Box 8.1 Initial wound management.

- Perform a complete physical examination.
- Cover the wound with a clean bandage before systemic problems are addressed.
- Provide sedation and analgesia, if indicated.
- Cover the wound with gauze soaked in isotonic saline solution or a water-soluble gel, and clip the surrounding hair.
- Clean the surrounding skin and administer local anesthesia to facilitate irrigation, debridement, exploration, and closure.
- Irrigate and surgically debride the wound.
- Explore the wound to determine involvement of deep structures.
- Select the appropriate approach to closure (primary closure, delayed primary or secondary closure) or manage by second-intention healing.

Primary closure

Primary closure is the preferred method of treatment for all wounds because suturing the wound protects it from further contamination, curtails the time required for complete healing, reduces scarring, thereby improving cosmetic and functional outcomes, and limits the cost incurred and aftercare required by the owner. For these reasons, even wounds that suffer a substantial loss of tissue can benefit from partial primary closure. When tissue has been lost, as much as possible of the wound should be closed, while avoiding excessive skin tension that might compromise the viability of tissue (Figure 8.4). This approach achieves a more cosmetic result than does leaving the entire wound open to heal by second intention.

Nevertheless, some heavily contaminated wounds and wounds containing crushed tissue are not amenable to primary closure. When closed primarily, these wounds often dehisce when contamination leads to infection, necessitating costly interventions.

The decision to perform primary closure is based on the location and conformation of the wound, the amount of residual contamination after cleansing and debridement, and the integrity of the blood supply to the wounded tissues. Closure may be performed with the horse sedated, using local anesthesia, or with the horse anesthetized. If the practitioner prefers to refer the horse for primary closure, the wound should be cleansed, and a protective bandage applied to the wound before the horse is transported. Potable tap water may be used to remove gross debris. If the horse is difficult to handle and the practitioner is unable to safely cleanse the wound with the horse standing prior to referral, a bandage should nevertheless be applied, after

(a) (b)

Figure 8.4 Example of a wound that can be partially closed and in which a drain should be used. **(a)** Acute wound of <4 hours duration involving the proximal region of the antebrachium. Note the skin flap at the distal aspect of the wound is displaced distad. Suturing the skin flap into its normal position would create a sizeable dead space underneath the skin flap. **(b)** The wound could not be completely closed because of tension. Note the Penrose drain exiting the undermined skin flap at the distal limit of the flap. The drain was anchored by sutures attaching it to the skin, proximad and distad. The drain's exit site was covered with a sterile bandage.

sedating the horse. The bandage protects the wound from further contamination and trauma during transport and also reduces the development of edema.

Contamination

The degree of bacterial contamination of a wound is often difficult to quantify in the field or even in a referral hospital. An infective concentration of bacteria is considered to be more than 10^5 organisms per gram of tissue or milliliter of exudate.[1] The time to reach this concentration, however, may vary considerably according to the wound's characteristics; minimally contaminated, minimally damaged tissue likely takes longer to reach this concentration than does heavily contaminated, extensively damaged tissue. Even if the time elapsed since the injury is known (which is uncommon in equine patients), using time to decide whether or not to close a wound primarily is likely inappropriate.

Various methods may be used to identify the type or quantify the number of bacteria within a wound after cleansing and debridement. For instance, Gram-stained smears of the wound may be examined to identify the type of bacteria present at the surface of the wound, although examination fails to inform on the bacterial status of the deeper tissues and cannot be used to confirm infection. Alternatively, a sample of the wounded tissue may be used to provide, via serial dilution cultures of a homogenate, quantitative information on the wound's bacterial burden.[10,11] These methods of bacterial identification and quantification, however, are not practical in field situations. Moreover, bacterial virulence and the immune status of the horse exert a considerable influence on the outcome of contamination so that the actual concentration of bacteria is only one factor in determining if a wound is infected.

Therefore, in a clinical context, the veterinarian must rely on visual assessment of the wound. The amount of gross contamination within the wound should be considered. Clinical signs of infection, such as inflammation (redness, heat, pain on palpation, edema/swelling, or cellulitis around the wound) and purulent discharge, indicate that the wound is less likely to heal successfully after primary closure than is an acute, uninfected wound. The extent and nature of the inciting trauma can also guide decision making. The decision to primarily close a relatively fresh and clean wound with sharp edges is easy; these are wounds such as those caused by sharp metal objects (metal siding, hoof knives) (Figure 8.1). Conversely, crushing or repeated abrasive action usually causes more damage than is initially apparent. Because the health of tissues damaged in this manner may degrade, wounds caused in this fashion are usually not amenable to primary closure. Likewise, wounds contaminated by fecal matter or soil and/or that are edematous are unlikely to heal successfully by primary closure.

Blood supply

Sufficient blood supply to the tissues damaged by wounding is a prerequisite to successful healing. Blood flow is crucial to resistance to infection because it ensures circulation of the host's defenses, including functional neutrophils and macrophages, as well as systemically administered antibiotics. Moreover, oxygen, carried by the red blood cells' hemoglobin, is required for neutrophils to function and to nourish the healing tissues. Because infection of a sutured wound invariably leads to dehiscence, the integrity of the blood supply is an important factor to consider when deciding whether to perform primary closure or to defer closure until later.

The integrity of the blood flow may be estimated by various non-invasive methods, such as infrared thermography, which measures skin temperature as a reflection of cutaneous blood flow, or Doppler ultrasound, but equipment necessary to use these methods is not readily available in most clinical situations. Furthermore, data obtained from a fresh wound may be difficult to interpret because reflex vasoconstriction followed by vasodilation occurs in response to wounding.[30,31] Consequently, the integrity of the blood supply to wounded tissues is largely determined by clinical observation and is based on a sound knowledge of the vascular supply to the injured area.

The anatomic location and configuration of the wound should be considered, particularly if trauma has created a flap of skin. The length, thickness, and orientation of the flap have a significant influence on the flap's vascular supply. Because the blood vessels of the skin run subdermally in the subcutaneous tissues or are closely associated with the *panniculus carnosus* muscle with branching vessels reaching the surface of the upper portion of the dermis, preservation of subcutaneous tissues, fascia, or muscle within the skin flap increases the probability of conserving adequate blood supply and is especially important when the flap is long and narrow.[32] A skin flap on a limb, that has its base located proximally is ideal with regards to preservation of its blood supply, although flaps oriented in this manner are seldom seen. Conversely, a thin skin flap that has its base located distally frequently accompanies degloving injuries to the distal aspect of the limb and is predisposed to avascular necrosis. Wounds to the head, on the other hand, are often amenable to primary closure, regardless of the direction of the flap, due to the good blood supply of the area. Primary closure of wounds of the head is often necessary to protect underlying structures, such as bones or the paranasal sinuses.

General principles of primary closure

After primary closure is determined to be the best method of treatment, the wound is prepared, as described previously and discussed in detail in Chapter 4. Non-viable tissue, including the frayed ends of damaged tendons or necrotic bone, should be debrided. After the wound has been debrided, gloves and instruments should be changed, and the wounded area re-draped prior to suturing.

Although the method of closure must be adapted to the characteristics of the wound and the patient, several general principles apply to primary closure. Sutures are foreign material, and so, the smallest number of sutures required to effectively appose the tissues should be used (the reader is referred to Chapter 9 for more information regarding the selection of suture materials for wound closure). Tissues deep to the skin, such as underlying

(a) (b)

Figure 8.5 In this extensive degloving injury to the distal aspect of the limb, the extensor tendons are lacerated and the metacarpal bone stripped of its periosteum. Despite gross contamination and the likelihood that a portion of the skin flap would suffer avascular necrosis, primary closure was attempted to protect the deep tissues from desiccation until granulation tissue covered the bony surface. Healing even a small portion of a wound by primary closure reduces the amount of second-intention healing required, thereby minimizing scarring and improving functional and cosmetic outcomes. **(a)** Sterile gel has been placed in the wound during cleansing and preparation of the skin flap, prior to irrigating the wound. **(b)** Releasing incisions have been made to reduce tension on the primary closure and to allow drainage; these are best made in the skin surrounding the wound rather than in the skin flap, the blood supply to which is already compromised. Stents made of plastic tubing are used in combination with a horizontal mattress suture pattern, interspersed with sutures placed in a simple interrupted pattern. This repair was protected by a bandage–cast for 2 weeks. This wound healed well, with only a small portion of the skin flap (2 cm) at the proximal extent of the wound lost to necrosis 1 week after primary closure. Placing a bandage over stents can result in pressure necrosis so the wound should be monitored closely for signs of this complication. Pressure on the bandage overlying the wound should be reduced to decrease the likelihood of pressure necrosis from developing beneath the stents. If damage to skin beneath the stents appears, the limb should be left unbandaged, or the stents should be removed in a staged approach.

muscle, fascia, or subcutaneous tissue, should be closed to add strength to the skin closure and to reduce dead space, thereby preventing the formation of a serum pocket. Synthetic, monofilament sutures that are absorbed rapidly are preferred to appose tissues deep to the skin.

Sutures may be used to close large rents in a synovial capsule (the reader is referred to Chapter 16 for more information regarding the management of wounds involving synovial structures) or to appose the ends of a lacerated flexor tendon; suturing lacerated extensor tendons is usually not necessary (the reader is referred to Chapter 17 for more information regarding the management of lacerations of tendons and the paratenon).

If a skin flap is situated over muscle and fascia, "walking sutures" may be placed between the underside of the flap and the wound's bed to incrementally pull the flap towards the center of the wound or towards the opposite margin of the wound, while distributing tension and obliterating subcutaneous dead space. Care must be taken to align the wound's edges and to avoid pulling the flap in the wrong direction.

Tension should be relieved, if necessary, prior to completing the primary closure. Techniques used to relieve tension include: (1) undermining the skin at the edges of the wound to mobilize the skin, and (2) creating "relaxing" or "releasing incisions" in the skin parallel and adjacent to the wound's edges to allow the intervening, meshed skin to contribute to the closure of the primary defect (Figure 8.5). Creating a wound to close a wound is justified when the releasing incisions allow primary closure of a wound that exposes underlying structures (e.g., tendons, nerves, vessels, bone) in exchange for a new defect in a less obtrusive location.[32] Tension-relieving sutures may be used to lessen tension on the primary suture line although they should not replace efforts to relieve the tension on the skin using the aforementioned methods. Types of tension-relieving suture patterns include horizontal and vertical mattress tension suture patterns, with or without supports/stents placed between the suture and the underlying skin in an effort to delay the suture from cutting through the skin in places of tension. Supports can be made by cutting rubber tubing into short sections and threading these on to the suture between suture bites through the tissue. Tension sutures with supports should not be used beneath casts or pressure bandages because the supports may create pressure points on the skin, causing necrosis. As few tension sutures as possible should be used because the mattress tension sutures increase the amount of suture material placed

in the wound. A simple approximating or everting suture pattern should be used in addition to the mattress tension sutures. The tension sutures should be removed within a maximum of 14 days and ideally in a staggered manner, over several days, beginning the first week after their placement. Timing of removal of tension sutures depends on the number of tension-relieving sutures used. The reader is referred to Chapters 9 and 10 for more information regarding methods to reduce skin tension during closure.

Because primary closure used to manage accidental wounds is commonly performed on tissues with some degree of contamination, the opportunity for drainage should be provided to avoid trapping within a closed space, any bacteria, tissue debris, or components of blood that provide a medium for bacterial proliferation. Moreover, drainage is required to channel unwanted fluid or gas from the wound to relieve pressure that might restrict tissue perfusion, thereby compromising healing. Drainage can be provided by leaving an opening at the most ventral portion of the wound or by temporarily implanting a drain (Figure 8.4). To avert descending bacterial contamination, the proximal or dorsal extremity of a passive drain (e.g., a Penrose drain) should not exit the skin but, rather, should be buried at the most proximal, most dorsal, or deepest extent of the wound. It should be secured at this site using a single suture, tied on the surface of the skin adjacent to the wound. Passive drains should exit the wound or the dead space distad or ventrad to the most distad or ventrad extent of the wound, through a single stab incision created in a dependent position near the wound (Figure 8.4b). This extremity of the drain should be secured to the skin, with one or more sutures to prevent it from retreating into the wound, and be covered with a sterile, absorptive dressing, which must be changed regularly.[33] The frequency with which the bandage should be changed is governed by the amount of discharge from the exit portal of the drain. The drain should be removed after 2–3 days, unless there is a strong indication (copious discharge, infection) to prolong its use, because it is irritating to the tissues. The reader is referred to Chapter 9 for more information regarding the classification of drains and the principles of using drains in wound management.

Tips

- Use a different color of suture material, and leave the suture ends extra long when securing the drain. This facilitates distinguishing the suture used to secure the drain from that used for the primary closure of the wound when the drain is removed.
- If exudate discharging via a passive drain is not absorbed by a bandage, petroleum jelly should be smeared on the skin adjacent to the exit portal of the drain to prevent skin scalding.

What to avoid

- Do not expect drainage to fully resolve as long as the drain remains within the wound; the drain is irritating to the tissues, because it is a foreign body, and elicits continued production of fluid.

What to do

- Remove the drain as soon as the drainage decreases substantially in volume and changes from purulent or serosanguineous to serous, non-odoriferous, and non-turbid.

Wounds on the distal aspect of the limb – a special situation

In most cases, degloving wounds to the distal extremities should be managed by primary closure, even in the face of considerable contamination. This is done to provide a humid environment to exposed surfaces of bone and tendon, thereby encouraging the formation of protective granulation tissue (Figure 8.5).

A large retrospective study of primary intention healing of accidental wounds in equids, more than two thirds of which were located on the distal aspect of the limb, showed that an attempt at primary closure was successful (defined as complete healing by primary intention without any degree of dehiscence) in only 26% of horses and 41% of ponies.[9] Although a portion or even all of the wound can be expected to dehisce, an attempt at primary closure must nevertheless be made with the aim to avoid prolonged healing and the development of exuberant granulation tissue (EGT) associated with second-intention healing of a wound on the limb. Indeed, another study of 129 horses suffering a wound on the distal aspect of the limb that included laceration of a digital extensor tendon, found that wounds managed by primary closure (most often supported by some form of external coaptation) had a superior cosmetic outcome (i.e., less scarring). Moreover, complete suture of the wound was significantly correlated with a positive athletic outcome, with horses treated in this manner being 2.6 times more likely to return to soundness than those in which the wound was left unsutured or was only partially sutured. No other variables, including the location of the wound, presence of a functional tendon, or involvement of a synovial structure, were significantly associated with outcome.[34]

Tip

- Owner education is critical before attempting primary closure of a degloving injury to the distal aspect of the limb because dehiscence, followed by loss of the skin flap, is common (usually occurring within 5–10 days). The skin flap should be considered a form of temporary "biologic bandage" that, even if eventually lost, encourages the formation of healthy, protective granulation tissue over the surface of exposed bone or tendon.

For more information regarding the management and complications associated with wounds of the distal aspect of the limb, the reader is referred to Chapters 13, 14, and 15.