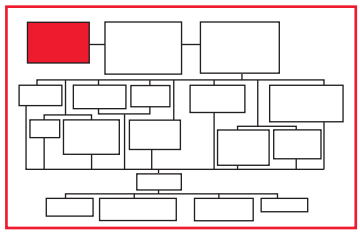
7 ACUTE WOUND CARE

Stephen R. Sullivan, M.D., Loren H. Engrav, M.D., F.A.C.S., and Matthew B. Klein, M.D.

Approach to Acute Wound Management

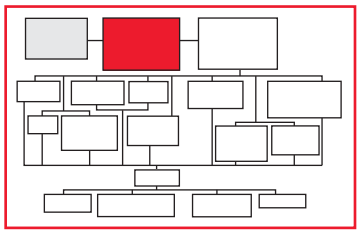


Acute wounds are the result of local trauma and may be associated with severe life-threatening injuries. The approach to a patient with an acute wound begins with assessment of the ABCs (*A*irway, *B*reathing, and *C*irculation). Management of any life-threatening injuries present is addressed first; only after more urgent problems have been ruled out or corrected is management of the wound itself addressed. A complete history is obtained and a thorough physical examination performed, with special attention paid to both local and systemic wound environment factors that may affect healing. Information about the cause of injury is sought. In the case of a hand injury, the patient's hand dominance and occupation are determined. All patients with acute wounds should be assessed for malnutrition, diabetes, peripheral vascular disease, neuropathy, obesity, immune deficiency, autoimmune disorders, connective tissue diseases, coagulopathy, hepatic dysfunction, malignancy, smoking practices, medication use that could interfere with healing, and allergies. The local wound environment should be evaluated to determine the extent and complexity of injury, the tissues involved, the presence or absence of contamination by microorganisms or foreign bodies, and the degree of any damage related to previous irradiation or injury to surrounding tissues.

Gloves and a shielded mask are worn to protect the practitioner from exposure to body fluids. Gloves must be powder free, as well as latex free (to prevent allergic reactions to latex).[1] The wound is carefully examined, with particular attention paid to size, location, bleeding, arterial or venous insufficiency, tissue temperature, tissue viability, and foreign bodies. The possibility of damage to vessels, nerves, ducts, cartilage, muscles, or bones in proximity to the injury is assessed. X-rays and a careful motor and sensory examination may be required to rule out such coexisting injuries. While these tests are being performed, moist gauze should be applied to wounds. For thorough assessment of injuries, it may be necessary to probe ducts (e.g., the parotid duct or the lacrimal duct).

At this point, decisions must be made about acute wound care. The goal of acute wound management is a closed, healing wound that will result in the best functional and aesthetic outcome. In what follows, we address the key considerations in management of the acute wound, including anesthesia, choice of repair site (i.e., operating room or emergency department), debridement, irrigation, hemostasis, closure materials, timing and methods of closure, appropriate closure methods for specific wound types, dressings, adjunctive treatment (e.g., tetanus and rabies prophylaxis, antibiotics, and nutritional supplementation), postoperative wound care, and potential disturbances of wound healing. Finally, we briefly review the physiology of wound healing.

Wound Preparation



ANESTHESIA

Adequate general or local anesthesia, preceded by careful motor and sensory examination, must be instituted before examination and treatment of the wound can begin. General anesthesia in the OR is employed if the patient is unable to tolerate local anesthesia; adequate pain control cannot be achieved with a local block; the wound requires significant debridement, exploration, or repair; bleeding is difficult to control; or the local anesthetic dose required for adequate pain control exceeds the maximum dose that can be safely delivered. Local anesthesia is usually sufficient for debridement and closure of most small traumatic wounds. Often, the local anesthetic may be injected directly into wounded tissue. However, direct wound injection may be less reliable in inflamed or infected tissue or may distort important anatomic landmarks used to align wound edges. In these situations, regional nerve blocks directed at specific sensory nerves outside the injured field may be employed instead.

The main injectable anesthetics can be broadly divided into amides and esters [*see Table 1*]. (An easy way of remembering which category an agent belongs to is to recall that the amides all have two *I*s in their generic name, whereas the esters have only one.) Lidocaine, an amide, is the most commonly used local anesthetic. Its advantages include its rapid onset of action (< 2 minutes), its extended duration of action (60 to 120 minutes), its relative safety in comparison with more potent anesthetics (e.g., bupivacaine), and its availability in multiple forms (e.g., liquid, jelly, and ointment) and concentrations (e.g., 0.5%, 1.0%, and 2.0%). In addition, lidocaine rarely causes allergic reactions, whereas ester anesthetics (e.g., tetracaine) are metabolized to para-aminobenzoic acid, to which some persons are allergic. Cocaine, an ester, is an excellent local anesthetic for wounds in

Table 1 Common Injectable Anesthetics[3]

Amides	Esters
Lidocaine (Xylocaine)	Procaine (Novocain)
Bupivacaine (Marcaine)	Chloroprocaine (Nesacaine)
Mepivacaine (Carbocaine)	Tetracaine (Pontocaine)
Prilocaine (Citanest)	Benzocaine (multiple brands)
Etidocaine (Duranest)	Propoxycaine (Ravocaine)
Phenocaine	Cocaine
Dibucaine (Nupercainal)	
Ropivacaine (Naropin)	
Levobupivacaine (Chirocaine)	

Patient presents with acute wound

Obtain complete history, and perform thorough physical examination. Life-threatening conditions take priority over wound care.

Examine local wound environment, look for local and systemic factors that may impair healing, and identify wounded structures.

Consider antibiotic prophylaxis for clean or clean-contaminated wounds if factors likely to impair wound healing [*see Table 7*] are present. Initiate antibiotic prophylaxis for contaminated and dirty wounds and for wounds with extensive devitalized tissue.

Initial measures are complete, and wound care is initiated

Prepare wound:

- *Anesthesia:* use local anesthesia in most cases. Use general anesthesia if local anesthesia cannot be tolerated, if pain cannot be controlled with local anesthesia, if wound requires significant repair, if bleeding is hard to control, or if local anesthetic dose needed would be unsafe.
- *Debridement:* debride necrotic tissue, and remove foreign bodies. If there is significant questionably viable tissue, defer debridement until status is clarified, and initiate dressing changes.
- *Irrigation:* use only nontoxic irrigants, avoiding antibiotics and strong antiseptics. Low pressure is preferable to high pressure (but bulb syringe is inadequate).
- *Hemostasis:* use pressure, cauterization, or ligation (but do not ligate lacerated arteries proximal to amputated part). Place drain if there is risk of hematoma or fluid collection.

Abrasion

Remove foreign bodies to prevent traumatic tattooing.

Allow healing by secondary closure. Tape or glue may be used.

Laceration

Close immediately if patient presents with clean wound within 8 hr of injury (or 24 hr for simple facial injury). Otherwise, delay closure or allow wound to heal without closure.

Close deep laceration in layers.

Crush injury

Severity of injury is not always apparent.

Monitor for compartment syndrome, and treat on urgent basis.

Puncture wound

Leave wound open, and allow healing by secondary closure.

Complex wound

Inform patient of potential for poor aesthetic outcome, and discuss alternatives.

Close immediately if wound is clean and tissue viable. Delay closure if wound is contaminated or there is significant nonviable or questionably viable tissue.

Perform primary closure if possible. Severe injury may necessitate delayed primary closure, secondary closure, skin grafting, or tissue transfer.

Extravasation injury

Conservative management (i.e., elevation, ice, and monitoring) suffices in most cases. Injury involving high volume, high osmolarity, or chemotherapeutic agent may necessitate additional measures (e.g., hydrocortisone, incision and drainage, hyaluronidase, saline, or aspiration).

Consider tetanus treatment, antibiotic prophylaxis, or both.

Apply dressings as appropriate for individual wound type.

Abrasion

Use occlusive dressings (impregnated gauze may be used for small superficial wounds). Avoid dry dressings.

Laceration, complex wound closed primarily, injection injury, high-velocity wound, bite wound, or sting

Consider three-layer dressings for open draining wound, with inner nonadherent layer, middle absorbent layer, and outer binding layer.

Consider ointment if there is minimal drainage.

Approach to Acute Wound Management

Wound is ready for closure

Select closure materials: sutures, tapes, staples, or adhesives.

Determine timing and methods of closure:

- *Immediate primary closure:* clean wound without contraindications to closure
- *Delayed primary closure:* contaminated wound, wound with questionably viable tissue, or patient who cannot tolerate immediate closure
- *Secondary closure (allowing wound to heal by itself):* wound with contamination or contraindication to closure, patient who cannot tolerate closure, or wound for which closure is not needed for aesthetic result
- *Skin grafting:* large superficial wound
- *Tissue transfer:* large wound with exposed vital structure

Formulate specific closure approach suitable for individual wound type.

Injection injury

Wound appearance is often deceptively benign. Examine wound area carefully and obtain appropriate radiographs.

Treat aggressively with incision, wide exposure, debridement, and removal of foreign bodies.

Allow healing by secondary closure.

Bite wound

Take into account risks of rabies, bacterial and other viral infections, and envenomation.

Treat with exploration, irrigation, and debridement.

Close immediately if wound is clean and tissue viable. Delay closure if wound is contaminated or there is significant nonviable or questionably viable tissue.

Perform primary closure if possible. Severe injury may necessitate secondary closure, skin grafting, or tissue transfer.

Consider rabies treatment, rabies prophylaxis, or both.

High-velocity wound

Wound appearance is often deceptively benign; foreign bodies are frequently present. Examine wound area carefully and obtain appropriate radiographs.

Debride wound extensively and identify all injured tissue.

Avoid immediate primary closure. Perform delayed primary closure or allow healing by secondary closure.

Sting

Take into account risk of envenomation.

Symptoms may be local or systemic. Treatment is usually directed toward local symptoms. For systemic reactions, epinephrine, diphenhydramine, and supportive airway and BP care may be required.

Complex wound left open or closed after delay

Generally, use wet-to-dry dressings; use wet-to-wet dressings if wound bed contains tendons, arteries, nerves, or bone. Avoid compression dressings.

Consider NPWT for large open wound.

Extravasation injury or crush injury

Avoid compression dressings.

mucous membrane (e.g., those in the nose or the throat). It is unique among local anesthetics in that it causes vasoconstriction, which helps reduce hemorrhage. Typically, cocaine is applied topically by soaking gauze or pledgets in a solution.

Vasoconstriction can also be produced by adding epinephrine to a local anesthetic, usually in a dilution of 1:100,000 or 1:200,000 (5 to 10 μg/ml). Through vasoconstriction, epinephrine prolongs the anesthetic agent's duration of action, allows a larger dose to be safely administered, and aids in hemostasis.[2] Traditionally, local anesthetics with epinephrine have not been used in finger and toe wounds, because of the theoretical risk of ischemia and tissue loss; however, these adverse effects have not yet been reported clinically or documented by any prospective studies.[3]

Local anesthetics can cause systemic toxicity when injected intravascularly or given in excessive doses. Manifestations of systemic toxicity begin with central nervous system effects (e.g., vertigo, tinnitus, sedation, and seizures) and may progress to cardiovascular effects (e.g., hypotension, cardiac conduction abnormalities, and cardiovascular collapse). Treatment for systemic toxicity is supportive, with oxygen, airway support, and cardiovascular bypass (if necessary) provided until the anesthetic has been metabolized by the liver. The maximum safe dose of lidocaine is 3 to 5 mg/kg without epinephrine and 7 mg/kg with epinephrine. Doses as high as 55 mg/kg have been used without toxicity for tumescent anesthesia in patients undergoing liposuction[4]; however, in this scenario, some of the anesthetic is aspirated by the liposuction, which means that the effective dose is lower. The lidocaine doses used for local wound injection should be substantially smaller than those used in liposuction. The maximum safe dose of cocaine is 2 to 3 mg/kg. To prevent local anesthesia from causing systemic toxicity, the recommended safe doses of the anesthetics should not be exceeded, and aspiration should be performed before injection into the wound to ensure that the agent will not be injected intravascularly.

The pain associated with injection of the local anesthetic can be minimized by using a small-caliber needle (27 to 30 gauge), warming the anesthetic, injecting the agent slowly, using a subcutaneous rather than an intradermal injection technique,[5] providing counterirritation, buffering the anesthetic with sodium bicarbonate to reduce acidity (in a 1:10 ratio of sodium bicarbonate to local anesthetic),[6] and applying a topical local anesthetic before injection. Topical local anesthetics (e.g., TAC [tetracaine, adrenaline (epinephrine), and cocaine] and EMLA [a eutectic mixture of lidocaine and prilocaine]) are as effective as injectable anesthetics when applied to an open wound.[7] EMLA requires approximately 60 minutes to induce sufficient anesthesia for open wounds; TAC requires approximately 30 minutes.[8] EMLA is more effective than TAC for open wounds of the extremity. Benzocaine 20% (in gel, liquid, or spray form) can also be used for topical anesthesia and is frequently employed before endoscopic procedures. It is poorly absorbed through intact skin but well absorbed through mucous membranes and open wounds. A 0.5- to 1-second spray is usually recommended, though even with a standardized spray duration, the delivered dose can vary considerably.[9] A 2-second spray results in a statistically, though not clinically, significant increase in methemoglobin levels.[10] Methemoglobinemia is a rare but life-threatening complication of benzocaine spray use. If symptoms of methemoglobinemia develop (e.g., cyanosis or elevated methemoglobin levels on cooximetry), prompt treatment with intravenous methylene blue, 1 to 2 mg/kg, is indicated.[9]

DEBRIDEMENT

Normal healing can proceed only if tissues are viable, if the wound contains no foreign bodies, and if tissues are free of excessive bacterial contamination. To reduce the risk of infection in an acute wound, necrotic tissue and foreign bodies must be removed.[11] The wound and the surrounding local tissue must be exposed so that necrotic tissue can be identified and debrided. Hair may be trimmed with scissors or an electric clipper or retracted with an ointment or gel to facilitate exposure, debridement, and wound closure. Close shaving with a razor should be avoided, however, because it potentiates wound infections.[12] Clipping of eyebrows should also be avoided, both because the eyebrows may not grow back and because the hair is necessary for proper alignment.

Some wounds contain a significant amount of questionably viable tissue. If there is enough questionably viable tissue to preclude acute debridement, dressing changes may be initiated. When all tissue has been declared to be either viable or necrotic and when the necrotic tissue has been debrided surgically or by means of dressing changes, the wound can be closed.

Most foreign bodies are easily removed from wounds either by hand or via surgical debridement. Abrasion injuries or gunpowder explosions can cause small foreign body fragments to be embedded in and beneath the skin. These small foreign bodies are often difficult to extract but should be removed as soon after the injury as possible. Irrigation usually suffices for removal of loose foreign bodies, but surgical debridement with a small drill, a sharp instrument, or a brush may be required for removal of more firmly embedded foreign material. If the interval between injury and treatment exceeds 1 to 2 days, the wounds will begin to epithelialize and the embedded material will be trapped in the skin, resulting in traumatic tattooing.

IRRIGATION

After debridement of necrotic tissue and foreign bodies, the next step is irrigation of the wound. This may be accomplished by means of several different methods, including bulb syringe irrigation, gravity flow irrigation, and pulsatile lavage. These methods can be further divided into high-pressure (35 to 70 psi) and low-pressure (1 to 15 psi) delivery systems. High-pressure pulsatile lavage reduces bacterial concentrations in the wound more efficiently than low-pressure and bulb syringe irrigation do,[13] but it also causes considerable disruption to soft tissue structure[14] and results in deeper penetration and greater retention of bacteria in soft tissue than low-pressure lavage does.[15] In general, low-pressure systems should be employed for acute wound irrigation, though merely running saline over a wound is of little value. To obtain continuous irrigation with pressures as low as 5 to 8 psi, one group recommended using a saline bag in a pressure cuff inflated to 400 mm Hg and connected to I.V. tubing with a 19-gauge angiocatheter.[16]

Only nontoxic solutions (e.g., 0.9% sterile saline, lactated Ringer solution, sterile water, and tap water) should be used for wound irrigation.[17] Irrigation with an antibiotic solution appears to offer no advantages over irrigation with a nonsterile soap solution, and the antibiotic solution may increase the risk of wound-healing problems.[18] Strong antiseptics (e.g., povidone-iodine, chlorhexidine, alcohol, sodium hypochlorite, and hydrogen peroxide) should not be placed directly into the wound, because they are toxic to the tissues and impede healing. The surrounding skin should be prepared with an antibacterial solution, and a sterile field created to limit contamination.

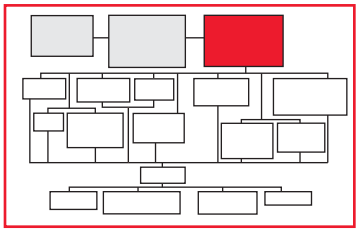
HEMOSTASIS

In most wounds, hemorrhage can be readily controlled with pressure, cauterization, or ligation of vessels. Lacerated arteries

proximal to amputated parts such as fingers or ears, however, should not be ligated, because an intact vessel is necessary for microsurgical replantation. Packing, wrapping, and elevating can help control hemorrhage temporarily. If necessary (though the need should be rare), a tourniquet may be applied to an injured extremity. Hemostasis prevents hematoma formation, which increases the risk of infection and wound inflammation. If there appears to be a potential risk of hematoma or fluid collection, drains should be placed. Although drains may help prevent accumulation of blood or serum in the wound, they are not a replacement for meticulous hemostasis. Drains facilitate approximation of tissues, particularly under flaps; however, they also tend to potentiate bacterial infections and should therefore be removed from the wound as soon as possible.[19]

As a rule, drains can be safely removed when drainage reaches levels of 25 to 50 ml/day. If a hematoma or seroma forms, the subsequent course of action depends on the size of the fluid collection. Small hematomas and seromas usually are reabsorbed and thus can be treated conservatively. Larger hematomas and seromas provide a significant barrier to healing, and treatment may require reopening the wound and placing drains. Intermittent sterile aspirations, followed by application of a compressive dressing, may be indicated for seromas. If this approach fails to eliminate the seroma, a drain may be reintroduced.

Wound Closure



MATERIALS

Once the appropriate preparatory measures have been taken (see above), the wound is ready to be closed. The first step is to choose the material to be used for wound closure. The materials currently available for this purpose include sutures, staples, tapes, and glues. Selection of the appropriate material is based on the type and location of the wound, the potential for infection, the patient's ability to tolerate closure, and the degree of mechanical stress imposed by closure. The selected material must provide wound edge approximation until the tensile strength of the wound has increased to the point where it can withstand the stress present.

The majority of wounds are closed with sutures. A suture is a foreign body by definition, and as such, it may generate an inflammatory response, interfere with wound healing, and increase the risk of infection. Accordingly, the number and diameter of sutures used to close a wound should be kept to the minimum necessary for coaptation of the edges.

Sutures are categorized on the basis of material used, tensile strength, configuration, absorbability, and time to degradation [*see Table 2*]. Suture material may be either natural or synthetic; natural fibers (e.g., catgut and silk) cause more intense inflammatory reactions than synthetic materials (e.g., polypropylene) do.[20] The tensile strength of suture material is defined as the amount of weight required to break a suture divided by the suture's cross-sectional area. It is typically expressed in an integer-hyphen-zero form, whereby larger integers correspond to smaller suture diameters (e.g., 3-0 sutures have a greater diameter and more tensile strength than 5-0 sutures do).[21] Closure of acute wounds rarely requires sutures larger than 4-0. In terms of configuration, suture material may be composed either of a single filament or of multiple filaments. Multifilament suture material may be twisted or braided, and the interstices created by braiding may harbor organisms and increase the risk of infection. Monofilament sutures hold knots less well than multifilament sutures, requiring five knots for security; multifilament sutures are easier to handle and require only three knots. With all sutures, the knots must be square to be secure and must be only tight enough to coapt the wound edges. To minimize foreign body bulk, buried suture knot ends should be cut right on the knot. In terms of absorbability, either absorbable or nonabsorbable sutures may be appropriate, depending on the situation. Absorbable sutures are generally used for buried sutures to approximate deep tissues (e.g., dermis, muscle, or fascia). Absorption of synthetic suture material occurs by hydrolysis and causes less tissue reaction than absorption of natural suture material, which occurs by proteolysis. Nonabsorbable sutures (e.g., those made of silk, nylon, polyester, or polybutester) are most commonly used for wounds in the skin, from where they will eventually be removed, or for wounds in deeper structures that require prolonged support (e.g., abdominal wall fascia, tendons, nerves, and blood vessels).

Staple closure is less expensive and significantly faster than suture closure, and it offers a slightly, though not significantly, better cosmetic outcome when used to close scalp wounds.[22,23] Contaminated wounds closed with staples have a lower incidence of infection than those closed with sutures.[24] In addition, staple closure eliminates the risk that a health care provider will experience a needle stick, which is a particularly important consideration in caring for a trauma patient with an unknown medical history.

The tapes used for wound closure either are rubber-based or employ an acrylate adhesive. Rubber-based tapes (e.g., athletic tape) are a potential irritant to skin, degrade with exposure to heat, light, and air, and are occlusive, thereby preventing transepidermal water loss. Tapes that include acrylate adhesives (e.g., Micropore and Steri-Strip), however, are hypoallergenic, have a long shelf life, and are porous, thereby allowing water to evaporate.[25] Linear wounds in areas with little tension are easily approximated with tape alone, whereas wounds in areas where the skin is more taut (e.g., the extremities) generally require that tape skin closure be supplemented by dermal sutures. The use of tape alone is desirable when feasible, in that it spares the patient the discomfort associated with suture removal, prevents suture puncture scars, and avoids the emotional upset that may attend suture closure of small facial wounds on children.[25] Tape closure has some significant advantages: it immobilizes wound edges, permits early suture removal, is easy to perform and comfortable for the patient, leaves no marks on the skin, and yields a lower infection rate in contaminated wounds than suture closure does.[26] It also has a few disadvantages: patients may inadvertently remove the tapes, and wound edge approximation is less precise with tapes alone than with sutures. In addition, tape will not adhere to mobile areas under tension (e.g., the plantar aspects of the feet) or to moist areas (e.g., mucous membranes and groin creases), and wound edema can lead to blistering at the tape margins and to inversion of taped wound edges.

The use of tissue adhesives (e.g., octylcyanoacrylate) is a fast, strong, and flexible method of approximating wound edges. Compared with sutures, staples, and tapes, adhesives provide a faster closure and are essentially equivalent in terms of cosmetic outcome, infection rate, and dehiscence rate.[27] Adhesives can be used on most parts of the body and have been employed to close wounds ranging from 0.5 to 50 cm in length. Their advantages include reduced cost, ease of application, and the absence of any need for needles or suture removal; their major disadvantage is lack of strength.[28] They must not be applied to tissues within wounds but, rather, should be applied to intact skin at wound edges, where they serve to hold injured surfaces together. In addi-

Table 2 Types and Characteristics of Suture Material Used for Wound Closure

Suture Type	Material	Comment	Configuration	Method of Absorption	Tensile Strength at 2 Wk	Time to Degradation
Absorbable	Plain catgut (bovine intestinal serosa)	Natural; high tissue reactivity	Monofilament	Proteolysis	0%	10–14 days
	Chromic catgut (bovine intestinal serosa treated with chromic acid)	Natural; stronger, less reactive, and longer-lasting than plain catgut	Monofilament	Proteolysis	0%	21 days
	Fast-absorbing catgut	Natural	Monofilament	Proteolysis	0%	7–10 days
	Polyglytone 6211 (Caprosyn)	Synthetic	Monofilament	Hydrolysis	10%	56 days
	Glycomer 631 (Biosyn)	Synthetic	Monofilament	Hydrolysis	75%	90–110 days
	Polyglycolic acid (Dexon)	Synthetic	Monofilament/ multifilament	Hydrolysis	20%	90–120 days
	Polyglactic acid (Vicryl)	Synthetic	Multifilament	Hydrolysis	20%	60–90 days
	Polyglyconate (Maxon)	Synthetic	Monofilament	Hydrolysis	81%	180–210 days
	Polyglycolide (Polysorb)	Synthetic	Multifilament	Hydrolysis	80%	56–70 days
	Polydioxanone (PDS)	Synthetic	Monofilament	Hydrolysis	74%	180 days
	Polyglecaprone 25 (Monocryl)	Synthetic	Monofilament	Hydrolysis	25%	90–120 days
	Polyglactin 910 (Vicryl RAPIDE)	Synthetic	Multifilament	Hydrolysis	0%	7–14 days
Nonabsorbable	Polybutester (Novafil)	Synthetic; low tissue reactivity; elastic; good knot security	Monofilament	—	High	—
	Nylon (Monosof, Dermalon, Ethilon)	Synthetic; low tissue reactivity; memory effect necessitates more knots	Monofilament	—	High	—
	Nylon (Nurolon)	Synthetic; low tissue reactivity	Multifilament	—	High	—
	Nylon (Surgilon)	Synthetic; silicon coated; low tissue reactivity	Multifilament	—	High	—
	Polypropylene (Prolene, Surgilene, Surgipro)	Synthetic; low tissue reactivity; slippery	Monofilament	—	High	—
	Polyethylene (Dermalene)	Synthetic	Monofilament	—	High	—
	Stainless steel	Lowest tissue reactivity of all sutures; poor handling; creates artifact on CT scan; moves with MRI	Monofilament/ multifilament	—	Highest	—
	Cotton	Natural	Multifilament	—	—	—
	Silk (Sofsilk)	Natural; high tissue reactivity; good knot security	Multifilament	—	Poor	—
	Polyester (Dacron, Mersilene, Surgidac)	Synthetic; uncoated; high friction; low tissue reactivity; poor knot security	Multifilament	—	High	—
	Polyester (Ticron)	Synthetic; silicon coated; low tissue reactivity; good knot security	Multifilament	—	High	—
	Polyester (Ethibond)	Synthetic; polybutylate coated; low tissue reactivity; good knot security	Multifilament	—	High	—
	Polyester (Ethiflex, Tevdek)	Synthetic; Teflon coated; low tissue reactivity; good knot security	Multifilament	—	High	—

tion, they should not be used for wounds in mucous membranes, contaminated wounds, deep wounds, or wounds under tension. Adhesives are particularly useful for superficial wounds or wounds in which the deep dermis has been closed with sutures.

TIMING AND METHODS

Appropriate materials having been selected, the next issue to address is the timing of wound closure. The choices are (1) to close the wound at the time of initial presentation, (2) to delay closure until after a period of healing or wound care, and (3) to allow the wound to heal on its own. The best choice in a given situation depends whether the patient is stable and able to undergo wound repair, whether hemorrhage is under control, whether necrotic material has been adequately debrided and foreign bodies removed, whether and to what degree bacterial contamination is present, and what the expected aesthetic outcome of immediate closure might be in comparison with that of delayed closure or secondary healing.

The timing of wound closure determines the method that will be employed. The closure methods available include (1) primary closure by direct approximation; (2) delayed primary closure, in which the wound is closed after a healing period; (3) secondary closure, in which the wound is allowed to heal on its own; (4) skin grafting; and (5) the use of local or distant flaps. The ideal wound closure method would support the wound until it has nearly reached full strength (i.e., about 6 weeks), would not induce inflammation, would not induce ischemia, would not penetrate the epidermis and predispose to additional scars, and would not interfere with the healing process. Unfortunately, no existing method accomplishes all of these goals in all cases; some sort of compromise is virtually always necessary. In the acute wound setting, the simplest method that will achieve a good closure is preferred.

Primary closure provides optimal wound healing when two perpendicular, well-vascularized wound edges are approximated without tension. Closure should proceed from deep to superficial. The initial step is to identify landmarks and line up tissues, using skin hooks or fine forceps to keep from causing wound edge trauma. Although wound closure is usually a straightforward process, situations occasionally arise in which special caution is necessary. For instance, when a wound crosses tissues with different characteristics (e.g., at the vermilion border of the lip, the eyebrow, or the hairline of the scalp), particular care must be taken to align the damaged structures accurately. In the repair of soft tissue, it is critical to handle tissue gently with atraumatic surgical technique, to place sutures precisely, and to minimize tension and contamination.

The next step is tissue-specific repair, which may require the consultation of an experienced surgeon. Bone fractures are reduced and repaired with plates, rods, or external fixation devices. Muscle lacerations should be repaired because muscle is capable of a significant degree of regeneration. A completely lacerated muscle that is properly repaired recovers approximately 50% of its ability to produce tension and 80% of its ability to shorten, whereas a partially lacerated muscle that is properly repaired recovers approximately 60% of its ability to produce tension and 100% of its ability to shorten.[29] Tendon lacerations should be meticulously approximated to allow gliding and restore tensile strength. Either 4-0 multifilament polyester or monofilament polypropylene is a reasonable choice for muscle and tendon repair.[30] Early active mobilization promotes the restoration of tensile strength in muscles and tendons. Penetrating nerve trauma is treated with tension-free coaptation at the time of wound closure by primary repair or repair with a nerve graft or nerve tube. Epineurial coaptation is typically achieved by placing 8-0 to 10-0 monofilament nylon sutures under loupe or microscope magnification. For ischemic or amputated tissues (e.g., an ear, a digit, or a limb), vessel repair is performed with 8-0 to 10-0 monofilament nylon sutures under magnification.

In subcutaneous fat, suture placement should be avoided whenever possible; if sutures in this location are absolutely necessary, they should be placed at the fat-fascia junction or the fat-dermis junction, not in fat alone. Fat cannot hold sutures by itself, and because it has a poor blood supply, suturing may lead to fat necrosis. The deeper fascial layers that contribute to the structural integrity of areas such as the abdomen, the chest, and the galea should be closed as a separate layer to prevent hernias, structural deformities, and hematomas.

At the skin level, the deep dermis is responsible for the strength of the acute wound closure. Deep dermal repair is performed with 4-0 absorbable suture material (e.g., polyglactin 910) and a cutting needle. The sutures are buried and placed 5 to 8 mm apart, with care taken to evert the skin edges. Buried dermal sutures are often used in conjunction with tapes (e.g., Steri-Strips), fine epidermal sutures, or adhesives to facilitate precise alignment. Skin edges should be coapted and everted with 4-0 to 6-0 nylon or polypropylene sutures placed in the superficial dermis and the epidermis. The distance between the sutures and the distance between the wound edge and the suture insertion point should be equal to the thickness of the skin (epidermis and dermis combined).

Several different skin suturing methods may be used, depending on the nature of the wound. Simple interrupted sutures are useful for irregular wounds. Vertical mattress sutures are good for either thick (e.g., scalp) or thin (e.g., eyelid) skin. Horizontal mattress sutures can lead to ischemia and thus must be applied loosely; they may look untidy early after repair, but they generally achieve good wound-edge eversion and long-term healing. Half-buried horizontal and vertical mattress sutures are used for flap edges to minimize ischemia. A continuous intradermal or subcuticular suture is easy to remove and relatively inconspicuous visually. A simple continuous suture should be used only for linear wounds; it is quick to place but tends to invert the wound edges. Flap tips should be sutured with a three-point method to prevent strangulation [*see Figure 1*]. For children, suture removal can be both emotionally and physically traumatic; accordingly, when suturing is employed for skin closure in a pediatric patient, the use of fast-absorbing suture material (e.g., plain catgut) or a pullout continuous subcuticular suturing method should be considered.

Primary direct approximation of wounds is not always indicated. In cases where obvious bacterial contamination is present, there is a substantial amount of questionably necrotic tissue, or the patient is unstable and unfit to undergo primary repair at the time of presentation, delayed primary closure is performed. Delayed primary closure involves direct approximation of wound edges after a period (usually 4 to 5 days) of wound hygiene. This closure method markedly diminishes the incidence of wound infection in patients with contaminated wounds.

Secondary closure, in which the wound is left open and allowed to heal on its own, is also sometimes chosen. Secondary closure depends on contraction of the surrounding tissue and epithelialization from the wound margins. When this approach is followed, caution and close observation are essential because the process of tissue contraction can sometimes lead to contracture, a pathologic scar deformity. Secondary closure can, however, yield acceptable results with specific wound types and at specific anatomic sites. With puncture wounds, for example, secondary closure is preferred because it diminishes the likelihood of infection. For both abrasions and puncture wounds, the functional and aesthetic

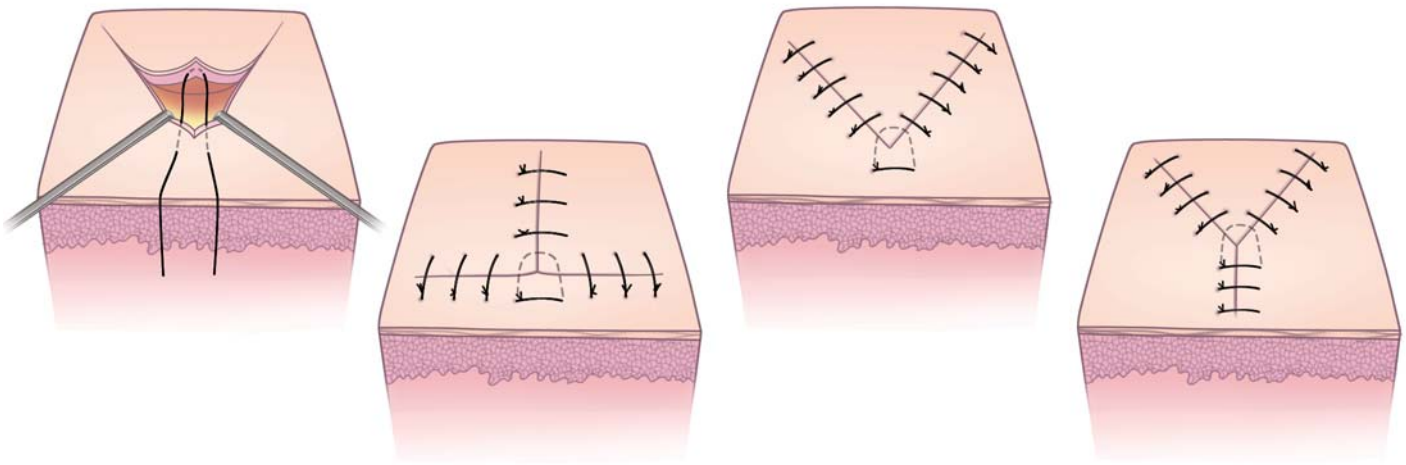


Figure 1 **Shown is the method for inserting three-point sutures, along with three different applications of this method.**

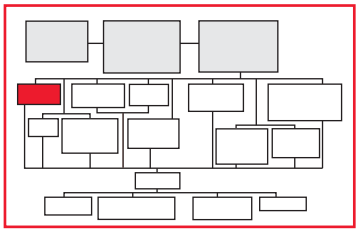
results of secondary closure are generally as good as or better than those obtained by primary or delayed primary closure. For wounds on anatomically concave surfaces (e.g., the medial canthal region, the nasolabial region, or the perineum), secondary wound healing generally yields excellent results.[31] Secondary closure should also be considered for severely contaminated wounds, infected wounds, wounds with significant amounts of devitalized tissue, wounds with foreign bodies, lacerations older than 24 hours, wounds in patients who are in shock, and high-velocity wounds.[32]

Occasionally, an acute wound is so large that neither primary nor secondary closure will suffice. Such wounds must be covered with skin grafts or transferred tissue (i.e., flaps) [*see 3:3 Open Wound Requiring Reconstruction and 3:7 Surface Reconstruction Procedures*]. Local or distant flaps must be considered for wounds that involve exposed bone denuded of periosteum, cartilage denuded of perichondrium, tendon denuded of paratenon, or nerve denuded of perineurium.

CLOSURE OF SPECIFIC TYPES OF WOUNDS

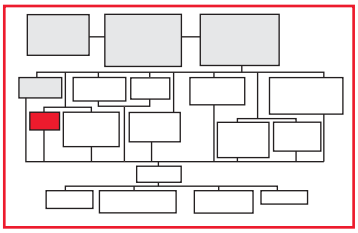
Wounds may be divided into 10 main types: abrasions, puncture wounds, lacerations, complex wounds, crush injuries, extravasation injuries, injection injuries, high-velocity wounds, bite wounds, and stings. In addition, the American College of Surgeons (ACS) has divided wounds into four major categories: clean, clean-contaminated, contaminated, and dirty [*see Table 3*]. The likelihood of infection after any surgical procedure is correlated with the ACS wound category: class I and II wounds have infection rates lower than 11%, whereas wounds in class IV have infection rates as high as 40%.[33]

Abrasions



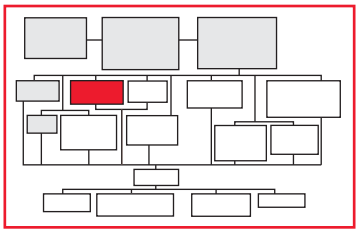
Abrasions are superficial wounds caused by scraping. They involve only the epidermis and a portion of the dermis and frequently heal secondarily within 1 to 2 weeks. If an abrasion is to be closed primarily, tape or glue may be used for epidermal approximation to prevent suture mark scars (which could be worse than the actual wound scar). In some patients who have experienced abrasion injuries (e.g., motorcycle accidents in which victims slide along asphalt) or blast injuries (e.g., firework explosions), small foreign body fragments become embedded in and beneath the skin, often proving quite difficult to remove. Complete debridement of these embedded foreign bodies within 24 to 48 hours of injury is crucial in preventing so-called traumatic tattooing. In the early postinjury period, surgical debridement with a small drill, a sharp instrument, or a scrub brush may suffice for removal of the foreign material causing the traumatic tattoo; later, dermabrasion will be necessary.[34,35] Once the wound is adequately debrided, semiocclusive dressings should be applied to optimize epithelialization.

Puncture Wounds



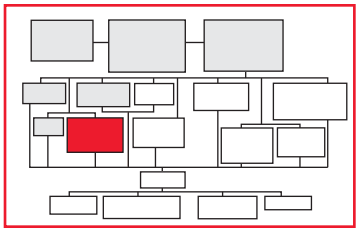
Puncture wounds should be examined for foreign bodies, which must be removed when found. They are typically left open, treated with wound care, and allowed to heal by secondary intention. With puncture wounds, secondary closure reduces the risk of infection and generally yields excellent aesthetic results.

Lacerations



The type of wound most commonly encountered by surgeons is a superficial or deep acute traumatic or surgical wound that is suitable for primary closure by direct approximation of the wound edges. In this setting, the goal is to provide the best possible chance for uncomplicated healing. If the wound is to be closed, primary closure at the time of evaluation is preferred if it is feasible. As a rule, closure should be completed within 6 to 8 hours of the injury, though simple noncontaminated wounds of the face can be safely closed as long as 24 hours after the injury. Primary closure is generally desirable in that it eliminates the need for extensive wound care, allows the wound to heal more quickly, and minimizes patient discomfort. However, lacerations containing foreign bodies or necrotic tissue that cannot be removed by irrigation or debridement and lacerations with excessive bacterial contamination should not be closed primarily, nor should wounds in which hemostasis is incomplete. Hematomas,[36] necrotic tissue,[37] and foreign bodies[38] all promote bacterial growth and place a mechanical barrier between healing tissues.

Complex Wounds



The term complex wounds includes stellate wounds and those caused by degloving, avulsion, and mutilation. The goals of treatment include achieving closure within 6 to 8 hours of the injury, providing treatment in a manner consistent with the patient's general health, keeping bacterial counts at a low level, protecting tissues from desiccation, applying only nonnoxious agents, and supplying adequate permanent coverage. In addition, it is important to discuss with the patient the particular treatment difficulties posed by these wounds. Often, a patient with a complex wound must be treated in the OR under general anesthesia because the injury is extensive or because there is a need for exploration of tissues, removal of foreign bodies, and debridement of nonviable tissue.

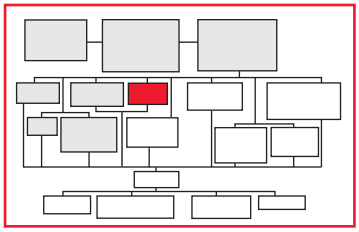
Stellate wounds can be approximated with careful placement of interrupted and three-point sutures. Severely injured tissue may have to be removed as an ellipse, with the resulting defect closed.

Degloving refers to circumferential elevation of skin and fat from muscle; the skin flap created by this process rarely survives. In the acute setting, questionably viable flaps of tissue may be evaluated by administering fluorescein, up to 15 mg/kg I.V., and observing the flap for fluorescence under an ultraviolet lamp after 10 to 15 minutes have elapsed.[39] Viable flap tissue fluoresces green. Tissue that is determined to be devascularized, on the basis of either physical examination or fluorescein testing, should be debrided. If the viability of a tissue segment is in doubt, the segment may be sewn back into its anatomic location and allowed to define itself as viable or nonviable over time.

Large open wounds resulting from avulsion can be either left to heal by secondary intention or treated with delayed skin grafting.[32]

Mutilating wounds caused by machinery (e.g., farm equipment) are often contaminated by a mixture of gram-positive and gram-negative organisms, though not always excessively so.[40] When such a wound is grossly contaminated, antibiotic therapy (preferably with an agent or combination of agents that offers broad-spectrum coverage) is indicated. Contaminated wounds closed with either tape or staples have a lower incidence of infection than those closed with sutures.[24,26]

Crush Injuries



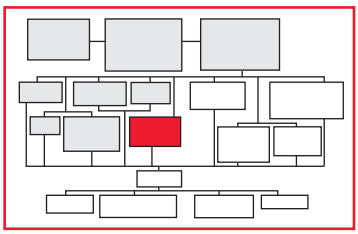
A notable feature of crush injury is that the severity of the wound is not always readily apparent. In many cases, no external laceration can be seen, even though deep tissue damage may be extensive. Ultrasonography or magnetic resonance imaging may help identify a hematoma that is amenable to evacuation.[32] Deep tissue injury can lead to compartment syndrome and subsequent extremity loss. Early diagnosis is the key to successful treatment. Generally, the diagnosis can be made on the basis of physical signs and symptoms, including increasing pain that is out of proportion to the stimulus, altered sensation, pain on passive stretching of the affected muscle compartment, muscle weakness, and palpable tenseness of the compartment.[41]

If compartment syndrome is suspected, the intracompartmental pressure should be measured.[42] If the intracompartmental pressure exceeds 30 mm Hg or if the so-called delta pressure (i.e., the diastolic blood pressure minus the intracompartmental pressure) is less than or equal to 30 mm Hg, compartment syndrome is considered to be present. If clinical symptoms develop or the delta pressure is below 30 mm Hg, appropriate therapeutic measures should be taken, including restoration of normal blood pressure in the hypotensive patient, removal of all constrictive dressings, and maintenance of the limb at heart level.[1] If the delta pressure remains below 30 mm Hg, clinical symptoms and signs persist despite conservative measures, or both, fasciotomies should be performed within 6 hours.[41] Hyperbaric oxygen therapy may also be beneficial in cases of crush injury with compartment syndrome in an extremity.[43] Compartment syndrome with muscle damage can also lead to rhabdomyolysis and renal failure. If an elevated serum creatine kinase concentration is reported, intravascular volume is stabilized, and urine flow is confirmed, a forced mannitol-alkaline diuresis should be initiated as prophylaxis against hyperkalemia and acute renal failure.[44]

Table 3 Classification and Infection Rates of Operative Wounds

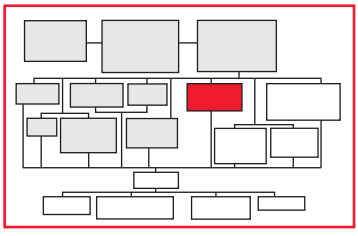
Classification	Infection Rate (%)	Wound Characteristics
Clean (class I)	1.5–5.1	Atraumatic, uninfected; no entry of GU, GI, or respiratory tract
Clean-contaminated (class II)	7.7–10.8	Minor breaks in sterile technique; entry of GU, GI, or respiratory tract without significant spillage
Contaminated (class III)	15.2–16.3	Traumatic wounds; gross spillage from GI tract; entry into infected tissue, bone, urine, or bile
Dirty (class IV)	28.0–40.0	Drainage of abscess; debridement of soft tissue infection

Extravasation Injuries



In some patients with arterial or venous catheters in place, a vessel may become occluded or a catheter dislodged from the intravascular space, leading to extravasation injury, whereby solutions or medicines are delivered into the interstitial space. The majority of acute extravasation injuries are quickly diagnosed and heal without complications, and in most cases, conservative management (i.e., elevation of the limb, application of ice packs, and careful monitoring) is adequate.[45] However, extravasation injuries involving high fluid volumes, high-osmolar contrast agents, or chemotherapeutic drugs can have more serious effects, resulting in skin ulceration and extensive soft tissue necrosis. Treatment of these injuries is not standardized; it may include conservative management, hydrocortisone cream, incision and drainage, hyaluronidase injection, saline injection, and aspiration by means of liposuction.[45-47]

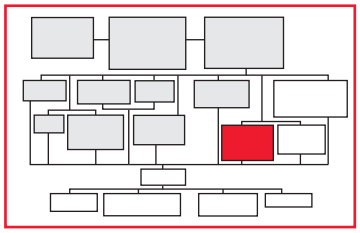
Injection Injuries



Wounds caused by injection of foreign materials (e.g., paint, oil, grease, or dirty water) can be severe. Injection injuries usually result from the use of high-pressure spray guns (600 to 12,000 psi) and

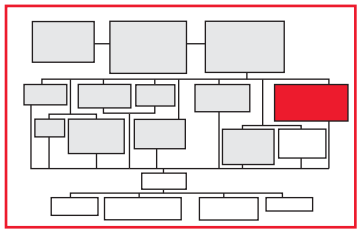
often occur on the nondominant hand.[48,49] On initial examination, the injury may appear deceptively benign, with only a punctate entry wound visible; however, foreign material is often widely distributed in the deeper soft tissues. Radiographs are obtained to identify any fractures present and, in some cases, to determine the extent to which the injected material is distributed. Injection wounds must be treated aggressively with incision, wide exposure, debridement, and removal of foreign bodies to prevent extensive tissue loss and functional impairment. The functional outcome is determined by the time elapsed between injury and treatment and by the type of material injected. Oil-based paint is more damaging to tissues than water-based paint, oil, grease, water, or air.[50,51]

High-Velocity Wounds



High-velocity wounds from explosions or gunshots cause extensive tissue damage as a consequence of the release of kinetic energy. Small entry wounds are common, but the seemingly benign appearance of such a wound often belies the actual severity of injury: the exit wound and interspace may contain large areas of ischemic and damaged tissue that affect critical structures (e.g., bone and blood vessels). Clothing and dirt may also be transmitted into the deep spaces. Radiographs may identify radiopaque foreign bodies (e.g., metal objects or pieces of leaded glass).[52] Treatment of wounds created by high-velocity missiles involves extensive debridement and identification of injured tissue. Wounds should be left open to heal by secondary or delayed primary closure.[32]

Bite Wounds



Treatment of bite wounds involves thorough exploration, irrigation, and debridement. X-rays must be obtained and wounds explored to evaluate the patient for fractures or open joint injuries. If a joint capsule has been violated, the joint must be thoroughly cleaned. Because of the infection risk, wounds may be allowed to heal by secondary or delayed primary closure; primary closure is also possible if thorough debridement is performed.[32] Rabies prophylaxis treatment should be considered for patients who have been bitten by wild animals [*see* Adjunctive Wound Treatment, Rabies Prophylaxis, *below*].

Humans and nonvenomous animals Most human bite wounds are clenched fist wounds sustained by young men.[53] Human bite wounds are considered infected from the moment of infliction and must be treated with antibiotics.[54,55] The antibiotic regimen should be selected on the basis of the bacterial species believed to be present. Common isolates from bite wounds includes *Streptococcus anginosus, Staphylococcus aureus, Eikenella corrodens, Fusobacterium nucleatum, Prevotella melaninogenica,* and *Candida* species.[53] To cover these species, a broad-spectrum antibiotic or combination of antibiotics (e.g., amoxicillin-clavulanate or moxifloxacin) should be administered.[53]

Nonhuman primates can cause viral infection, most commonly with cercopithecine herpesvirus type 1. If left untreated, such infection can lead to meningoencephalitis, which carries a 70% mortality. Accordingly, acyclovir prophylaxis is recommended.[56]

Wounds caused by cat bites or scratches are at high (80%) risk for infection, usually attributable to *Pasteurella multocida.* The aerobic and anaerobic organisms commonly found in cat-bite wounds are similar to those found in dog-bite wounds, and antibiotic prophylaxis with amoxicillin-clavulanate is appropriate.[57] Acute regional lymphadenitis after a cat scratch is known as cat-scratch disease and is caused by *Bartonella henselae*[58]; it is treated by administering azithromycin.[59]

Dog-bite wounds are at lower (16%) risk for infection than human-bite or cat-bite wounds and tend to be less severely contaminated with bacteria. The aerobic species commonly isolated from such wounds include *Pasteurella* (*P. canis*), *Streptococcus, Staphylococcus, Moraxella,* and *Neisseria;* common anaerobic isolates include *Fusobacterium, Bacteroides, Porphyromonas,* and *Prevotella*.[57] Prophylactic treatment with a combination of a β-lactam antibiotic with a β-lactamase inhibitor (e.g., amoxicillin-clavulanate) is appropriate.[57,60]

Venomous animals *Snake bites.* Four types of poisonous snakes are native to the United States: the coral snakes (*Micrurus* and *Micruroides* species), from the family Elapidae, and three species of pit vipers, from the family Viperidae (rattlesnakes [*Crotalus* species], copperheads [*Agkistrodon tortortrix*], and cottonmouths or water moccasins [*Agkistrodon piscivorus*]).[61-63] Pit vipers can be identified by the pit between the eye and the nostril on each side of the head, the vertical elliptical pupils, the triangle-shaped head, the single row of subcaudal plates distal to the anal plate, and the two hollow fangs protruding from the maxillae that produce the characteristic fang marks.[64] Coral snakes have rounder heads and eyes and lack fangs; they are identified by their characteristic color pattern, consisting of red, yellow, and black vertical bands.

Patients bitten by any of the pit vipers must be examined for massive swelling and pain, which, in conjunction with fang marks, suggest envenomation. Local pain and swelling typically develops within 30 minutes of the bite, though in some cases, these manifestations may take up to 4 hours to appear. Erythema, petechiae, bullae, and vesicles are sometimes seen. Severe envenomation may induce systemic reactions, including disseminated intravascular coagulation (DIC), bleeding, hypotension, shock, acute respiratory distress syndrome (ARDS), and renal failure. Patients bitten by coral snakes, on the other hand, show no obvious local signs when envenomation has occurred. Consequently, the physician must look for systemic signs, such as paresthesias, increased salivation, fasciculations of the tongue, dysphagia, difficulty in speaking, visual disturbances, respiratory distress, convulsions, and shock. These symptoms may not develop until several hours after the bite.

If signs or symptoms suggestive of envenomation are found, appropriate laboratory tests (hematocrit, fibrinogen level, coagulation studies, platelet count, urinalysis, and serum chemistries) should be ordered. Laboratory tests should be repeated every 8 to 24 hours for the first 1 to 3 days to determine whether envenomation is progressing. Severe envenomation can cause decreased fibrinogen levels, coagulopathy, bleeding, and myoglobinuria.

Treatment of venomous snake bites includes immobilization and elevation. If envenomation is suspected or confirmed, antivenin should be administered intravenously and as early as possible. Antivenins commonly used in the United States include Antivenin (Crotalidae) Polyvalent (ACP) (Wyeth Pharmaceuticals, Collegeville, Pennsylvania) and Crotalidae Polyvalent Immune Fab (Ovine) (CroFab; Protherics Inc., Nashville, Tennessee).[65] Fab antivenom (FabAV) is less allergenic and more potent than ACP and thus has largely supplanted it in the United States.[65,66] Patients are treated with a loading dose of four to six vials of FabAV, followed by three two-vial maintenance doses at 6, 12, and 18 hours to prevent recurrence of symptoms. If symptoms

progress despite antivenin treatment, an additional four to six vials of FabAV are given twice more; if symptoms continue to progress, consideration should be given to using ACP. ACP remains the most effective antivenin for patients with coral snake bites and those who do not respond to FabAV. Before ACP is administered, the patient must be tested for sensitivity. The major complication of antivenin therapy is serum sickness. This complication occurs in approximately 50% to 75% of patients treated with ACP but in only 16% of those treated with FabAV.[65,67]

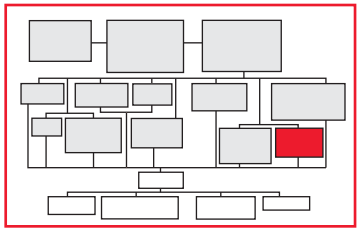
Compartment syndrome is a rare but severe complication of a snake bite. Fasciotomy is sometimes required to relieve extremity compartment syndrome, but it is not necessary for prophylactic purposes. Tourniquets, incision and suction, cryotherapy, and electric shock treatment are of little value for snake bites and may increase complication rates. There is no clear evidence to support antibiotic prophylaxis in this setting.[64]

Spider bites. The bites of most spiders found in the United States cause little to no wound or local reaction; however, there are three types that are capable of injecting venom with skin-penetrating bites. Brown recluse spiders (*Loxosceles reclusa*) can be identified by a violin-shaped dorsal mark. They are nocturnal, live in dark and dry places, and are found in the central and southern United States. The venom is a phospholipase enzyme that acts as a dermal toxin and almost always causes a local reaction.[68] Local signs and symptoms may be limited to minor irritation, though they may also progress to extreme tenderness, erythema, and edema. The onset of local signs and symptoms may be delayed for as long as 8 hours after a bite, and tissue necrosis may then develop over the following days to weeks. Systemic reactions may include mild hemolysis, mild coagulopathy, and DIC, though severe intravascular hemolytic syndrome and death have also been reported.[68,69] Oral administration of dapsone (50 to 100 mg/day) to minimize tissue necrosis has been advocated by some[70]; however, this treatment is of uncertain efficacy, and no prospective data currently support its use. Moreover, dapsone can cause a serious unwanted side effect, hemolytic anemia.[69] If systemic symptoms develop, systemic corticosteroid therapy and supportive measures are indicated. Brown recluse antivenin is not available in the United States.

Black widow spiders (*Latrodectus mactans*) can be identified by a red-hourglass ventral mark.[63] They live in dark, dry, and protected areas and are distributed widely throughout the continental United States. The venom is a neurotoxin that produces immediate and severe local pain. Local signs and symptoms include two fang marks, erythema, swelling, and piloerection.[68] Systemic reactions with neurologic signs may develop within 10 minutes and may include muscle pain and cramps starting in the vicinity of the bite, abdominal pain, vomiting, tremors, increased salivation, paresthesias, hyperreflexia, and, with severe envenomation, shock. Systemic symptoms may last for days to weeks. High-risk persons (e.g., those who are younger than 16 years, the elderly, pregnant women, hypertensive patients, or persons who continue to show symptoms despite treatment) may experience paralysis, hemolysis, renal failure, or coma. Treatment includes 10% calcium gluconate I.V. for relief of muscle spasm, methocarbamol or diazepam for muscle relaxation, and a single dose of antivenin. Antivenin causes serum sickness in as many as 9% of patients; consequently, its use is controversial except in cases where the patient is at high risk.[71]

Hobo spiders (*Tegenaria agrestis*) can be identified by their long hairy legs and a cephalothorax that is marked by two stripes and butterfly markings dorsally and two stripes ventrally. Found throughout the northwestern United States, they live in low places and build funnel-shaped webs in dark spaces. Hobo spiders have been reported to inflict painful bites that lead to wound ulceration, dermonecrosis, and a persistent headache, though the accuracy of such reports has been debated.[69,72,73] A slow-healing ulcer that leaves a central crater has been described. Treatment consists of local wound care.

Stings



Scorpions Stings from most of scorpion species found in the United States cause only limited local reactions that can be managed conservatively; however, stings from *Centruroides sculpturatus,* which is found in California and many southern states, may be more severe. *Centruroides* has a sting that causes envenomation with a neurotoxin. Erythema, edema, and ecchymosis at the site of the sting are evidence that envenomation did not take place. Instead, envenomation is indicated by an immediate and intense burning pain at the wound site.[74] The initial local pain may then be followed by systemic symptoms such as muscle spasm, excess salivation, fever, tachycardia, slurred speech, blurry vision, convulsions, or death.[68] Treatment consists of icing and elevation of the wounded area, followed by administration of barbiturates for control of neuromuscular activity and institution of supportive therapy with antihistamines, corticosteroids, and analgesics.[74]

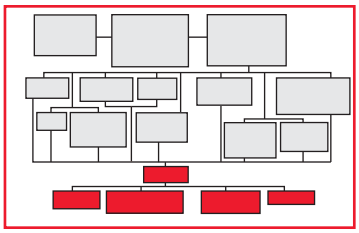
Centipedes Centipedes are slender, multisegmented, and multilegged arthropods that range in size from 1 to 30 cm and in color from bright yellow to brownish black. The first pair of legs are modified into sharp stinging structures that are connected to venom glands. Centipedes prefer dark, damp environments and may be found throughout the southern United States. Local symptoms associated with centipede stings include pain, erythema, edema, lymphangitis, lymphadenitis, weakness, and paresthesia. Skin necrosis may occur at the envenomation site. Systemic symptoms may include anxiety, fever, dizziness, palpitations, and nausea.[75] Treatment consists of symptomatic pain control, infiltration of local anesthetics, administration of antihistamines, and local wound care.[75]

Hymenoptera The order Hymenoptera includes wasps, bees, and ants. Wasps, which are found across the United States, live in small colonies and may attack in groups when provoked. Honeybees (*Apis mellifera*) and bumblebees (*Bombus* species), also found across the United States, are generally docile and rarely sting unless provoked. Africanized honeybees (*Apis mellifera scutellata,* also referred to as killer bees), found primarily in the southwestern states, are far more aggressive than other bees. Fire ants (*Solenopsis invicta* and *Solenopsis richteri*) are wingless, ground-dwelling arthropods that are found in many southern states and that attack in an aggressive swarm.

Although Hymenoptera stingers are small, they can evoke severe local and systemic reactions. The local response to a Hymenoptera sting is a painful, erythematous, and edematous papule that develops within seconds and typically subsides in 4 to 6 hours. Some stingers are barbed and must be removed with a scraping, rather than pinching, motion to prevent the injection of more venom. Systemic reactions occur in about 5% of the population and may lead to anaphylaxis with syncope, bronchospasm, hypo-

tension, and arrhythmias. Wounds and local reactions are treated with ice, elevation, and analgesics. Systemic reactions are treated with subcutaneous epinephrine, diphenhydramine, and supportive airway and blood pressure care.[68] Persons with a history of systemic reactions to insect stings should carry epinephrine kits.

DRESSINGS FOR SPECIFIC TYPES OF WOUNDS



Generally, the functions of a wound dressing include protection, antisepsis, pressure, immobilization, debridement, provision of a physiologic environment, absorption, packing, support, information, comfort, and aesthetic appearance. More specifically, the functions of a dressing should be tailored to the wound type, and the purpose of the dressing must be carefully considered before application.

Abrasions

Abrasions heal by epithelialization, which is accelerated by the warm, moist environment created by an occlusive dressing.[76,77] Such an environment not only promotes epithelialization but also enhances healing, both because of the moisture itself and because of the low oxygen tension that promotes the inflammatory phase.[78] A variety of dressings are suitable for treatment of abrasions, including biologic dressings, hydrogels, hydrocolloids, and semipermeable films. These dressings need not be changed as long as they remain adherent. Small, superficial wounds also heal readily when dressed with impregnated gauze dressings (e.g., Xeroform and Scarlet Red [Kendall, Mansfield, Massachusetts]), which allow exudates to pass through while maintaining a moist wound bed.[78] These less adherent dressings must be changed more regularly.[79]

Dry dressings (e.g., gauze) should be avoided with abrasions because they facilitate scab formation. Scabs slow epithelialization, in that advancing cells must enzymatically debride the scab-wound interface in order to migrate.[80] Wounds covered with a scab also tend to cause more discomfort than wounds covered with occlusive dressings.

Lacerations

For sutured deep wounds, the specific purposes of a dressing are to prevent bacterial contamination, to protect the wound, to manage drainage, and to facilitate epithelialization. Dressings used on such wounds usually consist of three basic layers. The inner (contact) layer is chosen to minimize adherence of the dressing to the wound and to facilitate drainage through itself to the overlying layers. Common choices for this layer include fine-mesh gauze, petrolatum gauze, Xeroform or Xeroflo (Kendall, Mansfield, Massachusetts) gauze, and Adaptic (Johnson & Johnson, New Brunswick, New Jersey). These substances should be applied only as a single layer; in multiple layers, they become occlusive. The middle layer is chosen for absorbency and ability to conform to shape of the wound area. It is usually composed of fluffs, Kerlix (Kendall, Mansfield, Massachusetts), or wide-mesh gauze, all of which facilitate capillary action and drainage.[81] The middle layer must not be allowed to become soaked, because if it is, exudate will collect on the wound surface, and maceration and bacterial contamination may occur. The outer (binding) layer serves to secure the dressing. Common choices for this layer include Kling (Johnson & Johnson, New Brunswick, New Jersey), ACE bandages (BD Medical, Franklin Lakes, New Jersey), and Coban (3M, St. Paul, Minnesota).

With sutured wounds, dressings are required only until drainage from the wound ceases. With nondraining wounds, dressings may be removed after 48 hours, by which time epithelial cells will have sealed the superficial layers of the wound. An alternative method of treating minimally draining incisional wounds is to apply an antibacterial ointment [*see* Adjunctive Wound Treatment, Topical Antimicrobials, *below*]. Such ointments are occlusive and maintain a sterile, moist environment for the 48 hours required for epithelialization. In anatomic areas that are difficult to dress (e.g., the scalp), it may be reasonable to forgo a dressing and simply apply ointments or allow a scab to form on the wound surface. Operative incisional wounds are also sometimes covered with an occlusive dressing to optimize epithelialization [*see* Abrasions, *above*]. Some of these dressings are transparent, allowing observation of the wound. The disadvantage of occlusive dressings is their limited absorptive capacity, which allows drainage from the wound to collect underneath.

Complex Wounds

For complex wounds containing questionably necrotic tissue, foreign bodies, or other debris that cannot be removed sharply, wet-to-dry dressings are effective, simple, and inexpensive. A single layer of coarse wet gauze is applied to a wound, allowed to dry over a period of 6 hours, and removed. Necrotic tissue, granulation tissue, debris, and wound exudate become incorporated within the gauze and are removed with the dressing. The disadvantages of wet-to-dry dressings are pain and damage to or removal of some viable tissue. If the wound bed contains tendons, arteries, nerves, or bone, wet-to-wet dressings should be used to prevent desiccation of these critical structures.

Wet-to-wet dressings, which are not allowed to dry, cause less tissue damage than wet-to-dry dressings but do not produce as much debridement. Most wet-to-wet dressings are kept moist with saline. Wounds with significant bacterial contamination may be treated with dressings that contain antibacterial agents (e.g., mafenide, silver sufadiazine, silver nitrate, or iodine).

Biologic and semipermeable films also maintain a moist wound bed, but they are difficult to use on deep or irregular wounds and wounds with a great deal of drainage. Consequently, wet-to-wet dressings with agents such as silver sulfadiazine are often used for these types of wounds. Enzymatic agents can debride wounds effectively and are a reasonable alternative to wet-to-dry or wet-to-wet dressings for wounds that contain necrotic tissue.[82]

Table 4 Recommendations for Tetanus Immunization[89,90]

Tetanus Immunization History	Tt*	TIG
Unknown	Yes	Yes
> 10 yr since last booster	Yes	Yes
≥ 5 and ≤ 10 yr since last booster	Yes	No
< 5 yr since last booster	No	No

Note: Tetanus toxoid (Tt) and tetanus immune globulin (TIG) should be administered with separate syringes at different anatomic sites. Tetanus and diphtheria toxoids are contraindicated for the wounded patient if there is a history of a neurologic or severe hypersensitivity reaction after a previous dose. Local side effects alone do not preclude continued use. If a systemic reaction is suspected of representing allergic hypersensitivity, immunization should be postponed until appropriate skin testing is performed. If a contraindication to a Tt-containing preparation exists, TIG alone should be used.

*For patients younger than 7 years, diphtheria-tetanus-pertussis vaccine (DTP) (or tetanus and diphtheria toxoids, if pertussis vaccine is contraindicated) is preferable to Tt alone. For patients 7 years of age or older, Tt alone may be given.

Some wounds are difficult to dress and require special consideration. For wounds with flaps or questionably viable tissue, compression dressings should not be used, because they may cause ischemia. Wounds that cross joints are best dressed with plaster splints for temporary immobilization; semipermeable films are flexible and may also be used in this setting. Wounds with high levels of exudates may be dressed with hydrocolloids, hydrogels, or alginates.[78] For large or irregular wounds, negative-pressure wound therapy (NPWT) with the VAC system (Kinetic Concepts Inc., San Antonio, Texas) is recommended; VAC dressings conform well and remain adherent. Additionally, NPWT uses subatmospheric pressure to remove excess wound fluid, stimulates the formation of granulation tissue, improves peripheral blood flow and tissue oxygenation, and reduces the size of the wound.[83,84] Use of the VAC system is contraindicated in wounds with exposed blood vessels or bowel.

Adjunctive Wound Treatment

PROPHYLACTIC SYSTEMIC ANTIBIOTICS

For most wounds, antibiotic prophylaxis is not indicated. When it is called for, the agent or agents to be used should be selected on the basis of the bacterial species believed to be present. The anatomic location of a wound may also suggest whether oral flora, fecal flora, or some less aggressive bacterial contaminant is likely to be present. Gram staining can provide an early clue to the nature of the contamination. Ultimately, the choice of a prophylactic antibiotic regimen is based on the clinician's best judgment regarding which agent or combination of agents will cover the pathogens likely to be present in the wound on the basis of the information available.

As a rule, clean and clean-contaminated wounds are adequately treated with irrigation and debridement. There are, however, some local factors (e.g., impaired circulation and radiation injury) and systemic factors (e.g., diabetes, AIDS, uremia, and cancer) that increase the risk of wound infection; in the presence of any of these factors, prophylactic antibiotics should be considered. In addition, prophylactic antibiotics should be given to patients with extensive injuries to the central area of the face (to prevent spread of infection through the venous system to the meninges), patients with valvular disease (to prevent endocarditis), and patients with prostheses (to reduce the risk of bacterial seeding of the prosthesis). Lymphedematous extremities are especially prone to cellulitis, and antibiotics are indicated whenever such extremities are wounded.

Contaminated and dirty wounds are associated with a higher risk of infection and are therefore more likely to necessitate antibiotic prophylaxis. Human bite wounds, mammalian bite wounds, and wounds contaminated with dirt, bodily fluids, or feces are all prone to infection and must be treated with antibiotics.[54,55] Prophylactic administration of a combination of a β-lactam antibiotic with a β-lactamase inhibitor (e.g., amoxicillin-clavulanate) is appropriate.[57,60] Antibiotic prophylaxis is also indicated for mutilating wounds with extensive amounts of devitalized tissue. Such wounds are often contaminated by a mixture of gram-positive organisms and gram-negative organisms.[40] When antibiotics are indicated for these injuries, broad-spectrum coverage is appropriate.

TOPICAL ANTIMICROBIALS

Topical antimicrobials (e.g., antibiotic ointments, iodine preparations, and silver agents) are commonly used to prevent wound infection. Application of mupirocin ointment to a clean surgical wound before an occlusive dressing does not reduce the infection rate and may promote antibiotic resistance.[85] For uncomplicated traumatic wounds, however, application of bacitracin and neomycin ointment results in a significantly lower infection rate than application of petrolatum.[86] Neomycin-containing ointments reduce bacterial counts in partial-thickness wounds in animals, but many other over-the-counter antibiotic ointments are not effective at reducing bacterial counts in wounds.[87]

Wounds contaminated by bacteria can be treated with dressings that contain antibacterial agents such as mafenide, silver nitrate, silver sulfadiazine, or iodine. Mafenide penetrates eschar well, but it can cause pain and has the potential to induce metabolic acidosis through inhibition of carbonic anhydrase. Silver has microbicidal effects on common wound contaminants and may also be affective against methicillin-resistant *S. aureus* (MRSA).[84] Silver nitrate does not cause pain, but it can cause hypochloremia, and it stains fingernails and toenails black. Silver sulfadiazine is frequently used because of its broad antibacterial spectrum, its relatively low side effect profile (transient leukopenia is occasionally seen), and its ability to maintain a moist wound environment (thereby speeding healing and epithelialization).[88]

TETANUS PROPHYLAXIS

Tetanus is a nervous system disorder that is caused by *Clostridium tetani* and is chacracterized by muscle spasm. In the past, wounds were classified as either tetanus-prone or non–tetanus-prone on the basis of their severity. It is now clear, however, that wound severity is not directly correlated with tetanus susceptibility; tetanus has been associated with a wide variety of injury types over a broad spectrum of wound severity.[89] Accordingly, all wounds, regardless of cause or severity, must be considered tetanus prone, and the patient's tetanus immunization status must always be considered. Tetanus wound prophylaxis should be provided as appropriate [*see Table 4*].[89,90]

RABIES PROPHYLAXIS

Rabies is an acute progressive encephalitis that is caused by viruses from the family Rhabdoviridae. The rabies virus can be transmitted by any mammal, but viral reservoirs are found only in carnivores and bats. In North America, raccoons, skunks, bats, and foxes are the animals most commonly responsible for transmission.[91] Bite wounds in which the animal's saliva penetrates the dermis are the most common cause of exposure.

Postexposure treatment consists of wound care, infiltration of rabies immune globulin into the wound, and administration of vaccine.[91,92] Wound care involves washing with soap and water, as well as the use of iodine- or alcohol-based virucidal agents.[93] Guidelines for postexposure prophylaxis have been established [*see Table 5*]. The vaccination regimen is determined by the patient's previous vaccination status [*see Table 6*].

Postoperative Wound Care

Closed wounds should be kept clean and dry for 24 to 48 hours after repair. Epithelialization begins within hours after wound approximation and forms a barrier to contamination. Gentle cleansing with running water will help remove bacteria and crusting. The patients should not place tension on the wound or engage in strenuous activity until the wound has regained sufficient tensile strength. In the first 6 weeks after repair, the wound's tensile strength increases rapidly; after this period, tensile strength increases more slowly, eventually reaching a maximum of 75% to 80% of normal skin strength [*see Figure 2*].

Table 5 Recommendations for Postexposure Rabies Prophylaxis[91-93]

Animal Type	Animal Disposition and Evaluation	Prophylaxis
Dogs, cats, ferrets	If animal is healthy and available, it is confined for 10 days of observation	Start vaccination if animal exhibits rabies symptoms*
	If animal is rabid or suspected of being rabid, no observation is indicated	Provide immediate vaccination
	If animal's rabies status is unknown, consultation is indicated	Consult public health official
Bats, skunks, raccoons, foxes, bobcats, coyotes, mongooses, and most carnivores	Animal is regarded as rabid unless brain laboratory tests are negative	Provide immediate vaccination unless brain laboratory tests are negative
Livestock, small rodents (e.g., squirrels, chipmunks, rats, hamsters, gerbils, guinea pigs, and mice), large rodents (e.g., woodchucks and beavers), rabbits, hares, and other mammals	Each case is considered indivdually; rabies reported in large rodents in some areas	Consult public health officials; almost never require antirabies treatment

*If the isolated animal shows symptoms of rabies, postexposure prophylaxis is started immediately, and the animal is euthanized for laboratory testing. Vaccination prophylaxis is stopped if laboratory tests are negative for rabies.

Wounds at risk for infection should be assessed by a medical provider within 48 hours of care. In addition, the patient should be taught to look for signs of infection (e.g., erythema, edema, pain, purulent drainage, and fever).

The timing of suture or staple removal is determined by balancing the requirements for optimal cosmesis against the need for wound support. On one hand, it is clear that for optimal cosmesis, sutures should be removed early, before inflammation and epithelialization of suture tracts. An epithelialized tract will develop around a suture or staple that remains in the skin for longer than 7 to 10 days; once the suture or staple is removed, the tract will be replaced by scar.[94] On the other hand, it takes a number of weeks for the wound to gain significant tensile strength, and early removal of wound support can lead to dehiscence of wounds that are under substantial tension. Early suture removal is warranted for some wounds. For example, sutures in aesthetically sensitive areas (e.g., the face) may be removed on day 4 or 5, and sutures in areas under minimal tension (e.g., in wounds parallel to skin tension lines) may be removed on day 7. Sutures in wounds subject to greater stress (e.g., wounds in the lower extremities or the trunk) should remain in place longer, as should sutures in wounds sustained by patients who have a condition that hinders healing (e.g., malnutrition). In such cases, suture-mark scars are considered acceptable. The appropriate method of removing a suture is first to cut it, then to pull on the knot parallel to or toward, rather than away from, the wound.

After suture removal, numerous methods are employed to minimize unsightly scar formation. The cosmetic outcome of a scar is largely determined by the nature and severity of the wound, which are outside the surgeon's control. The greatest impact a surgeon can have on cosmetic outcome is derived from providing meticulous care when the acute wound is initially encountered. Postoperative wound care measures employed to optimize cosmetic outcome include massage, the use of silicone bandages or pressure garments, and the application of lotions. These interventions appear to help, but prospective trials are needed to confirm their efficacy and establish treatment guidelines. The healing wound is fragile, and topical application of ointments to achieve an improved scar appearance may actually achieve the opposite result. For example, vitamin E, which is commonly applied to healing wounds, can induce contact dermatitis and cause scars to look worse.[95]

Table 6 Recommendations for Postexposure Rabies Vaccination[91-93]

Vaccine	Dosage	
	No Previous Vaccination	Previous Vaccination
Human rabies immune globulin (HRIG)	Full dose of 20 IU/kg infiltrated around wound(s) at initial presentation; use separate syringe and anatomic site from vaccine	Not administered
Human diploid cell vaccine (HDCV), rabies vaccine adsorbed (RVA), or purified chick embryo cell vaccine (PCECV)	1.0 ml IM on days 0, 3, 7, 14, and 28*	1.0 ml IM on days 0 and 3*

*Vaccine administration site for adults is the deltoid; for children, the anterolateral thigh may be used. To prevent sciatic nerve injury and reduce adipose depot delivery, the gluteus is never used.

Factors That May Hinder Wound Healing

Despite a surgeon's best efforts, healing does not always occur in an undisturbed fashion: sometimes, a closed wound dehisces. If the dehiscence is sudden, the wound is clean, and only skin and superficial tissues are involved, then the wound should be reclosed, and the cause of the dehiscence should be corrected if possible. If the dehiscence is slow and the wound is contaminated or infected, then the wound should be allowed to heal secondarily, with dressing changes and scar revision to be performed at a later date.

There are a number of local and systemic factors [*see Table 7*] that can interfere with wound healing (see below). Accordingly, it is essential for clinicians to be aware of and knowledgeable about these factors and, whenever possible, to take appropriate measures to improve the chances for optimal healing. The use of nutrients and growth factors to stimulate wound healing may be considered; this measure is currently the subject of extensive research.

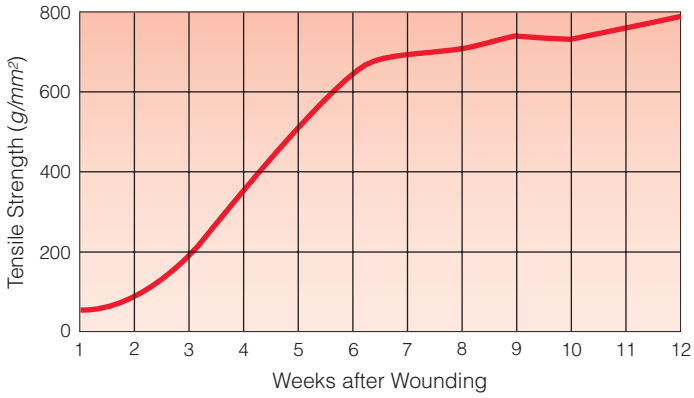


Figure 2 **The tensile strength of skin wounds increases rapidly for approximately 6 weeks after wounding; it then continues to increase slowly for 6 to 12 months after wounding, though it never reaches the tensile strength of unwounded tissue. Collagen is remodeled and replaced with highly cross-linked collagen along tissue stress lines. The process of collagen replacement and scar remodeling continues for years.**

LOCAL FACTORS

Tension

Tension—whether from inherent skin tension, poor surgical technique, movement of joints, or inadequate wound support—may lead to separation of wound edges. It should be minimized by undermining the wound edges during closure to allow easy coaptation. Tissue ellipses from complex wound edges should be kept as narrow as possible and should be created along relaxed skin tension lines. Adequate support of the wound after suture removal is critical; many surgeons keep tapes (e.g., Steri-Strips) over a wound for 3 weeks, until the strength of the wound equals that of the deep sutures and tapes. Wounds over joints should be splinted to reduce tension.

Foreign Body

All foreign bodies that contaminate a wound should be removed at the time of initial debridement and before wound closure. Retained foreign bodies may cause failed healing, infection, or traumatic tattooing. Iatrogenic foreign bodies may also interfere with wound healing and promote infection. Suture material is a foreign body; thus, the number and size of sutures placed in a wound should be kept to the minimum necessary for coaptation of the wound edges.

Infection

All traumatic wounds are contaminated and should therefore be irrigated to remove organisms. Infection occurs when bacteria are too numerous (>10^5 organisms/g tissue) or virulent for local tissue defenses to be able to control them.[96] As noted [*see* Adjunctive Wound Care, Prophylactic Antibiotics, *above*], local factors (e.g., impaired circulation and radiation injury) increase the risk of infection, as do various systemic diseases (e.g., diabetes, AIDS, uremia, and cancer). Wound cultures should be obtained, and broad-spectrum antibiotic therapy should be started when infection is diagnosed. The antibiotic regimen is adjusted on the basis of culture results and sensitivities.

Ischemia

Ischemic wound tissue readily becomes infected and therefore must be debrided. Tissue with dermal edges that do not bleed or that show no perfusion on fluorescein testing is ischemic. Questionably viable tissue should be monitored closely and debrided when declared nonviable.

Hematoma and Seroma

Hematomas and seromas increase the risk of infection and the likelihood of wound dehiscence. To prevent their formation, hemostasis at the time of wound closure must be meticulous, and bleeding diatheses must be corrected. Because the rubbing of wound edges against one another is associated with the formation of hematomas and seromas, wound edge movement should be minimized and immobilization employed as necessary. Wounds at significant risk for hematoma or seroma formation should be closed over a drain.

Large hematomas or seromas that are recognized early, before infection develops, should be evacuated, and the wound should be reclosed. Small hematomas or seromas can usually be treated conservatively until they are reabsorbed, but close observation is required. If a hematoma or seroma is not recognized until late, when infection has already set in, the wound should be opened, drained, and allowed to heal secondarily; scar revision may be carried out at a later point.

Trauma

Tissue injury is obviously associated with external trauma, but it can also be iatrogenic. Rough handling of tissue edges with forceps produces minute crush injuries, which promote wound infection. It is preferable to handle wound edges with hooks, using gentle surgical technique.

Edema

Edema results from the accumulation of fluid in the interstitial space. It may occur as an acute process, in which tissue injury leads to histamine release, leaky capillaries, and inflammation, or as a chronic process, in which venous insufficiency, lymphatic insufficiency, and a low plasma oncotic pressure may cause fluid to collect in the interstitium. In both cases, edema raises tissue pressure and inhibits perfusion and healing. The proteinaceous and fibrin-rich fluid also forms clot and fibrous tissue, which hinder the supply of oxygen and inflammatory cells.[97] Clearance of wound edema is necessary for healing and may be successfully accomplished by means of compression therapy[98] or NPWT with a VAC device.[83]

Table 7 Local and Systemic Factors That Impair Wound Healing

Local Factors	Systemic Factors
Tension	Inherited connective tissue disorders
Foreign body	Hypothermia
Infection	Oxygen
Ischemia	Tobacco smoking
Hematoma and seroma	Malnutrition
Edema	Jaundice
Irradiation	Age
	Diabetes mellitus
	Uremia
	Steroids
	Chemotherapeutic agents
	Other drugs

Irradiation

Irradiation damages the skin and can cause wounds to heal slowly. It also induces chronic skin changes: previously irradiated tissues demonstrate delayed healing when wounded.[99] Irradiated tissue is characterized by a thickened and fibrotic dermis, a thin epidermis, pigment changes, telangiectasia, decreased hair, and increased dryness (as a consequence of damage to sebaceous and sweat glands). The microvasculature of the skin is obliterated, leading to tissue ischemia and impaired healing. Keratinocytes, which are necessary for wound epithelialization, exhibit impaired mitotic ability and slow progressive desquamation (as a consequence of their superficial location and high replication rate).[97] Collagen bundles become edematous and fibrotic. Fibroblasts, which are necessary for collagen synthesis, also show diminished migration and proliferation.[100]

Because irradiated skin is irreversibly damaged, tissue transfer may be required for repair of wounds in areas subjected to radiation. Vitamin A supplementation can lessen the adverse effects of irradiation on wound healing.[101]

SYSTEMIC FACTORS

Inherited Connective Tissue Disorders

Several inherited connective tissue disorders are known to interfere with normal wound healing. Ehlers-Danlos syndrome exists as multiple types that exhibit certain differences, but in general, the syndrome leads to deficient collagen cross-linking, which results in lax and fragile skin, lax joints, and impaired wound healing. For example, an Ehlers-Danlos patient who undergoes an elective hernia repair or facelift may have a poor outcome as a consequence of deficient collagen formation and poor wound healing.[102,103] Osteogenesis imperfecta is a procollagen formation disorder that is clinically manifested by brittle bones, increased laxity of ligaments and skin, bone deformities, and impaired wound healing.[104] Marfan syndrome is an autosomal dominant disorder characterized by deficient synthesis of fibrillin, which is a key component in elastin formation. Patients with this syndrome have long extremities and hyperextendable joints; those who are seriously affected have lax ligaments, dissecting aneurysms, dislocated eye lenses, pectus excavatum, and scoliosis. Surgical repair of aneurysms and hernias is usually successful in this population, though healing difficulties may be encountered.[103] Cutis laxa is a disease in which an elastase inhibitor deficiency gives rise to defective elastic tissue. Patients with this disease have thick, coarse, and drooping skin, along with hernias, aneurysms, heart disease, and emphysema. Unlike patients with the other heritable diseases mentioned, cutis laxa patients often show no impairment of wound healing.[105]

Hypothermia

Hypothermia may develop as a consequence of administration of anesthetic drugs, exposure to cold, or redistribution of body heat; it leads to peripheral vasconstriction and impaired wound oxygen delivery.[106] Wound tensile strength increases more slowly when healing occurs in a cold environment. Prevention or correction of hypothermia reduces the wound infection rate and increases collagen deposition in patients undergoing abdominal surgery.[107] Preoperative systemic and local warming also reduces the wound infection rate in patients undergoing elective operations.[108] A warm body temperature must be maintained in all wounded patients to reduce subcutaneous vasoconstriction and maximize wound healing potential.

Oxygen

Tissue oxygenation is necessary for aerobic metabolism, fibroblast proliferation, collagen synthesis, and the antimicrobial oxidative burst of inflammatory cells. Transcutaneous oxygen tension is directly correlated with wound healing.[109] Wound tissue oxygenation is determined by blood perfusion, hemoglobin dissociation, local oxygen consumption, fraction of inspired oxygen (F_IO_2), oxygen-carrying capacity (as measured by hemoglobin content), arterial oxygen tension (P_aO_2), circulating blood volume, cardiac function, arterial inflow, and venous drainage.[106,110] Each of these variables should be addressed in promoting wound healing.

Supplemental administration of oxygen (inspired or hyperbaric) has beneficial effects on wound healing. The incidence of infection in surgical wounds can be reduced by improving the F_IO_2 with supplemental oxygen.[111] In a study of patients undergoing colon surgery, for example, the wound infection rate was 50% lower when an F_IO_2 of 0.8 was maintained intraoperatively and for 2 hours postoperatively than when an F_IO_2 of 0.3 was maintained.[112] Hyperbaric oxygen therapy (i.e., the delivery of oxygen in an environment of increased ambient pressure) has been used for treatment of many types of wounds in which tissue hypoxia may impair healing.[43] It increases tissue oxygen concentrations tenfold while also causing vasoconstriction, which results in decreased posttraumatic edema and decreased compartment pressures.[113] The elevated pressure and hyperoxia induced by hyperbaric oxygen therapy may promote wound healing; for patients with an acute wound, this modality may be a useful adjunct in treating limb-threatening injury, crush injury, and compartment syndrome.[43]

Circulating volume can be improved by administering crystalloids or blood. However, anemia alone is not associated with impaired wound healing unless it is severe enough to limit circulating blood volume.[114] The vasculature may be compromised either systemically (e.g., by diabetes mellitus or peripheral vascular disease) or locally (e.g., by trauma or scar). Vascular bypasss may be necessary to improve tissue oxygenation in patients with poor arterial inflow.[97]

Tobacco Smoking

Tobacco smoking reduces tissue oxygen concentrations, impairs wound healing, and contributes to wound infection and dehiscence.[115,116] The effects of smoking are attributable to vasoconstriction (caused by nicotine), displacement of oxygen binding (resulting from the high affinity of carbon monoxide for hemoglobin), increased platelet aggregation,[117] impairment of the inflammatory cell oxidative burst,[118] endothelial damage, and the development of atherosclerosis.[115,116,119] All acutely injured patients should stop smoking, and ideally, all noninjured patients scheduled to undergo surgery should stop smoking at least 3 weeks before an elective surgical wound is made.[118,120] Like smoked tobacco, transcutaneous nicotine patches alter the inflammatory cell oxidative burst and cause vasoconstriction; accordingly, they too should not be used when a wound is present.[118]

Malnutrition

On average, hospitalized patients show a 20% increase in energy expenditure, and this increase calls for appropriate nutritional compensation.[97] Good nutritional balance and adequate caloric intake (including sufficient amounts of protein, carbohydrates, fatty acids, vitamins, and other nutrients) are necessary for normal wound healing.[121]

All patients who have sustained wounds should undergo nutritional assessment,[122] which typically includes measuring serum

levels of albumin, protein, prealbumin, transferrin, and insulinlike growth factor–1 (IGF-1).[97] The serum albumin level is one of the best predictors of operative mortality and morbidity.[123] A value lower than 2.5 g/dl is considered severely depressed, and a value lower than 3.4 g/dl is associated with higher perioperative mortality.[124,125] Protein provides an essential supply of the amino acids used in collagen synthesis, and hypoproteinemia results in impaired healing; consequently, it is not surprising that protein replacement and supplementation can improve wound healing.[126,127] In particular, supplementation specifically with the amino acids arginine, glutamine, and taurine (which are essential for anabolic processes and collagen synthesis) is known to enhance wound healing.[128-130] Glutamine is the most abundant free amino acid in the body, and under catabolic conditions, it is released from muscle unless provided as a supplement.

Vitamins C, A, K, and D are essential for normal healing. Vitamin C (ascorbic acid) hydroxylates the amino acids lysine and proline during collagen synthesis and cross-linking. A deficiency of this vitamin causes scurvy, marked by failed healing of new wounds and dehiscence of old wounds. Vitamin C supplementation (100 to 1,000 g/day) can improve wound healing.[97,130] Vitamin A (retinoic acid) is essential for normal epithelialization, proteoglycan synthesis, and normal immune function.[131-133] Retinoids and topical tretinoin may help foster acute wound healing by accelerating epithelialization of full- and partial-thickness wounds, activating fibroblasts, increasing type III collagen synthesis, and decreasing metalloprotease activation.[134,135] Oral retinoid treatment significantly increases the decreased hydroxyproline content, tumor growth factor–β (TGF-β) level, and IGF-1 concentration associated with corticosteroids.[134] In addition, all aspects of corticosteroid-impaired healing—other than wound contraction—can be reversed by providing supplemental oral vitamin A at a recommended dosage of 25,000 IU/day.[136] The retinoic acid derivative isotretinoin (13-*cis*-retinoic acid), however, impairs wound epithelialization and delays wound healing.[137] Vitamin K is a cofactor in the synthesis of coagulation factors II, VII, IX, and X, as well as thrombin. Consequently, vitamin K is necessary for clot formation and hemostasis, the first step in acute wound healing. Vitamin D is required for normal calcium metabolism and therefore plays a necessary role in bone healing.

Dietary minerals (e.g., zinc and iron) are also essential for normal healing. Zinc is a necessary cofactor for DNA and RNA synthesis. A deficiency of this mineral can lead to inhibition cell proliferation, deficient granulation tissue formation,[138] and delayed wound healing.[139] Zinc replacement and supplementation can improve wound healing.[130] However, daily intake should not exceed 40 mg of elemental zinc, because excess zinc can immobilize macrophages, bind copper, and depress wound healing.[140] Iron is also a cofactor for DNA synthesis, as well as for hydroxylation of proline and lysine in collagen synthesis.[97] However, iron deficiency anemia does not appear to affect wound strength.[141]

Jaundice

The effect of jaundice on wound healing is controversial. Jaundiced patients appear to have a higher rate of postoperative wound healing complications,[142] as well as a lower level of collagen synthesis.[143] However, obstructive jaundice does not affect healing of blister wounds in humans.[143] Jaundiced animals show a significant delay in collagen accumulation within the wound, but no significant reduction in the mechanical strength of the wound.[144] Biliary drainage may be considered in jaundiced patients with wounds; this measure will improve collagen synthesis, though it may not have any appreciable effect on the healing rate.[143]

Age

Aging has a deleterious effect on the capacity for wound healing.[145] Increasing age is associated with an altered inflammatory response, impaired macrophage phagocytosis, and delayed healing.[146] Nevertheless, even though the wound healing phases begin later in elderly persons, proceed more slowly, and often do not reach the same level that they would in younger persons, elderly patients are still able to heal most wounds with ease.[147]

Diabetes Mellitus

Diabetes mellitus is associated with poor wound healing and an increased risk of infection. Diabetic neuropathy leads to sensory loss (typically in the extremities) and diminished ability to detect or prevent injury and wounding. Once present, wounds in diabetic patients heal slowly. The etiology of this healing impairment is multifactorial. Diabetes is associated with impaired granulocyte function and chemotaxis, depressed phagocytic function, altered humoral and cellular immunity, peripheral neuropathy, peripheral vascular disease, and various immunologic disturbances, any of which may hinder wound healing.[148-151] In addition, it is associated with a microangiopathy that can limit perfusion and delivery of oxygen, nutrients, and inflammatory cells to the healing wound.[152] Diabetes-induced impairment of healing, as well as the attendant morbidity and mortality, may be reduced by tightly controlling blood sugar levels with insulin.[153] Diabetic patients must also closely monitor themselves for wounds and provide meticulous care for any wounds present.

Uremia

Uremia and chronic renal failure are associated with weakened host defenses, an increased risk of infection, and impaired wound healing.[154] Studies using uremic animal models show delayed healing of intestinal anastomoses and abdominal wounds.[155] Uremic serum also interferes with the proliferation of fibroblasts in culture.[103,155] Treatment of this wound healing impairment includes dialysis.

Uremic patients with wounds may experience bleeding complications. In this situation, appropriate evaluation includes determining the prothrombin time (PT), the activated partial thromboplastin time (aPTT), the platelet count, and the hematocrit. Treatment includes dialysis without heparin; administration of desmopressin (0.3 μg/kg), cryoprecipitate, conjugated estrogens (0.6 mg/kg/day I.V. for 5 days),[156] and erythropoietin; and transfusion of red blood cells to raise the hematocrit above 30%.[157,158]

Uremic patients with hyperparathyroidism may also exhibit the uremic gangrene syndrome (calciphylaxis), which involves the spontaneous and progressive development of skin and soft tissue wounds, usually on the lower extremities. Patients with this syndrome typically are dialysis dependent and have secondary or tertiary hyperparathyroidism. Wound biopsies demonstrate fat necrosis, tissue calcification, and microarterial calcification.[159] Treatment includes local wound care, correction of serum phosphate levels with oral phosphate binders,[160] correction of calcium levels with dialysis, and subtotal parathyroidectomy.[159]

Drugs

Steroids Corticosteroids are anti-inflammatory agents that inhibit all aspects of healing, including inflammation, macrophage migration, fibroblast proliferation, protein and collagen synthesis,

development of breaking strength, wound contraction, and epithelialization.[103,136,161] In the setting of an acute wound that fails to heal, corticosteroid doses may be reduced, vitamin A administered topically or systemically, and anabolic steroids given to restore steroid-retarded inflammation.[103,136]

Unlike corticosteroids, anabolic steroids accelerate normal collagen deposition and wound healing. Oxandrolone is an oral anabolic steroid and testosterone analogue that is employed clinically to treat muscle wasting, foster wound healing, and mitigate the catabolism associated with severe burn injury. Supplementation with this agent leads to significant improvements in the wound healing rate.[162] In burn patients treated with oral oxandrolone, hospital length of stay is significantly reduced, and the number of necessary operative procedures is decreased.[163] In ventilator-dependent surgical patients receiving oxandrolone, however, the course of mechanical ventilation is longer than in those not treated with oxandrolone. It has been suggested that the very ability of oxandrolone to enhance wound healing may increase collagen deposition and fibrosis in the later stages of ARDS and thereby prolong recovery.[164] Acute elevation of liver enzyme levels has been seen in some patients treated with oxandrolone; accordingly, hepatic transaminase concentrations should be intermittently monitored in all patients treated with this agent.[163]

Chemotherapeutic agents Both wound healing and tumor growth depend on metabolically active and rapidly dividing cells. Consequently, chemotherapeutic anticancer drugs that hinder tumor growth can also impair wound healing. These agents (which include adrenocorticosteroids, alkylating agents, antiestrogens, antimetabolites, antitumor antibodies, estrogen, progestogens, nitroureas, plant alkaloids, and random synthetics) attenuate the inflammatory phase of wound healing, decrease fibrin deposition, reduce the synthesis of collagen by fibroblasts, and delay wound contraction.[97] Some cytotoxic drugs (e.g., methotrexate and doxorubicin) substantially attenuate the early phases of wound repair and reduce wound tear strength.[165] The magnitude of these effects is influenced by the timing of the chemotherapeutic agent's delivery in relation to the time when the wound is sustained. Preoperative delivery has a greater adverse effect on healing; for example, doxorubicin impairs wound healing to a greater extent if given before operation than if treatment is delayed until 2 weeks after operation.[166] Chemotherapy also results in myelosuppression and neutropenia that can decrease resistance to infection, allowing small wounds to progress to myonecrosis and necrotizing soft tissue infections.[167] In all acutely wounded patients who have recently been treated with, are currently taking, or will soon begin to take chemotherapeutic agents, the wounds must be closely observed for poor healing and complications.

Other drugs Many other commonly used drugs affect wound healing and thus should be avoided in the setting of an acute wound. Nicotine, cocaine, ergotomine, and epinephrine all cause vasocontriction and tissue hypoxia. Nonsteroidal anti-inflammatory drugs (e.g., ibuprofen and ketorolac) inhibit cyclooxygenase production and reduce wound tensile strength. Colchicine decreases fibroblast proliferation and degrades newly formed extracellular matrix. Antiplatelet agents (e.g., aspirin) inhibit platelet aggregation and arachidonic acid–mediated inflammation. Heparin and warfarin impair hemostasis by virtue of their effects on fibrin formation.[84,168,169] As noted [*see* Malnutrition, *above*], isotretinoin inhibits wound epithelialization and delays wound healing.[137] Vitamin E (α-tocopherol) impairs collagen formation, inflammation, and wound healing[170]; topical application of this agent can causes contact dermatitis and worsen the cosmetic appearance of scars.[95]

Discussion

Physiology of Wound Healing

Wound healing is not a single event but a continuum of processes that begin at the moment of injury and continue for months. These processes take place in much the same way throughout the various tissues of the body and, for the purposes of description, may be broadly divided into three phases: (1) inflammation, (2) migration and proliferation, and (3) maturation [*see Figure 3*]. Humans, unlike (for instance) salamanders, lack the ability to regenerate specialized structures; instead, they heal by forming a scar that lacks the complex and important skin structures seen in unwounded skin [*see Figure 4*].

INFLAMMATORY PHASE

The inflammatory phase of wound healing begins with hemostasis, followed by the arrival first of neutrophils and then of macrophages. This response is most prominent during the first 24 hours after a wound is sustained. Signs of inflammation (i.e., erythema, edema, heat, and pain) are apparent, generated primarily by changes in the venules on the distal side of the capillary bed. In clean wounds, signs of inflammation dissipate relatively quickly, and few if any inflammatory cells are seen after 5 to 7 days. In contaminated wounds, inflammation may persist for a prolonged period.

Because wounds bleed when blood vessels are injured, hemostasis is essential. In the first 5 to 10 minutes after wounding, vasoconstriction contributes to hemostasis, and the skin blanches as a result. Vasoconstriction is mediated by catecholamines (e.g., epinephrine and norepinephrine) and prostaglandins (e.g., prostaglandin $F_{2\alpha}$ [$PGF_{2\alpha}$] and thromboxane A_2 [TXA_2]). As vessels contract, platelets aggregate and adhere to the blood vessel collagen exposed by the injury. Aggregating platelets release alpha-granule proteins, resulting in further platelet aggregation and triggering cytokine release. The cytokines involved in cutaneous wound healing include epidermal growth factors, fibroblast growth factors, transforming growth factor–β, platelet-derived growth factor, vascular endothelial growth factor (VEGF), tumor necrosis factor–α (TNF-α), interleukin-1 (IL-1), IGF-1, granulocyte colony-stimulating factor, and granulocyte-macrophage colony-stimulating factor.[171] Some of these cytokines have direct effects early in the healing process; others are bound locally and play critical roles in later healing phases. The use of specific cytokines to reverse healing deficits or promote wound healing appears to be a promising clinical tool and is currently the subject of ongoing basic scientific and clinical research.[172]

The coagulation cascade also contributes to hemostasis. The extrinsic pathway is essential to hemostasis and is stimulated by the release of tissue factor from injured tissue; the intrinsic cascade is not essential and is triggered by exposure to factor XII. Both coagulation pathways lead to the generation of fibrin, which acts with platelets to form a clot in the injured area [*see 1:4 Bleeding and Transfusion*]. Fibrin both contributes to hemostasis and is the primary component of the provisional matrix [*see* Migratory and Proliferative Phase, Provisional Matrix Formation, *below*].

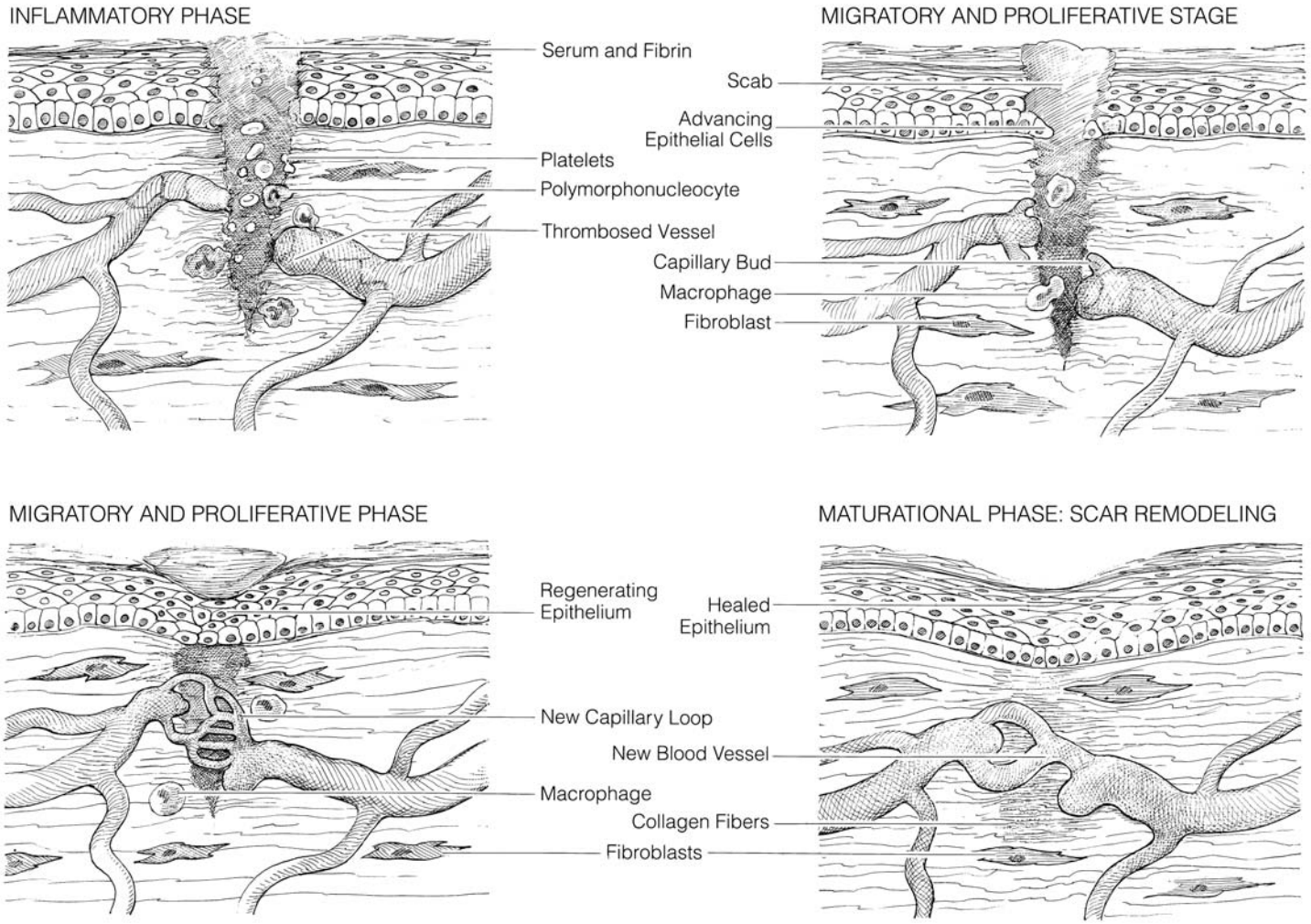


Figure 3 **Depicted are the phases of wound healing. In the inflammatory phase (top, left), platelets adhere to collagen exposed by damage to blood vessels to form a plug. The intrinsic and extrinsic pathways of the coagulation cascade generate fibrin, which combines with platelets to form a clot in the injured area. Initial local vasoconstriction is followed by vasodilatation mediated by histamine, prostaglandins, serotonin, and kinins. Neutrophils are the predominant inflammatory cells (a polymorphonucleocyte is shown here). In the migratory and proliferative phase (top, right; bottom, left), fibrin and fibronectin are the primary components of the provisional extracellular matrix. Macrophages, fibroblasts, and other mesenchymal cells migrate into the wound area. Gradually, macrophages replace neutrophils as the predominant inflammatory cells. Angiogenic factors induce the development of new blood vessels as capillaries. Epithelial cells advance across the wound bed. Wound tensile strength increases as collagen produced by fibroblasts replaces fibrin. Myofibroblasts induce wound contraction. In the maturational phase (bottom, right), scar remodeling occurs. The overall level of collagen in the wound plateaus; old collagen is broken down as new collagen is produced. The number of cross-links between collagen molecules increases, and the new collagen fibers are aligned so as to yield an increase in wound tensile strength.**

Vasoconstriction and hemostasis are followed by vasodilatation, which is associated with the characteristic signs of erythema, edema, heat, and pain. Vasodilatation is mediated by prostaglandins (e.g., PGE_2 and PGI_2 [prostacyclin]), histamine, serotonin, and kinins.[173,174] As the blood vessels dilate, the endothelial cells separate from one another, thereby increasing vascular permeability. Inflammatory cells initially roll along the endothelial cell lining, subsequently undergo integrin-mediated adhesion, and finally transmigrate into the extravascular space.[175]

For the first 48 to 72 hours after wounding, neutrophils are the predominant inflammatory cells in the wound. About 48 to 96 hours after wounding, however, monocytes migrate from nearby tissue and blood and transform into macrophages, and eventually, macrophages become the predominant inflammatory cells in the wound. Both neutrophils and macrophages engulf damaged tissue and bacteria and digest them. After neutrophils phagocytose damaged material, they cease to function and often release lysosomal contents, which can contribute to tissue damage and a prolonged inflammatory response. Macrophages, however, are essential to wound healing and do not cease to function after phagocytosing bacteria or damaged material.[176] In the wound environment, macrophages also secrete collagenase, elastase, and matrix metalloproteinases (MMPs) that break down damaged tissue. Macrophages also produce cytokines that mediate wound-healing processes, as well as IL-1 (which can lead to a systemic response, including fever) and TNF-α.[171]

MIGRATORY AND PROLIFERATIVE PHASE

The migratory and proliferative phase is marked by the attraction of epidermal cells, fibroblasts, and endothelial cells to the

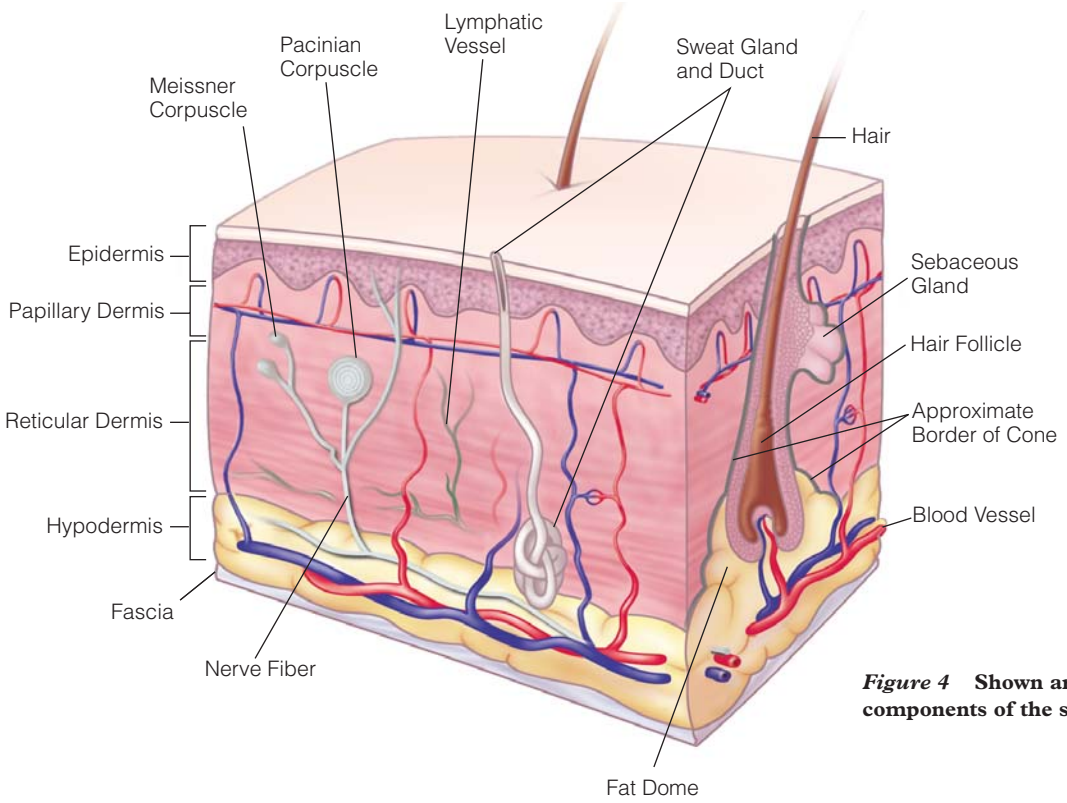


Figure 4 **Shown are the key anatomic components of the skin.**

wound. Cells migrate along the scaffolding of fibrin and fibronectin. This process involves the upregulation of integrin receptor sites on the cell membranes, which allows the cells to bind at different sites in the matrix and pull themselves through the scaffolding. Migration through the provisional matrix is facilitated by proteolytic enzymes. Cytokines and growth factors then stimulate the proliferation of these cells.[171,176]

Epithelialization

Within approximately 24 hours of injury, epidermal cells from the wound margin and skin appendages begin to migrate into the wound bed. These migrating epidermal cells dissect the wound, separating desiccated eschar from viable tissue.[80] At 24 to 48 hours after wounding, epidermal cells at the wound margin begin to proliferate, producing more migrating cells.[171] As epidermal migration is initiated, the desmosomes that link epidermal cells together and the hemidesmosomes that link the epidermal cells to the basement membrane disappear.[177] Migrating epidermal cells express integrin receptors that allow interaction with extracellular matrix proteins, laminin, collagen, and fibrin clot.[178] When epidermal cells migrating from two areas meet, contact inhibition prevents further migration. The cells making up the epidermal monolayer then differentiate, divide, and form a multilayer epidermis.

Provisional Matrix Formation

Formation of the provisional matrix and granulation tissue begins approximately 3 to 4 days after wounding. Fibroblasts synthesize an extracellular matrix of fibrin, fibronectin, and proteoglycans that supports epidermal and endothelial cell migration and proliferation.[178,179] Proteoglycans (e.g., dermatan sulfate, heparin, heparan sulfate, keratan sulfate, and hyaluronic acid) consist of a protein core that is linked to one or more glycosaminoglycans; they anchor proteins and facilitate the alignment of collagen into fibrils.

Fibrin becomes coated with vitronectin and fibronectin, which are glycoproteins that facilitate the adhesion of migrating fibroblasts and other cells to the provisional extracellular matrix.[180] By influencing cellular attachment, fibronectin helps modulate cell migration into the wound.[181] In addition, the fibrin-fibronectin lattice binds various cytokines that are released at the time of injury and serves as a reservoir for these factors in the later stages of healing.[182]

Fibroblasts then replace the provisional extracellular matrix with a collagen matrix, and the wound gains strength. The rate of collagen synthesis increases greatly after the initial 3 to 5 days and continues at an increased rate for 21 days before gradually declining.[183] Of the many types of collagen, the ones that are of primary importance in the skin are types I and III. Approximately 80% to 90% of the collagen in the skin is type I collagen; the remaining 10% to 20% is type III. The percentage of type III collagen is higher in embryonic skin and in skin that is in the early stages of wound healing.

Collagen molecules are synthesized by fibroblasts. Lysine and proline residues within the collagen molecule become hydroxylated after being incorporated into polypeptide chains. This process requires specific enzymes, as well as various cofactors (i.e., oxygen, vitamin C, α-ketoglutarate, and ferrous iron). The result is procollagen, which is released into the extracellular space. Individual collagen molecules then align and associate with one another to form fibrils. Covalent cross-links form between various combinations of the hydroxylated residues (lysine and hydroxylysine) in aligned collagen fibrils, with the strongest links occurring between hydroxylysine and hydroxylysine. These cross-links are essential to the tensile strength of the wound. Cofactor deficiencies (e.g., vitamin C deficiency in scurvy) and the use of corticosteroids can lead to the synthesis of weak, underhydroxylated collagen that is incapable of generating strong cross-links.

Angiogenesis

The growth of new blood vessels, which is necessary to support the wound tissue, begins 2 to 3 days after wounding. This process of angiogenesis may be stimulated by the hypoxic and acidic

wound microenvironment, as well as by cytokines (e.g., VEGF) derived from epidermal cells and macrophages.[171,184] Endothelial cells from surrounding vessels express fibronectin receptors and grow into the provisional matrix. These migrating endothelial cells create paths in the matrix for developing capillaries by releasing plasminogen activator, procollagenase, heparanase, and MMPs, which break down fibrin and basement membranes.[171,185] The budding capillaries join and initiate blood flow. As the wounded area becomes better vascularized, the capillaries consolidate to form larger blood vessels or undergo apoptosis.[186]

MATURATIONAL PHASE

Wound Contraction

Myofibroblasts are specialized fibroblasts containing alpha–smooth muscle actin microfilaments that contribute to wound contraction.[187,188] The wound edges are pulled together by the contractile forces supplied by the myofibroblast. Wound contraction generally begins in the 4- to 5-day period after wounding and continues for 12 to 15 days or until the wound edges meet. The rate at which contraction occurs varies with the laxity of the tissue and is highest at anatomic sites with redundant tissue. Excessive contraction can lead to contracture, a pathologic scarring that impairs the function and appearance of the scar.

Scar Remodeling

Collagen remodeling begins approximately 3 weeks after wounding. Collagen synthesis is downregulated, the rates at which collagen is synthesized and broken down reach equilibrium, and the wound becomes less cellular as apoptosis occurs. During this process, the extracellular matrix, including collagen, is continually remodeled and synthesized in a more organized fashion along stress lines.[183] Collagen breakdown is mediated by MMPs.[189] The number of cross-links between collagen fibers increases,[183] and the realigned, highly cross-linked collagen is much stronger than the collagen produced during the earlier phases of healing. The tensile strength of the wound increases rapidly for 6 weeks after injury; accordingly, during this period, heavy lifting and any other activity that applies stress across the wound should be avoided. After the initial 6 weeks, tensile strength increases more slowly for a further 6 to 12 months, though it never reaches the tensile strength of unwounded tissue [*see Figure 2*].

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Figures 1 and 4 Thom Graves.
Figure 2 Janet Betries.
Figure 3 Carol Donner.