Current Concepts in Wound Management and Wound Healing Products

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KEYWORDS

• Wound management • Wound products • Moist wound healing • Bandaging
• Autolytic debridement

KEY POINTS

- Autolytic debridement is a type of selective debridement in which the body's own immune system removes unhealthy tissue and contaminants.
- The contact layer of the bandage can be used to maintain a moist wound environment, which can promote autolytic debridement and wound healing.
- Selection of the most appropriate contact layer is based on the stage of wound healing and the amount of exudate being produced.

INTRODUCTION

Open wounds must often be managed for days to weeks until they can be closed or they heal by second intention. Most wounds will heal without complications. Basic wound care incorporates the principles of aseptic technique and gentle tissue handling. In addition, many wound care products are available that will potentially debride the wound without damaging healthy tissue, reduce infection, and improve the rate of wound healing. This article is an overview of some of the current wound dressings, topical products, and modalities used in the management of open wounds.

INITIAL MANAGEMENT

Care of traumatic wounds may begin immediately after wounding by covering the wound with a clean, dry bandage to prevent further contamination and reduce hemorrhage (**Box 1**). A bandage also stabilizes the tissues to reduce further trauma and improve comfort. Potentially life-threatening conditions should be addressed before performing detailed wound management. Thorough wound assessment may require

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Box 1
Initial wound management

- Cover wound with clean bandage
- Address potentially life-threatening conditions (eg, shock)
- Sedate or anesthetize when patient is stable
- Cover wound surface with sterile, water-soluble gel
- Surgically clip hair with wide margin around wound for bandage to adhere well
- Irrigate the wound with balanced electrolyte solution, avoiding high pressure
- Consider surgical debridement, but avoid if there is any question
- Bandage with a semiocclusive dressing

sedation or general anesthesia, which may need to be delayed until patients have been stabilized. Definitive wound management should begin as soon as patients are stable. The skin adjacent to an open wound should be prepared as for aseptic surgery. However, the surgical scrub detergents are cytotoxic and should not be allowed to contact the wound surface. Whenever the wound is uncovered, the principles of strict aseptic technique should be followed. At a minimum, involved personnel should wear surgical masks and sterile gloves to avoid further contaminating the wound, particularly in the early stages of healing.

DEBRIDEMENT

The focus of initial wound care is to reduce the presence of foreign material, bacterial load, and damaged or necrotic tissue. The presence of these substances can provide a focus for infection, prolong the inflammatory phase of healing, and impede wound contraction and epithelialization. If a wound is minimally contaminated and has healthy tissue, it may be closed after cleaning. If the wound has gross contamination, foreign material, severely damaged tissue, or loss of soft tissues, management as an open wound may be required. The wound may be allowed to heal by second intention or may be closed surgically (as primary closure or by use of grafts or flaps) once the wound bed is composed of healthy, uninfected tissue.

Debridement may be selective or nonselective. Selective debridement generally involves the use of endogenous or exogenous enzymes to remove only debris or damaged tissue while leaving healthy tissue intact. In contrast, during nonselective debridement, some healthy tissue is inadvertently removed along with the necrotic tissue and debris. Nonselective debridement involves physical removal of tissue and debris and is also referred to as mechanical debridement (**Table 1**).

NONSELECTIVE DEBRIDEMENT

Wound Irrigation

Mechanical debridement may be used to clean the wound bed, with the most common method being wound irrigation. The purpose of wound irrigation is to mechanically flush away surface bacteria, foreign material, and necrotic debris. Although it is a nonselective type of debridement, it will not damage healthy tissues if appropriate irrigation solutions and pressures are used. There is no strong evidence that cleansing wounds increases healing or reduces infection, but it is almost universally recommended.[1,2]

Table 1
Methods of nonselective (mechanical) wound debridement

Method of Debridement	Advantages	Disadvantages	Indications
Irrigation	There is rapid removal of surface exudate and contaminants. Tissue damage is minimal if done properly.	Hypotonic or cytotoxic solutions can damage tissue. High-pressure irrigation can damage tissue or force contaminants into deeper tissue layers. It will not remove embedded contaminants or attached necrotic tissue.	It is used to remove wound contaminants. Lavage with copious amounts of fluid is most appropriate in the first few days of wound management.
Surgical excision	It can quickly remove large amounts of necrotic tissue and debris.	Accurate assessment of tissue viability is not always possible. Some viable tissue will likely be removed. Excision may be limited by adjacent structures, (eg, nerves, arteries and tendons) that must be preserved for function.	It is used to remove large areas of obviously necrotic tissue. It is used to remove contaminants that are large enough to be grasped with thumb forceps.
Adherent bandage (eg, wet-to-dry or dry-to-dry)	—	It will remove and/or damage viable tissue. It is uncomfortable for patients to wear. Bandage removal is painful.	It is not recommended.

Balanced electrolyte solutions are preferred for use in wound irrigation (**Table 2**). Tap water is acceptable for the initial wound irrigation, although the hypotonic nature of tap water can cause cell destruction.[3] Antibiotics or antiseptics may be added to the lavage solution. If antiseptics are used, the solution must be created with sufficient dilution in order to minimize tissue injury.[4] No one type of fluid has been shown to be superior in preventing wound infection, and there is some question as to the importance of wound irrigation as a means to reduce infection.[2,5]

A 0.05% chlorhexidine diacetate solution is created using one part of a 2% stock solution to 40 parts of an isotonic fluid, which is equivalent to approximately 25 mL of stock antiseptic solution into 1 L of a balanced electrolyte solution. Chlorhexidine forms precipitate in electrolyte solutions, but this does not reduce its effectiveness.[6] More potent solutions may be cytotoxic and delay granulation tissue formation. Chlorhexidine solution has a broad spectrum of activity, with residual activity, and is not inactivated by organic matter.[7,8]

An alternative solution is 0.1% povidone-iodine solution, which is created by combining 1 part 10% stock solution with 100 parts of an isotonic fluid. This amount

Table 2
Irrigation solutions

Type of Fluid	Examples	Indications
Isotonic fluids	Balanced electrolyte solutions: Lactated Ringer solution Normosol-R (Hospira, Inc, Lake Forest, IL) Plasma-Lyte (Baxter Healthcare Corporation, Deerfield, IL) Unbalanced electrolyte solution: Normal (0.9%) saline	A balanced electrolyte fluid is preferred.
Hypotonic fluids	Tap water Distilled water	Tap water is acceptable for wound irrigation, although it has some cytotoxic effects; prolonged use may delay wound healing. Distilled water is not recommended.
Antiseptic irrigation solutions	0.05% Chlorhexidine diacetate (~25 mL of stock solution per liter of balanced electrolyte solution) 0.1% Povidone-iodine (~10 mL of stock solution per 100 mL of balanced electrolyte solution) 0.01% Chlorhexidine gluconate with tris-EDTA solution	Chlorhexidine diacetate and povidone-iodine solutions must be properly diluted to avoid cytotoxicity. These fluids primarily work by their mechanical action and have no significant advantage over isotonic fluids. Tris-EDTA solution will greatly increase the antimicrobial effectiveness of the solution.
Other irrigation solutions	Hydrogen peroxide Dakin solution Acetic acid	All are cytotoxic. None are recommended.

Abbreviation: EDTA, ethylenediaminetetraacetic acid.

is equivalent to approximately 10 mL of stock antiseptic solution into 1000 mL of a balanced electrolyte solution. Povidone iodine has a wide spectrum of antimicrobial activity; but is inactivated by organic matter, such as blood or exudate. There is also a risk of contact sensitization with povidone iodine. The residual activity of povidone iodine is poor compared with chlorhexidine.[9]

Tris–ethylenediaminetetraacetic acid (EDTA) may be added to lavage solutions to help lyse gram-negative bacteria, such as *Pseudomonas aeruginosa, Escherichia coli*, and *Proteus vulgaris*, and may have synergistic effects with certain systemic antibiotics.[7] Tris-EDTA solution may be prepared by adding 1.2 g of EDTA and 6.05 g of tris to 1 L of sterile water. Then sodium is added until the pH is 8, and the solution is autoclaved for 15 minutes. This solution can be added to 0.01% chlorhexidine gluconate solution. Hydrogen peroxide, Dakin solution, and acetic acid all have poor antimicrobial activity, are cytotoxic, and are not recommended for use in open wounds.[10]

The ideal amount of pressure used to flush wounds has not been established. Very high pressures (70 psi), such as that produced by pulsatile lavage instruments, may drive contaminants and debris into loose tissue planes and damage the tissue, which could reduce tissue health and resistance to infection.[8] A common technique is to use a 35-mL syringe with an 18-gauge needle to generate 7 to 8 psi. Low-pressure irrigation can be done by flowing sterile fluid from a drip set spiked into a bag of sterile fluid or pouring fluid from a sterile bottle or by use of a bulb syringe. The level of pressure most appropriate for irrigation is unclear, and no one irrigation technique has been

shown to be superior.[11,12] Use of sponges to scrub wounds is not recommended because it will damage tissues, resulting in reduced ability to resist infection.

Surgical Debridement

Surgical debridement is indicated for removing large amounts of necrotic debris. Sterile instruments, electrosurgery, or surgical laser may be used for surgical debridement. Aseptic technique must be used to prevent iatrogenic contamination. Foreign debris that was not removed by wound irrigation may be removed with thumb forceps. Excessive removal of healthy tissue should be avoided because it may delay wound healing and make closure more difficult.

Tissue viability can be difficult to determine during the preliminary wound assessment, so initial tissue debridement should be conservative. Tissue that is obviously necrotic should be excised, but tissue with questionable viability should be reassessed at a later day (**Box 2**). Necrotic skin may be black, although normal pigmentation can obfuscate this assessment. Severe skin contusions may recover or may progress to necrosis. Lack of bleeding when the skin edge is cut may indicate congestion and does not consistently predict skin viability. Conversely, bleeding at the skin edge is no guarantee that the tissue will maintain viability over the first few days.

Debridement is begun in the superficial tissues and proceeds to the deeper tissue layers in a stepwise fashion. After excising any necrotic skin, the subcutaneous tissues are assessed for viability and managed accordingly. Subcutaneous tissue that is compromised and contaminated may be excised from the underlying skeletal muscle, taking care to avoid excising fat from the overlying skin. The extent of tissue necrosis is usually apparent within 24 to 48 hours after tissue injury, so repeated debridement may be done as the extent of tissue necrosis becomes more apparent. When managing an open wound, surgical debridement is often done in conjunction with some type of selective debridement (eg, bandages to promote autolytic debridement) to completely rid the wound of contaminants and devitalized tissue.

Gauze Sponges

Mechanical debridement may be accomplished by the use of dry-to-dry or wet-to-dry bandages. A dry-to-dry bandage is applied by placing dry gauze sponges on the wound surface. The sponges absorb serous discharge from the wound and then dry, so tissue and debris on the surface of the wound are physically removed when the bandage is pulled away from the wound. A wet-to-dry bandage is similar, except the gauze sponges contacting the wound surface are moistened to help reduce the viscosity of wound fluid to promote absorption of exudate into the bandage. The gauze dries by the time of bandage removal, which results in adherence to the wound surface and nonselective debridement of tissue and debris as the gauze is removed.

Box 2
Reassess wound

- Sedate or anesthetize patients.
- Involved personnel should wear surgical masks to avoid wound contamination.
- Remove the bandage and clip more hair if needed to keep the wound clean and promote bandage adherence.
- Irrigate to remove any exudate, if it is present.
- Reassess the tissue viability, and surgically debride if necessary.

An unfortunate consequence is removal of some healthy tissue and destruction of epithelial cells. The adherent nature of wet-to-dry and dry-to-dry bandages makes them painful to remove. The open weave of the gauze sponges allows fibers to become embedded in the wound, causing patient discomfort.[13] These gauze bandages also promote dehydration of the wound surface, which results in delayed wound healing.[13,14] In addition, these bandages generally need to be changed 1 to 3 times daily.

Although wet-to-dry and dry-to-dry bandaging were commonly used for wound care in the past, bandaging techniques that use selective debridement are now recommended. Advances in bandage products enable the bandage dressing to maintain a moist wound environment, which results in selective autolytic debridement.[14] These advanced dressings also allow effective gas exchange, enabling improved wound metabolism. In addition, newer bandage materials are more comfortable for patients and require less frequent bandage changes. Healing of chronic wounds has been demonstrated to be superior when advanced dressings are used.[15] Thus, the use of wet-to-dry and dry-to-dry bandages is no longer recommended.

SELECTIVE DEBRIDEMENT

Enzymatic Debridement

Enzymatic debriding agents can be applied to the wound surface to selectively destroy necrotic tissue and liquefy coagulum and bacterial biofilm (**Table 3**). This enzymatic effect allows antibiotics and components of the immune system better access to tissues that are compromised or infected. Enzymatic debridement may be used instead of surgical debridement when patients have a poor anesthetic risk or other surgical contraindication and may also be used as an adjunct to surgical debridement when excision could potentially compromise healthy tissues that must be preserved for adequate reconstruction or functional outcome.

Enzymatic agents are available as ointments or gels containing streptokinase, trypsin, fibrinolysin, protease, or collagenase.[16] Enzymatic debridement can be slow and expensive. Its use may be limited in the treatment of large areas. Ideally, enzymatic debridement is selective and occurs without pain or bleeding. However, it can damage or dehydrate normal tissue. Enzymatic debridement can cause collagenase and fibrinolysin to inhibit the cellular products needed for wound repair, thus delaying wound healing.[16] In addition, enzymes should be contained within the wound bed because persistent contact with adjacent healthy tissues will result in maceration. The enzyme preparation should be covered by a nonadherent dressing, which should typically be changed in 12 to 24 hours.

Biosurgical Debridement

Medical maggots may be used to debride wounds that are necrotic or infected and are particularly useful when effective surgical debridement is not possible.[17,18] Sterile maggots are bred specifically for this purpose using greenbottle fly (*Phaenicia sericata or Lucilia sericata*) larvae. The maggots secrete proteolytic digestive enzymes into the wound and consume up to 75 mg of necrotic tissue per day.[7] This species of maggots will not damage healthy dermis or subcutaneous tissue, although they can destroy healthy epithelium. Maggots have the potential to lyse bacteria, including methicillin-resistant *Staphylococcus aureus*. Biosurgical debridement does not cause bleeding and is associated with minimal or no pain.

Maggots require a certain temperature, oxygen supply, and a moist wound surface, which can be achieved with a cage dressing. A wound dressing, such as a

Table 3
Methods of selective wound debridement

Method of Debridement	Advantages	Disadvantages	Indications
Enzymatic agents (ointments or gels) Accuzyme (Healthpoint Ltd, Blackpool, England) Granulex (Pfizer, New York City, NY) Collagenase Santyl (Smith & Nephew, London, England)	Minimal tissue damage if done properly Not painful Selective debridement	Slow process May be expensive Can damage normal tissue with prolonged contact Not practical for large wounds	Use instead of surgical debridement, when risk of anesthesia is high Use in regions where surgical excision has risk of compromising healthy structures that are needed for wound reconstruction or functional outcome
Biosurgical Medical maggots (Monarch Labs, Irvine, CA)	Can destroy bacteria Usually nonpainful Selective debridement	Must buy or create cage dressing to contain maggots Can be uncomfortable in some wounds	Same indications as for enzymatic agents
Autolytic debridement (maintain moist wound environment with bandage)	Destroys bacteria Does not damage healthy tissue Bandage not painful or pruritic No pain with bandage removal Infrequent bandage changes Selective debridement	Variety of products available confusing	Any open wound Can be used after wound irrigation or surgical debridement

hydrocolloid, is used to absorb wound secretions at the perimeters of the wound. Maggots are applied directly on the wound at a density of 5 to 8 per square centimeter.[19] The maggots are contained within the wound by lightly covering them with gauze and Dacron chiffon mesh or nylon stocking. Maggots are generally removed within 48 to 72 hours and replaced if needed.

Autolytic Debridement

Autolytic debridement is optimal because healthy tissue is spared. Autolytic debridement occurs when a moist environment is maintained at the wound surface. This moisture allows normal cellular processes to destroy bacteria and remove or repair damaged tissue. Autolytic debridement is promoted by using hydrophilic, occlusive, or semiocclusive bandages, which allow some wound exudate to remain in contact with the wound surface and keep it moist. Wound exudate contains endogenous enzymes, growth factors, and cytokines that stimulate angiogenesis, granulation tissue formation, and epithelialization. White blood cells migrate more readily in a moist environment, so phagocytosis of necrotic debris and bacteria is improved. If patients are receiving systemic antibiotics, they will be present in the wound exudate, helping to prevent or control infection.[8] Bandages also keep the wound surface warm, which enhances enzymatic activity. Moist wounds are less painful and less pruritic than wounds that are allowed to become dry.

Oxygen delivery is important for aerobic metabolism and is needed for formation of granulation tissue, fibroblast formation, wound contraction, and epithelialization. Thus, semiocclusive bandages are generally desirable because they allow gaseous exchange of water and air.

Proper wound preparation is needed to create an optimal environment for autolytic debridement. Autolytic debridement may be inhibited by the presence of large amounts of necrotic tissue. Surgical debridement may be indicated before bandaging if gross contamination or large areas of necrotic tissue are identified. Wound irrigation may be indicated to remove excessive wound exudation and surface contaminants.

An appropriate bandage is required to maintain a moist wound environment that enables autolytic debridement. A moist wound surface is desirable, but the presence of excessive amounts of exudate can separate tissue layers to delay healing.[8] Therefore, wound dressings should absorb excessive exudates, without dehydrating the wound surface. Bandaging the wound also helps maintain normal tissue temperatures, which improves wound blood flow and cellular functions.

The principle of moist wound healing is put into practice by the use of hydrophilic dressings (**Box 3**). The rate of wound exudation often dictates selection of the most

Box 3
Types of hydrophilic dressings: promote moist wound environment and autolytic debridement

- Calcium alginate
- Polyurethane foam
- Hydrogel
- Hydrocolloid
- Hydrofiber
- Some topical products (eg, maltodextrin, collagen)

appropriate primary layer of the wound bandage. A wound with minimal exudate may benefit from some form of a hydrogel dressing, which can provide moisture to the wound and maintain a thin film of fluid on the wound surface. For a mild to moderately exudative wound, a hydrocolloid or foam may be more appropriate. These dressings are dry on contact but absorb wound exudate to form a gelatinous layer at the wound surface. Heavily exudative wounds may be dressed with alginate, which absorb copious secretions. Some of these dressings are also available with antimicrobial agents impregnated. Dressings should be maintained by a semiocclusive covering to allow exchange of gases. The bandage dressing should be sterile and applied using aseptic technique. This practice is particularly important before the formation of granulation tissue, when the wound is most susceptible to infection.

ANTIMICROBIALS

Bacterial infection can delay wound healing, so clinically relevant infections should be avoided or eliminated. Most traumatic wounds heal normally without prophylactic antimicrobial treatment. Wounds may be contaminated with microorganisms that are cultured from swabs of the wound surface or exudate, but this is not necessarily a clinical problem.[20] There is debate regarding the use of antibiotics and antiseptics in the treatment of nonhealing wounds that have no clinical signs of infection.[21] Diagnosis of wound infection should be based on culture and sensitivity of samples taken from the deep wound tissue, and these results should inform selection of systemic antibiotics.[20]

There is no consensus regarding when and how infected wounds should be treated. Systemic antimicrobial therapy is indicated for advancing cutaneous infections or infections involving the deeper tissues.[21] Treatment with an antimicrobial that has a narrow spectrum of activity is preferred because prolonged administration of broad-spectrum antibiotics will favor the proliferation of more resistant organisms. Systemic antimicrobial therapy can usually be discontinued once healthy granulation tissue is present, partly because penetration into chronic granulation tissue is limited.[22] Wounds that only have localized signs of infection may be treated by topical methods alone. These methods may include antimicrobial products and antimicrobial bandage dressings, along with bandaging methods to promote moist wound healing. The use of modalities such as hyperbaric oxygen therapy, electrical stimulation, or laser therapy may also be considered.

TOPICAL PRODUCTS

Many topical products are advocated to enhance wound healing (**Table 4**). Most wounds will heal well using basic wound care techniques with proper bandage application. However, various topical products may be considered for patients with chronic, nonhealing wounds or when factors are present that may delay wound healing (**Box 4**). After applying a topical product, a bandage is applied to cover the wound and maintain the product on the wound surface. There is not sufficient evidence in the veterinary literature to make recommendations for or against various topical wound products.[10]

Topical Antimicrobials

Topical treatment with antiseptics, silver-based dressings, hyperosmotic dressings, and other dressings that support autolytic debridement provide broad-spectrum reduction in microbial burden. Additional topical agents may be used early in wound management to reduce contaminating microbes and are preferred over systemic

Table 4
Topical products

Agent	Products Available	Comments
Antibiotics	Triple antibiotic ointment Neosporin (Johnson & Johnson, New Brunswick, NJ) Silver sulfadiazine cream Thermazene cream (Covidien, Minneapolis, MN) Nitrofurazone cream/ointment Gentamycin ointment	Most products have a broad spectrum and may be used in combination with systemic antibiotics. Ointments may prevent tissue desiccation. Some products may delay wound contraction and/or epithelialization.
Tripeptide-copper complex	Iamin hydrating gel (ProCyte, Redmond, WA)	It stimulates granulation tissue in chronic wounds.
Maltodextrin	Maltodextrin gel or powder Multidex (DeRoyal, Powell, TN)	It creates a layer on the wound surface that promotes a moist wound environment. It has antibacterial properties. It promotes autolytic debridement.
Acemannan	Acemannan gel or freeze-dried powder CarraVet gel (CarraVet, Palmetto, GA)	It stimulates early wound healing. It can promote excessive granulation tissue, which inhibits wound contraction.
Aloe vera	Included in commercial lotions and ointments	Antithromboxane and antiprostaglandin properties benefit superficial inflammation (eg, burns). It may not benefit an open wound.
Growth factors	Available in gels or dressings Regranex (Smith & Nephew, London, England)	It stimulates granulation tissue. The use of a single growth factor has questionable value but may benefit a chronic nonhealing wound.
Platelet-rich plasma	Plasma concentrates	It may stimulate chronic wound healing. There is limited evidence, so its use is controversial.

Chitosan	Impregnated in bandage dressing: HemCon bandages (HemCon Medical Technologies, Inc, Portland, OR) Opticell (Medline Industries, Inc, Mundelein, IL)	It enhances the function of inflammatory cells, fibroblasts, and cytokines to stimulate granulation tissue. It is hemostatic.
Collagen	Bovine collagen gel, powder, sheet or sponge Woun'Dres Collagen Hydrogel (Coloplast, Minneapolis, MN) Medifil Collagen particles (Human Biosciences, Inc, Gaithersburg, MD) Puracol Collagen (Medline Industries, Inc) Collasate (PRN Pharmacal, Pensacola, FL) Biostep Collagen Matrix (Smith & Nephew) Fibracol Plus (Systagenix, San Antonio, TX)	It absorbs fluid from highly exudative wounds and maintains a moist wound surface. It promotes autolytic debridement. It provides scaffold for extracellular matrix.
Honey	Raw honey or impregnated in bandage dressing Medihoney (Derma Sciences, Princeton, NJ) TheraHoney sheet (Medline Industries, Inc) TheraHoney foam (Medline Industries, Inc) TheraHoney gel (Medline Industries, Inc)	The hyperosmotic effect dehydrates microorganisms and reduces tissue edema. It is antimicrobial. It stimulates granulation tissue. It is appropriate until granulation tissue is present. The bandage may need frequent changing with a highly exudative wound. Honey bandages may be painful.
Sugar	Granulated sugar	The hyperosmotic effect dehydrates microorganisms. It stimulates tissue granulation tissue but is less effective than honey. The bandage may need to be changed up to 3 times daily. Sugar bandages may be painful.

Box 4
Factors that contribute to delayed wound healing

- Host factors
  - Malnourishment
  - Geriatric
  - Hepatic disease
  - Hyperadrenocorticism
  - Diabetes mellitus
  - Uremia
  - Obesity
- Wound factors
  - Foreign material
  - Infection
  - Antiseptics
  - Lack of warmth
  - Excessive exudate
  - Tissue desiccation
  - Impaired blood supply
- Extrinsic factors
  - Radiation therapy
  - Some chemotherapy
  - Corticosteroids

antibiotics. Potential benefits of topical drugs should outweigh their potential cytotoxic effects. A variety of topical antimicrobial agents are available.

A triple antibiotic ointment, containing bacitracin zinc, neomycin sulfate, and polymyxin B sulfate, may be used for a broad-spectrum antimicrobial effect to prevent infection of mildly contaminated wounds. It is not cytotoxic and may enhance wound epithelialization by promoting a moist wound surface, although it may delay wound contraction.[7]

Silver sulfadiazine ointment has been used on burn wounds because of its antibacterial and antifungal effects. However, in a study of partial-thickness burn wounds in people, honey dressings seemed to be superior to silver sulfadiazine ointment.[23] Silver-impregnated dressings may be a better choice than silver sulfadiazine ointment because the dressings are associated with less pain and less frequent bandage changes.[24]

Nitrofurazone has broad-spectrum activity but little effect against *Pseudomonas spp*. Nitrofurazone delays epithelialization,[25] and it has reduced the antibacterial effect in the presence of organic matter.

Gentamicin sulfate is effective against gram-negative bacteria and *Staphylococcus* spp. It is applied as an oil-in-water cream that may inhibit wound contraction and epithelialization.[25,26] However, gentamicin in an isotonic solution does not inhibit contraction and promotes epithelialization.

Tripeptide-Copper Complex

Tripeptide-copper complex has been reported to stimulate neovascularization, collagen deposition, wound contraction, and epithelialization. It may be used in the late inflammatory and early repair phase to stimulate granulation tissue and may be appropriate to stimulate healing of chronic, ischemic open wounds.[27]

Maltodextrin

Maltodextrin is a D-glucose polysaccharide derived from hydrolysis of corn or potato starch. Hydrolysis of maltodextrin may provide a source of glucose to the cells.[8] Maltodextrin may be used to promote healing of slow-healing, infected wounds. It is available in powder or gel form, and it absorbs moisture to form a protective layer on the wound surface to promote a moist wound environment. Maltodextrin reportedly attracts white blood cells and cytokines into the wound and may enhance early granulation tissue formation and epithelialization.[7] It also has antibacterial properties.[7] Maltodextrin must be flushed from the wound surface before reapplication during daily bandage changes.

Acemannan

Acemannan is derived from the aloe vera plant.[28] It is available as a topical wound hydrogel or freeze-dried gel form. Acemannan has hydrophilic properties that promote a moist wound environment. It enhances the early stages of wound healing by serving as a growth factor and increasing cytokine levels. Acemannan stimulates macrophages, angiogenesis, and epidermal growth but can also cause excess granulation tissue, which inhibits wound contraction.[7,8]

Growth Factors

Growth factors are naturally occurring hormones that cause cellular growth and regulate the wound healing process. Platelet-derived growth factor is available as a gel, and epidermal growth factor has been incorporated in a wound dressing.[29] Because the healing process is dynamic and complex, involving multiple endogenous factors at various times, application of a single growth factor is of questionable value.[8]

Platelet-Derived Products

Platelets are a good source of complex growth factors. Commercial products are available that allow veterinarians to harvest and concentrate platelets to produce platelet-rich plasma (PRP). The use of PRP has been shown to enhance fibroblast proliferation and migration and accelerate epithelial differentiation. Gel created from PRP enhanced wound epithelialization in an equine model.[30] It also resulted in faster healing of chronic decubital ulcers in dogs as compared with paraffin-impregnated gauze.[31] Application of autologous PRP gel did not improve wound healing in another equine study.[32] There is currently a lack of evidence to support the use of PRP in chronic wounds in humans.[33] The use of PRP in clinical or contaminated wounds has not been fully evaluated, and its use remains controversial.

Chitosan

Chitosan is a natural biopolymer that is derived from chitin in the exoskeleton of shellfish. It is thought to promote various aspects of wound healing by upregulation of growth factors.[34] Chitosan is biodegradable, biocompatible, nontoxic, nonantigenic, and antimicrobial.[35] It may also be used to help achieve hemostasis following surgical debridement. Fatal hemorrhagic pneumonia has been reported in dogs that were

administered more than 50 mg/kg subcutaneously. Various wound products contain chitosan embedded in the dressing.[36]

Collagen

Collagen products are available in sheet, powder, or sponge form. Collagen is hydrophilic, which helps maintain a moist wound environment for autolytic debridement[37]; it may also provide substrate for fibroblasts. Collagen also has hemostatic properties, so may be used after surgical debridement. Collagen can serve as a scaffold to facilitate wound healing, with the collagen fibrils providing a network for fibroblast migration.[7] Collagen has been used to promote granulation and epithelialization, particularly in chronic wounds with delayed healing.

Honey

Honey is available as raw honey in tubes or jars or impregnated in dressings. Honey enhances wound debridement, reduces edema and inflammation, and promotes granulation tissue formation and epithelialization.[7] It accelerates collagen maturation and maintains optimal pH conditions for fibroblast activity. Honey is purported to contain amino acids, vitamins, sugars, and trace elements that stimulate tissue growth.[8] Honey has an osmotic effect that dehydrates microorganisms, but the antimicrobial effects of honey cannot be explained by hyperosmolality alone. Low pH, phytochemicals, and the release of small amounts of hydrogen peroxide and methylglyoxal also contribute to its antimicrobial properties.[38,39] Because honey is a natural product, its effectiveness may vary with the source of the product and the processing methods used. Therefore, use of medicinal honey is recommended; medical-grade honey is rated according to its antimicrobial properties. Manuka honey, derived from the flowers of the tea tree, is considered to be the most effective honey.[7]

Honey dressings may be used in the inflammatory and early repair phases of healing and is discontinued when debridement is complete and healthy granulation tissue is present.[8] Gauze soaked in honey may be used as a primary bandage layer. The osmotic action of the honey draws fluid from the tissues, which may be painful. A honey-soaked gauze dressing may need to be replaced 1 to 3 times daily for highly exudative wounds because the exudate will dilute the honey and diminish its osmotic effects. If the wound produces a small amount of exudate, the honey dressing may be changed in 1 to 3 days. Honey is water soluble, so it is flushed from the wound during dressing changes.

When using a honey-soaked gauze, the gauze may adhere to viable tissues, causing pain and irritation during removal. This effect may be avoided by adhering to the principles of moist wound healing and using commercial hydrophilic dressings that are impregnated with honey.

Sugar

Sugar has hypertonic effects similar to honey, which dehydrates microorganisms and inhibits their growth.[7] Sugar is primarily used during the inflammatory stage of wound healing. Sugar may also enhance granulation tissue formation and epithelialization but does not have the same inherent antiinflammatory and wound stimulation effects as honey.[8] Sugar is applied in a 1-cm thick layer on the wound surface and covered by an absorbent bandage.[7] Bandage changes are typically required 2 to 3 times daily to maintain the osmolality of the wound. Application of sugar is reportedly uncomfortable for some human patients. There are very few studies on the use of sugar in wound management; it has been advocated for use in human medicine in remote areas or disaster situations, when medical resources are limited.[40,41]

BANDAGING TO PROMOTE MOIST WOUND HEALING

Bandages are used to support the tissues, protect the wound from external trauma and contamination, and promote wound healing. In addition, the bandage can apply pressure to control hemorrhage or help obliterate dead space. The outer layers of the bandage function to absorb wound exudate, stabilize the tissue, and maintain the dressing in position over the wound. The portion of the bandage that contacts the wound is called the primary layer but may also be referred to as the dressing.

There are several advanced wound dressings, which interact with the wound surface to enhance healing.[13,20] The dressing may perform several functions, including absorption of wound exudate, transfer of exudate to the secondary layer, maintain a moist wound environment, facilitate wound debridement, deliver a product to promote healing, and reduce bacterial numbers. The most appropriate material for the primary layer varies with the stage of wound healing (**Table 5**) and the amount of exudate. No single dressing is suitable for all types of wounds, and there is no perfect dressing (**Box 5**). A hydrophilic dressing is one that attracts fluid and maintains a moist environment at the wound surface (see **Box 3**). Hydrophilic dressings should be made to fit completely within the wound bed to avoid maceration of adjacent skin.

Time between bandage changes depends on the type of dressing and the amount of wound exudate. For a noninfected wound, hydrophilic dressings generally need to

Table 5
Stages of wound healing

Stage or Phase	Approximate Time	Characteristics	Goal of Bandage
Inflammatory	0–5 d	Inflammatory cells eliminate contaminants and nonviable tissue. Platelets release growth factors to attract fibroblasts, which produce fibrin and collagen. Fluid extravasation may cause edema.	Maintain a moist wound environment to promote autolytic debridement. Protect the wound from external contaminants. Provide support to tissues.
Repair	5–21 d	Inflammatory cells and mediators diminish. Collagen and neovascularization form granulation tissue, which provides a barrier to infection. Epithelialization may begin once there is granulation tissue. Myofibroblasts in granulation tissue cause wound contraction.	Maintain a moist wound environment to stimulate granulation tissue, epithelialization, and wound contraction. Bandage may need to support tissues, depending on location and severity of tissue damage.
Maturation	21 d to weeks or months	Collagen reorganizes and forms cross-links to strengthen the tissue. Tissue structures are reformed.	Wound is typically no longer open and has contracted/epithelialized. Bandage is no longer needed, unless to support weakened tissues.

Box 5
Characteristics of an optimal wound dressing

- Maintains moist wound environment that supports selective autolytic debridement, granulation, epithelialization, and/or contraction
- Low adherence to wound surface
- Provides mechanical protection
- Requires infrequent changes
- Cost-efficient
- Provides thermal insulation
- Absorbs excess exudate and blood at wound surface
- Protects wound from external contaminants
- Adequate gaseous exchange
- Nontoxic, nonirritating
- Easy to change
- Conforms well to the wound surface

be changed every 2 to 3 days during the inflammatory stage and every 4 to 7 days during the repair phase. Dressing changes are needed more frequently in infected wounds than noninfected wounds. Each time the bandage is changed, the wound should be assessed to determine the most appropriate wound dressing (Table 6). If the dressing seems to have additional capacity to absorb exudate, the outer layers of the bandage may be changed without disturbing the dressing.

Nonadherent Dressings

Nonadherent dressings are most commonly used over a healthy wound or skin graft to enable bandage removal with minimal disruption of the underlying tissue. They may be composed of mesh fabric impregnated with paraffin or petrolatum. Another type of nonadherent dressing is composed of a thin layer of absorbent cotton fibers enclosed in a perforated plastic film. Both allow transfer of tissue fluids through the dressing to an overlying absorptive layer of the bandage and can speed the rate of wound epithelialization.[42–44]

Hypertonic Saline

Hypertonic dressings (20% saline-soaked sponges) use the osmotic gradient to lyse and destroy bacterial cells.[7] However, this may also destroy fibroblasts, thus slowing wound healing. The hyperosmotic effect removes exudate and accompanying debris from the wound and reduces surrounding tissue edema.[7] This same osmotic effect can dehydrate viable tissue if the dressing is left in place too long. Hypertonic saline dressings are indicated for necrotic, infected wounds with heavy exudates. The osmotic action desiccates bacteria and necrotic tissue.

Hydrogel

Hydrogel preparations are available as water- or glycerin-based amorphous gels, impregnated gauze, or sheet dressings. Hydrogels are hydrophilic, insoluble dressings made primarily from synthetic polymers. Hydrogels help maintain a moist wound environment that promotes debridement, granulation tissue, and epithelialization.[42]

Because of their high water content, they do not absorb large amounts of exudate; so they should be reserved for less exudative wounds. Hydrogels can also be used to rehydrate dry wound beds. They are nonadherent and provide some pain relief. Sheet dressings should be cut to the size of the open wound to prevent maceration of the skin at the wound edges. Hydrogel may be used to promote autolytic debridement during the inflammatory stage of wound healing and can also be used over granulation tissue to promote epithelialization and contraction.[8,14]

Foam Dressings

Foam dressings are composed of absorbent, nonirritating synthetic polymer, such as polyurethane foam. They create a moist environment to promote granulation and epithelialization.[14] Foam dressings provide thermal insulation to the wound. Foam dressings are nonadherent to the wound surface, but some products have adhesive borders that adhere to normal adjacent skin. Foam products vary in conformability and absorbency. However, foam products absorb light to heavy amounts of exudate; so they are most suited for highly exudative wounds. In wounds with minimal exudate, foam may be moistened before application. The dressing should be changed when absorbed fluid comes within 1 in of the foam edge.[45]

Hydrocolloid

Hydrocolloid dressings are occlusive or semiocclusive dressings composed of biocompatible hydrophilic polymers, such as carboxymethylcellulose with gelatins or pectin.[20] Hydrocolloid products are available as powders, pastes, or sheets. As the hydrocolloid absorbs wound exudate, it liquefies to form a viscous gel on the wound surface.[37] This gel provides a moist wound environment that enables autolytic debridement. The surrounding skin should be protected from hydrocolloid pads to prevent maceration. Hydrocolloids may contain an occlusive outer covering that prevents water vapor exchange between the wound and air; however, as the gel forms it becomes progressively more permeable. Hydrocolloids are primarily used for superficial wounds with minimal exudate to promote granulation or epithelialization.[20] Absorbency is low to moderate, depending on the composition of the product. Hydrocolloid pads contour easily, but their relative stiffness may impede wound contraction. Some hydrocolloid dressings have a self-adhering border and can be applied without a secondary dressing. However, adherence can be a problem in dogs and cats; so a light bandage may be needed to hold the hydrocolloid in place. Hydrocolloid sheets should be changed when the sheet feels like a fluid-filled blister. When changing the dressing, any gel is flushed from the wound surface before applying a new dressing.

Hydrofiber

Hydrofiber dressings are nonwoven pads or ribbons composed of sodium carboxymethylcellulose fibers.[20] They are essentially hydrocolloid dressings in the form of a hydrophilic nonwoven sheet of fibers. They conform well and are very absorbent. Fluid absorption occurs vertically only, so no fluid should travel horizontally.[20] The advantage of the vertical absorption is that maceration of wound margins is avoided. Hydrofiber products may be used for very exudative wounds and will promote wound cleansing and granulation tissue formation.[20] They should not be used on dry wounds because they are designed to interact with wound exudate to form a gel on the wound surface. Hydrofiber dressings may be left in place for several days, depending on the amount of exudate.

Table 6
Bandage dressings

Dressing	Products Available	Indications
Nonadherent	Fabric impregnated with paraffin or petrolatum Cotton within perforated plastic film Adaptic (Systagenix, San Antonio, TX) Telfa (Covidien, Minneapolis, MN)	Prevent adherence of overlying bandage Allows transfer of exudate into overlying bandage Wound exudate: minimal Stage of healing: repair; also for partial-thickness skin wounds or to cover healing grafts or sutured wounds
Hypertonic saline	Hypertonic saline-impregnated gauze Curasalt (Covidien)	Good for highly contaminated or infected wounds; hyperosmotic effect dehydrates microorganisms and reduces tissue edema Can be used to debride an eschar Caution: can dehydrate wound and adjacent tissues if left in place too long for the amount of exudate Wound exudate: moderate to copious Stage of healing: inflammatory
Hydrogel	Gel, impregnated gauze, sheet Curafil Amorphous Gel (Covidien) Curafil Hydrogel Impregnated Gauze (Covidien) Curagel Hydrogel Dressing (Covidien) Carrasyn Hydrogel (Medline Industries, Inc, Mundelein, IL) CarraDres Clear Hydrogel Sheets (Medline Industries, Inc) Tegagel Hydrogel (3M, St Paul, MN)	Can rehydrate wound or prevent desiccation Caution: may macerate periwound skin Exudate: may be odiferous and yellow and should not be misinterpreted as evidence of infection Wound exudate: minimal or none Stage of healing: inflammatory or repair; good for partial-thickness wounds
Polyurethane foam	Sheet Kendall Foam Wound Dressing (Covidien) Hydrasorb Foam (Covidien) Allevyn Foam (Smith & Nephew, London, England)	Good thermal insulation Wound exudate: moderate to copious; can use on dry wound, if premoistened Caution: can dehydrate wound if left in place too long for the amount of exudate Stage of healing: inflammatory
Hydrocolloid	Powder, paste, or sheet DuoDERM (ConvaTec, Skillman, NJ) Medihoney Hydrocolloid Dressing (Derma Sciences, Princeton, NJ) Nu-Derm Hydrocolloid Wound Dressing (Systagenix, San Antonio, TX) 3M Tegaderm Hydrocolloid Wound Dressing (3M)	Caution: may macerate periwound skin May inhibit wound contraction Exudate: may be odiferous and yellow and should not be misinterpreted as evidence of infection Wound exudate: minimal to moderate Stage of healing: inflammatory or repair

Hydrofiber	Sheet or rope Aquacel (ConvaTec)	Vertical absorption of fluid to prevent maceration of adjacent tissue Wound exudate: moderate to copious Stage of healing: inflammatory
Alginate	Sheet or rope Curasorb Zinc Calcium Alginate (Covidien) Medihoney Calcium Alginate (Derma Sciences) Maxorb Extra (Medline Industries, Inc) Nu-Derm Alginate (Systagenix) Sorbsan Alginate (Pharma-Plast Ltd, Deeside, UK) 3M Tegaderm Alginate (3M) 3M Tegagen (3M)	Hemostatic, so consider after surgical debridement Caution: can dehydrate wound if left in place too long for the amount of exudate, so avoid over exposed bone or tendon Exudate: may be odiferous and yellow and should not be misinterpreted as evidence of infection Exudate: moderate to copious Stage of healing: inflammatory
Transparent film (semiocclusive)	Adhesive, semipermeable, polyurethane membrane Polyskin II (Covidien) Opsite (Smith & Nephew) 3M Tegaderm Transparent Film (3M)	May have adhesive borders that enable it to be used alone or to cover and maintain the position of a different dressing (eg, hydrogel, foam, hydrocolloid) Caution: waterproof and does not absorb wound fluids, so must be changed if fluid accumulates underneath; may also promote bacterial growth Exudate: minimal or none Stage of healing: partial-thickness skin wounds or sutured wounds
Antimicrobial	PHMB impregnated in dressings, gauze sponges, or roll gauze Kendall AMD Antimicrobial Foam (Covidien) Kerlix AMD Rolls (Covidien) Kerlix AMD Super Sponges (Covidien) Kerlix AMD Gauze Dressing (Covidien) Telfa AMD Dressing (Covidien) May incorporate silver in various forms in various types of bandage dressings (eg, foam, alginate, hydrofiber) Aquacel Ag: hydrofiber dressing (Convatec) Silvasorb wound gel (Medline Industries, Inc) Opticell Ag (Medline Industries, Inc) Biostep Ag Collagen Matrix (Smith & Nephew) Acticoat (Smith & Nephew) Silvercel Nonadherent (Systagenix) Actisorb Silver 220 (Systagenix)	May use PHMB-impregnated roll gauze in outer layers of bandage to maintain dressing in place over wound Both PHMB and silver products: broad-spectrum antimicrobial activity to resist infection Caution: silver dressings may cause green exudate that should not be mistaken for *Pseudomonas* infection Exudate: depends on composition of base dressing Stage of healing: all

Abbreviation: PHMB, polyhexamethylene biguanide.

Alginate Dressings

Alginates are composed of natural polysaccharide fibers or are derived from algae.[20] They are available as soft, nonwoven fibers in the form of sheets or rope. Alginate products conform to the wound and absorb exudate to form a hydrophilic gel-like substance, which contains the bacteria and wound debris and maintains a moist wound environment.[20] Alginates absorb 20 to 30 times their weight, so they are useful for moderately exudative wounds.[20] Depending on the product, the dressing may supply calcium, zinc, or manganese to the wound fluid. Silver ions have also been added to some alginate dressings to enhance antibacterial properties. Alginates have a hemostatic effect, so are suitable for use following surgical debridement. Alginate products are often useful in the early management of wounds, when there is excessive exudate and hemorrhage.[20] An absorbent bandage layer should be applied over the alginate to help retain the wound drainage. Alginate products may be left on the wound for several days, to avoid disturbing the healing tissues. When changing the bandage, the alginate gel is lifted from the wound or flushed with normal saline, which causes minimal wound disruption. Any fragments of alginate left in the wound are broken into calcium and simple sugars, and will not elicit a foreign body reaction. A gel will not form in a dry wound, so alginate should be avoided or should be premoistened for use on minimally exudative wounds. Alginate bandages may remain in place for 1 to 7 days or until drainage is seen on the outer dressing.

Transparent Films

Transparent films are adhesive, semipermeable, polyurethane membrane dressings. They are waterproof and impermeable to contaminants and bacteria but permit transfer of water vapor and atmospheric gases.[7] They have no ability to absorb drainage and need to be changed when fluid accumulates underneath. Their ability to trap moisture could promote the proliferation of skin organisms under the film. Because they are transparent, wounds can be assessed without removing the dressing. Some films have a thin, nonadherent contact layer with an adhesive border. They may be used as a primary layer over partial-thickness wounds or sutured incisions; but use of the film alone should be avoided in the presence of infection, necrotic tissue, or highly exudative wounds.[7] Transparent films are also used as a secondary dressing to protect and secure a primary wound dressing, such as hydrogel sheets, foams, or hydrocolloids. Adhesive films will adhere more readily if the hair is removed and the skin is clean and dry. The film does not adhere well to mobile regions or areas with skin folds.

Antimicrobial Dressings

Polyhexamethylene biguanide (PHMB) is an antibacterial substance that is present in some wound dressings and bandage materials. PHMB has antimicrobial action against gram-positive and gram-negative bacteria and has no apparent negative effects on wound healing.[1] Products containing PHMB resist bacterial colonization on wounds and have prolonged local activity. In addition, gauze rolls impregnated with PHMB may be used in the secondary layer of the bandage to reduce existing microbial burden and protect the wound from further contamination.[46]

Wound products may contain silver in the form of silver ions, elementary silver, nanocrystalline silver, or inorganic silver complexes. Ionic silver-impregnated dressings are available in a variety of formulations, including foam, alginate, polyester mesh, and carboxymethylcellulose fiber dressings. Silver ions may be attached to the wound dressing or may be released into the gel that is produced after contacting the wound exudate. Silver ions form complexes with bacterial proteins, which

irreversibly damage the bacteria.[20] Silver dressings have antimicrobial activity against a range of aerobic and anaerobic bacteria, including antibiotic-resistant strains.[47,48] Silver dressings may cause the wound to produce a green exudate resembling that seen with *Pseudomonas* infections, so the exudate must be flushed from the wound before evaluating the wound bed.

OTHER THERAPIES

In most cases, appropriate debridement with proper bandaging results in adequate wound healing. The wound should be closed when it seems healthy and free of infection, unless adequate wound closure by contraction and epithelialization is anticipated. New modalities are always being developed in attempts to hasten healing. Adjunctive therapies may be most beneficial for chronic wounds or when delayed healing is anticipated (see **Box 4**). Physical modalities, such as extracorporeal shock wave, laser, electrical stimulation, or therapeutic ultrasound typically need to be applied to an uncovered wound. When these treatments are desired, they can be administered at the time of a bandage change.

Hyperbaric Oxygen

Chronic nonhealing wounds are frequently hypoxic because of poor perfusion.[21] Low oxygen tension has also been recorded in infected and traumatized tissue. Oxygen is essential for cell growth, wound healing, and resistance to infection. Increased oxygen delivery to the tissues results in angiogenesis and improved immune function.

Hyperbaric oxygen therapy (HBOT) is the inhalation of pure oxygen at a pressure greater than 1 atm. This therapy greatly increases the amount of dissolved oxygen in plasma, resulting in increased tissue oxygen tension. HBOT seems to improve the healing of diabetes-related foot ulcers in people, but there is insufficient evidence to support or refute its effect on other wounds.[49] There are no prospective randomized controlled studies on the indications for HBOT in veterinary medicine.[50] Extrapolating from human medicine, HBOT may be beneficial for necrotizing soft tissue infections or thermal burns.[50]

HBOT chambers are available in various sizes, with some designed specifically for small animals and others designed for equine patients. Veterinary personnel with training in hyperbaric medicine should monitor patients during each therapy session. Hyperbaric chambers are not readily available to most practitioners and can be cost prohibitive.

Potential contraindications for HBOT include pneumothorax, pulmonary disease, history of thoracic or ear surgery, fever, and pregnancy. Complications of HBOT include barotrauma, cataracts, pulmonary dyspnea, and seizures.[50,51]

Extracorporeal Shock Wave Therapy

Extracorporeal shock wave therapy (ESWT) is the delivery of high-energy waves through the tissues. ESWT has been used to suppress exuberant granulation tissue in an equine model to improve wound healing.[52] It has also been shown to increase the rate of epithelialization in both equine and porcine models.[53,54] There is no consensus on the optimal therapeutic protocol regarding duration, strength, or number of pulses; but treatments in humans are commonly administered once or twice weekly, using low or medium energy. A systematic review of the literature concluded that ESWT is a safe, mostly painless adjunctive therapy for wounds in humans; but further studies are needed to evaluate its efficacy and cost-effectiveness.[55]

Laser Therapy

Laser therapy may aid healing of open wounds (**Box 6**).[56–58] However, higher doses of laser can inhibit wound healing or even create cellular damage. Therapeutic laser is typically performed using a wavelength range of 630 nm (visible light) to 904 nm (infrared), with between 1 and 15 W of power. One of the difficulties in evaluating the literature is that the type of laser and therapeutic protocols may vary greatly between studies. In addition, most studies on wound healing have been done in vitro or in vivo on humans, whose skin characteristics are quite different than furred animals. Some studies indicate beneficial effects, whereas others suggest no benefit.[59,60] Laser therapy may have the most promise for wounds with impaired healing properties.

Therapeutic lasers are readily available, with various brands being marketed to the veterinary community. The general guideline for laser treatment is 2 to 6 J/cm^2 once daily for 7 to 10 days for acute wounds and 2 to 8 J/cm^2 once daily for chronic wounds.[61] However, optimal dosages are not known and may vary depending on the wavelength. The laser head should not contact the wound and should be cleaned before and after treatment. There are some cautions for the use of laser therapy (**Table 7**). Hospital personnel can be trained to use the laser and must also be trained with respect to laser safety. All individuals in the room (including patients) must wear protective eyeglasses.

Electrical Stimulation

Several types of transcutaneous electrical stimulation have been used to promote wound healing.[62,63]

Microcurrent electrical stimulation uses continuous or pulsed electrical current waveforms in the microamperage range (1 to 999 μA) to accelerate healing of chronic wounds that have delayed healing.[64] The value of microcurrent electrical stimulation is based on the theory that normal tissue healing is partially mediated by endogenous bioelectrical signals, so the therapy is designed to enhance that effect. When the anode (+) is placed on a moist sterile gauze over the wound bed, with the cathode (−) on the adjacent skin, negatively charged cells (macrophages and neutrophils) will migrate toward the anode, thus promoting the inflammatory stage of wound healing.[64] If the cathode is placed over the wound bed with the anode on the adjacent skin, positively charged cells (fibroblasts, keratinocytes, epidermal cells) will migrate toward the cathode.[64] Thus electrode placement may need to be planned based on the stage of wound healing, or the polarity may be reversed every 3 to 4 treatments to balance the migration of positively and negatively charged cells. There is limited evidence to suggest that an electrical current may inhibit microbial growth, with either

Box 6
Potential effects of laser on wound healing

- Accelerate angiogenesis
- Stimulate fibroblasts
- Promote collagen formation
- Enhance production of adenosine triphosphate, protein, and growth factors
- Cause vasodilation
- Improve lymphatic drainage

Table 7
Potential risks associated with laser therapy

Potential Effect/Risk	Recommendation
Retinal damage	Do not treat near the eyes. All individuals present must wear eyewear that is protective for the specific wavelength being used. Therapy should be delivered in a closed room without windows to avoid accidental exposure to others. Beware that laser light may reflect off smooth surfaces.
Darkly pigmented skin, tattoos, and hair can absorb more laser light	Adjust treatment settings to avoid burning hair or skin. Hair may need to be removed if it prevents the laser light from reaching the targeted tissue.
Stimulate cellular activity	Avoid treating over the infected area. Avoid treating directly over a malignant lesion.
Alter cellular activity	Avoid using it directly over testicles. Avoid using it over thyroid gland.
Vasodilation	Avoid using it over hemorrhagic tissue.

the anode or the cathode over the wound bed. The wound may be treated for 30 to 60 minutes, 2 or 3 times daily, 5 to 7 days per week. There is some evidence to justify the use of microcurrent therapy to treat chronic dermal ulcers in humans.[64]

High-voltage pulsed current therapy (HVPC) is another type of electrical stimulation advocated as an adjunctive treatment of chronic, nonhealing wounds.[64–67] The rationale for its use is the same as for microcurrent electrical stimulation. The suggestions for electrode placement are the same as for microcurrent therapy. There is no evidence to suggest that one polarity is better than the other or that continuous delivery is better than pulsed mode. The voltage amplitude is set between 150 and 250 V, using a frequency between 0.1 and 200 pulses per second. There are some potential contraindications to the use of HVPC (**Table 8**). The wound may be treated for 30 to 90 minutes, once daily, 5 to 7 days per week. There is some evidence to justify the use of HVPC to treat dermal wounds in humans.[64]

Therapeutic Ultrasound

Therapeutic ultrasound is the delivery of acoustic or mechanical energy waves through the tissues. Ultrasound may have a stimulating effect on cells during the inflammatory stage of wound healing, and may also increase collagen strength.[68–71]

Table 8
Potential risks associated with HVPC therapy

Potential Effect/Risk	Recommendation
Increased blood flow	Avoid using it over malignancies. Avoid using it over hemorrhagic tissue.
Electrical current	Avoid using it over pacemakers. Use it with caution over the ventral neck (vagus nerve, carotid sinuses). Use with caution over thorax, especially if patients have cardiac disease. Avoid using it over the head, particularly in patients with seizures.

Table 9
Potential risks associated with conventional therapeutic ultrasound

Potential Effect/Risk	Recommendation
Increased blood flow	Tumor growth may be promoted, so avoid using over malignancies. Hemorrhagic response may be enhanced, so use caution over hemorrhagic areas. Use caution with use over infected region because blood flow may spread the infection.
Interfere with electronics	Avoid using over pacemakers
Retinal damage	Avoid using it over the eyes, especially if using ultrasound thermal effects.

Conventional ultrasound therapy is characterized by ultrasonic energy delivered at high frequency (3 MHz) and intensity (0.1–3.0 W/cm^2).[64] The energy is delivered to the tissue through a hand piece that contacts the skin. Transmission of ultrasound energy is improved by use of a coupling medium (typically ultrasound gel) applied to the skin surface to interface with the handpiece. Ultrasound has both thermal and mechanical effects within the tissues that may promote wound healing. The ultrasound energy can be delivered continuously or in a pulsed mode. The pulsed mode may be preferred if the intent is to cause more mechanical than thermal effects. There are some potential risks associated with therapeutic ultrasound, particularly related to the thermal effects (**Table 9**). A typical treatment would be the application of ultrasound for 5 to 10 minutes every other day. There is some evidence to justify the use of conventional ultrasound in the treatment of dermal ulcers in humans.[64]

The MIST therapy system (Celleration Inc, Eden Prairie, MN) is ultrasonic energy that is delivered at a much lower frequency (40 kHz) than conventional ultrasound.[64] It is indicated for cleaning or debriding wounds that contain fibrin, exudates, or bacteria and may also promote healing of chronic wounds.[72–74] A mist of sterile saline transfers ultrasonic energy to the wound bed without direct contact by the handpiece. The energy is delivered in continuous mode. A typical treatment would be the application of ultrasound for 5 to 10 minutes daily. The MIST therapy system seems to have merit for debriding open wounds and promoting wound healing but may not be cost-effective for veterinary use.

SUMMARY

Most wounds will heal without complications. The goals of open wound management are to protect the wound from additional contamination and to maintain a moist wound environment, which is optimal for infection control and wound healing. Conservative surgical debridement may be indicated to remove large areas of necrotic tissue or gross contamination. Wound irrigation is also performed to remove excessive exudation or unattached foreign materials. These nonselective debridement techniques are used in conjunction with hydrophilic bandage dressings that promote selective wound debridement. Dressing selection is based on the stage of wound healing and the amount of exudate, so the most appropriate dressing will change as the wound heals.

Care of chronic nonhealing wounds is more complex. Advanced wound dressings that create a moist wound environment are still indicated. A topical product may be considered, although most have limited evidence supporting their efficacy. The appropriate use of systemic or topical antibiotics and topic antiseptics also remains

controversial. In addition, some physical modalities show promise as adjunctive therapy and warrant further investigation.

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