occurs, or the graft is separated from its bed.[1,2,6] During the first 4 to 12 days (when the graft is revascularizing and is fixed to the recipient bed by fibrin), the graft should be protected from the environment, if possible, by a snug and well-padded bandage.[4,18] After this period, continued support of the grafted site with a bandage may lessen edema and decrease the possibility of self-mutilation.[6] Because many areas on a horse are difficult to bandage, a tie-over dressing can be used to secure a nonadherent sterile dressing directly over the graft (e.g., a large wound on the back).[6,19]

In our opinion, it is beneficial to change the bandage every 2 to 3 days. Frequent changes allow a cleaner environment for the grafted site and quick recognition of infection. The bandage must be carefully removed at each changing. Soaking the bandage with saline before removal may help loosen fibrinous attachments between the graft and bandage. Discharge should be swabbed (not wiped) with gauze that is moistened with a dilute antimicrobial agent.

In our experience, a 0.05% solution of chlorhexidine diacetate is a useful antimicrobial agent; it is not systemically absorbed, causes no systemic toxicosis, is not inactivated by organic matter, and is superior to povidone–iodine in killing *Staphylococcus aureus*.[39] At this concentration, chlorhexidine diacetate has significantly more bactericidal activity than does 0.1% or 1.0% povidone–iodine or physiologic saline.[40] Unlike povidone–iodine, chlorhexidine diacetate (at 0.005% or 0.05%) has residual effects 6 hours after irrigation.[40]

Systemic administration of broad-spectrum antibiotics for 5 days after skin grafting, especially after grafting fresh wounds, may be beneficial.[19] In our experience, however, daily application of topical antimicrobials is more effective than systemic treatment in maintaining the health of the wound and allowing graft acceptance. We most often use 1.0% water-miscible, silver sulfadiazine cream; this agent is effective against most gram-positive and gram-negative organisms and promotes rapid epithelialization.[41,42]