Wound dressings

Gerald T. Lionelli, MD,
W. Thomas Lawrence, MPH, MD*

Section of Plastic Surgery, Sutherland Institute, Kansas University Medical Center, 3901 Rainbow Boulevard, Kansas City, KS 66160-7389, USA

Lacerations, abrasions, and wounds of all varieties have been the result of accidents, injuries, errors in judgment, and ravages of war for millennia. Considering this, self-repair is a vital human function. Dressings have been used since antiquity to facilitate the healing process. The choice of which dressing to use for a particular wound requires an understanding of tissue repair and knowledge of the properties of available dressings.

Brief history of dressings

Historically, wounds were treated with homespun remedies derived in part from ritualistic teachings and in part from careful observation. The “three healing gestures” were described (circa) 2200 BC on an ancient clay tablet [1]: (1) washing the wound, (2) making plasters (mixtures of herbs, ointments, and oils that were applied to wounds to aid in the healing process), and (3) bandaging the wound. References to early wound care are seen in the Bible, “…went to him, and bound his wounds, pouring oil and wine” (Luke, 10:34); ancient Assyrian writings, “…the surface of the sick part with butter you shall anoint…”; and ancient Greek texts, “With bandage firm, Ulysses’ knee they bound” (Homer, The Odyssey).

The first antiseptic dressings were introduced in 1867 by Lister, who soaked lint and gauze in carbolic acid (phenol) before applying them to wounds. True sterilization did not become available until nearly the turn of the twentieth century, however [2]. One of the earliest nonadherent dressings was tulle gras, which gained popularity in World War I and consisted of gauze impregnated with paraffin [2]. Owens first discussed fine mesh gauze
as a minimally adherent intermediary underlying more absorptive materials in 1944 [2].

Many sophisticated dressings have become available to the wound care practitioner more recently. These newer materials and agents supplement older dressing materials, such as gauze, which still are commonly used. The decision of which dressing to use for a particular wound can be challenging given the array of products available.

**Desirable dressing characteristics**

Certain features are desired in a dressing regardless of its structure and the type of wound on which it is placed, as follows:

- Protect wound from bacteria and foreign material
- Absorb exudate from wound
- Prevent heat and fluid loss from wound
- Provide compression to minimize edema and obliterate dead space
- Be nonadherent to limit wound disruption
- Create a warm, moist occluded environment to maximize epithelialization and minimize pain
- Be esthetically attractive

All dressings ideally should protect wounds from trauma and contamination by bacteria and foreign material. Dressings also should absorb exudate generated by the wound. Another priority is to provide compression to minimize edema and obliterate dead space. In most circumstances, maintenance of a warm, moist environment is desirable to maximize the rate at which healing functions occur [3]. Prevention of heat and fluid loss is also important, especially in wounds covering a large surface area, such as burns. Nonadherence is generally desirable to limit disruption of healing tissues during dressing changes. All dressings should be esthetically attractive.

No single dressing can provide all of these functions optimally, and not all functions are required for all wounds. Different dressing materials provide different functions to greater or lesser degrees, and the attributes of each dressing material need to be matched to the specific wound on which it is placed.

An alternative to the application of a dressing is simply allowing a scab to form on a wound. Scabs are nature’s dressing. Essentially, they are crusts of dried serum with trapped erythrocytes, platelets, and other blood-borne cells. Scabs provide many functions often provided by dressings, including provision of a barrier against foreign material, reduction of pain, holding the wound edges in approximation, facilitation of wound contraction [4], and minimizing the loss of fluid and proteins. Although scabs perform many useful functions, they are not ideal. They slow epithelialization [5], and they can fix bacteria on the wound surface, which can lead to infection.
Concept of occlusion

Understanding the concept of occlusion has been fundamental to the evolution of wound dressings and has created a paradigm shift in the management of wounds. Before this understanding, wounds often were kept dry, as advocated by Pasteur to keep them “germ-free” [6]. Winter [5] published his seminal work on the effects of occlusion on the rate of epithelialization in 1962. In his porcine model, surgically created wounds were left to heal either open to air or occluded under a transparent film. The rate of epithelialization under the occlusive dressing was twofold that of the wounds left undressed.

Occlusive dressings limit the transmission of fluids, water vapor, and gasses from the wound bed to the external environment. In general, a moisture vapor transmission rate less than 35 g of water vapor transmitted per square meter of dressing per hour is considered low enough to maintain a moist environment on the surface of most wounds [7]. By maintaining an occluded moist environment, these dressings maintain a mildly acidic pH and a relatively low oxygen tension on the wound surface [8]. These wound characteristics mirror the usual early wound environment [9]. A steep oxygen gradient stimulates angiogenesis, an important factor in wound healing [10]. A low oxygen tension also provides optimal conditions for fibroblast proliferation and granulation tissue formation [11]. Granulation tissue formation and epithelialization also are encouraged by cytokines, which are more likely to be preserved in an occluded wound environment. Moisture prevents desiccation, which leads to cell death. Moisture also facilitates epidermal migration, angiogenesis, and connective tissue synthesis [12]. In addition, it supports autolysis of necrotic material by providing the solute for enzymatic débridement. Occlusive dressings limit the pain associated with partial-thickness wounds to a much greater degree than nonocclusive dressings [13].

Special wound requirements

In some wounds, factors may be present that interfere with normal healing. In these situations, the need for a warm, moist occluded environment may be superseded by the need to eliminate the factors interfering with normal healing. As mentioned, wounds related to infection and wounds that are heavily contaminated by bacteria require a dressing that diminishes the bacterial count in the wound. Placing an occlusive dressing on an infected wound encourages bacterial proliferation and exacerbates the infection.

Heavily exudative wounds often require a degree of absorption that no occlusive dressing can provide. Large amounts of exudate can macerate the skin surrounding a wound and dilute intrinsic factors such as cytokines, which promote healing. Absorption of excessive exudate becomes a priority in these wounds.
Dressing regimens that contribute to wound débridement are required in wounds containing nonviable tissue. Similar dressings are required in wounds with foreign bodies or debris. In wounds involving toxins, such as brown recluse spider bites or infiltrated chemotherapeutic agents, débridement is required to limit ongoing damage by the toxic agent, although surgical débridement generally is required in these scenarios.

**Dressing options**

As mentioned previously, no single dressing can provide all things to all wounds, and the needs of each individual wound need to be prioritized. These needs must be matched to the pros and cons of possible dressings. Frequently, there is not one clear best choice, especially because most wounds have a variety of needs. The practitioner must decide which dressing functions to maximize to choose among the possibly acceptable dressing candidates.

Dressings can be classified based on their construction and function (Table 1). These include nonadherent fabrics; absorptive dressings; non-biologic occlusive dressings, including films, hydrocolloids, alginates, and hydrogels; biologic occlusive dressings; and creams and ointments. Some newer devices, such as the VAC unit (KCI, Kinetic Concepts, Inc., San Antonio, TX), also have been used for wound care. Each of these will be considered individually. Dressing labeling is confusing at best and unintelligible at worst. Each manufacturer generally produces at least one dressing involving each of the key materials and frequently hybrid dressings.

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that combine materials. It is frequently difficult to determine which dressings from different companies fit in the same category, and it is even more difficult to ascertain the differences between similar products produced by different companies.

Nonadherent fabrics

Nonadherent fabrics are derivatives of fine mesh Owens gauze and tulle gras. Many of the dressings in this category consist of fine mesh gauze with a supplement provided to augment its occlusive properties, its nonadherent properties, its healing facilitating capabilities, or its antibacterial characteristics. Examples include Scarlet Red (The Kendall Company, Mansfield, MA), Vaseline gauze (The Kendall Company, Mansfield, MA), Xeroform (The Kendall Company, Mansfield, MA), and Xeroflo (The Kendall Company, Mansfield, MA). There are also synthetic nonadherent fabrics, such as Mepitel (Möllycke Health Care, Göteborg, Sweden), Adaptic (Johnson and Johnson Medical, Arlington, TX), Telfa (The Kendall Company, Mansfield, MA), and N-terface (Winfield Laboratories, Dallas, TX).

Scarlet Red consists of fine mesh gauze impregnated with O-tolylazo-O-tolylazo-B-naphthol. It has some antimicrobial activity, but it primarily gained popularity as a dressing for partial-thickness wounds because of limited evidence suggesting it is a stimulant of epithelialization [14]. Xeroform is a relatively occlusive, hydrophobic dressing composed of 3% bismuth tribromophenate in a petrolatum base. Xeroflo also includes bismuth tribromophenate but uses a hydrophilic base. These materials help mask the offensive odors of some wounds and have limited antimicrobial activity against *Staphylococcus aureus* and *Escherichia coli* [15]. Mepitel is a silicone-coated polyamide (nylon) gridlike net dressing designed to be maximally nonadherent [16]. It is bacteriostatic as well [17].

Nonadherent fabrics can be divided into hydrophobic and hydrophilic dressings. Hydrophobic fabrics are more occlusive and include Scarlet Red, Xeroform, Telfa, and Vaseline gauze. These materials do not facilitate the drainage of fluid through them readily. Hydrophilic materials include Xeroflo, Mepitel, Adaptic, N-terface, and fine mesh gauze. These materials more readily facilitate the drainage of fluid into overlying dressing layers.

Absorptive dressings

As mentioned previously, absorption of exudate is a desirable dressing attribute. A study showed that exudate production from leg ulcers averages about 5 g/10 cm²/24 h (range, 4 to 12 g/10 cm²/24 h) [18]. Exudate collects and contributes to wound maceration if not wicked away from the wound surface. Wide mesh gauze is excellent at wicking exudate away from a wound, although it loses effectiveness when saturated [19,20]. Gauze commonly is placed over nonocclusive, nonadhering fabric dressing materials to absorb material draining through them. Wide mesh gauze
adheres to a wound if placed in direct contact with it. Although dis-
advantageous for most wounds, this characteristic can be advantageous if
wound débridement is desired.

Foams
Foam dressings consist of hydrophobic, polyurethane foam sheets. Early
foam dressings were custom polymerized or cut for individual wounds [21].
The advantages of foam dressings are that they are absorbent and
nonadherent, and they can expand and conform to wounds with unusual
configurations. They are comfortable and can be removed easily for cleaning.
Foam dressings have disadvantages as well. Custom foam dressings are labor
intensive to produce, and as wounds heal, they need to be replaced with
additional dressings that correspond in size to the shrinking wound. Also,
they provide limited protection from bacterial contamination. Because they
absorb fluid from the environment, they cannot be used while bathing.

Most modern foam dressings are prepackaged and are not custom
produced for individual wounds. They are thinner than the early custom
dressings and often include a nonabsorbent, adhesive cover that is occlusive.
Although these off-the-shelf dressings are simple to use and provide more
protection from the external environment, they cannot fill large or irregularly
shaped wounds. There are multiple brands of foam dressings on the market,
including Lyofoam (Convatec, Princeton, NJ), Allevyn (Smith and Nephew,
Largo, FL), Curafilm (The Kendall Company, Mansfield, MA), Flexzan
(Dow Hickham, Sugar Land, TX), Biopatch (Johnson and Johnson Medical,
Arlington, TX) Vigifoam (Bard, Murray Hill, NJ), and Mepilex (Molnlycke
Health Care, Göteborg, Sweden).

Regardless of whether the dressing is custom-made or not, epithelializa-
tion does not occur as readily under foam dressings as under occlusive
dressings. This may be a result of less precise occlusion or possibly
mechanical impairment of keratinocyte migration created by the irregular
foam surface [22]. In addition, the wicking property of foams may leach
cytokines from the wound surface.

Occlusive dressings
Currently, occlusive dressings can be divided into two classes, non-
biologic and biologic. Nonbiologic occlusive dressings include films,
hydrocolloids, alginites, and hydrogels. Depending on their construction,
some foam dressings fit in this category as well. Biologic occlusive dressings
include allograft, xenograft, amnion, and skin substitutes. The subclass of
skin substitutes includes Integra (Integra LifeSciences Corp, Plainsboro,
NJ), Dermagraft (Smith and Nephew, Largo, FL), Apligraf (Novartis,
Basel, Switzerland), and AlloDerm (LifeCell, Branchburg, NJ), with many
new products on the horizon. All occlusive dressings, regardless of type,
provide the benefits of insulation, moisture retention, mechanical pro-
tection, and a barrier function against bacteria.
Films

Film dressings are generally clear polyurethane membranes with acrylic adhesive on one side for adherence [23]. Examples include Tegaderm (3M, Healthcare, St. Paul, MN, New York, NY), Mefilm (Mölnlycke Health Care, Göteborg, Sweden), Carrafilm (Carrington, Irving, TX), Bioclusive (Johnson and Johnson Medical, Arlington, TX), Transeal (DeRoyal, Powell, TN), Blisterfilm (The Kendall Company, Mansfield, MA), and Op-Site (Smith and Nephew, Largo, FL). They are waterproof but allow the transmission of oxygen, carbon dioxide, and water vapor. The degree of permeability varies with the product. Because they are generally transparent, the underlying wounds can be visualized easily, and because they are extremely thin, they do not interfere with patient function.

Film dressings have disadvantages as well. They are nonabsorptive so that exudate collects under them and frequently leaks out. This leaking disrupts the antibacterial seal created by the dressing in addition to being messy. Dressing changes frequently are required when this occurs. Another disadvantage is that there needs to be intact skin surrounding the area being dressed for dressing adherence. This skin may not be available when large donor sites are created, as in burn patients. Wound contraction may be slowed by occlusive dressings, and removal of the dressings can disrupt new epithelium.

Hydrocolloids

The term hydrocolloid is used to describe a family of dressings containing a hydrocolloid matrix composed of such materials as gelatin, pectin, and carboxymethylcellulose. Hydrocolloid dressings are available as adhesive wafers or as pastes or powders [23]. On contact with wound exudate, the matrix absorbs water, swells, and liquefies to form a moist gel. Products vary in absorption capacity and may or may not leave a residue in the wound. The ability of hydrocolloids to absorb wound exudate differentiates them from films. Otherwise, they share many positive characteristics, including limited moisture and gas transmission and impermeability to bacteria. Hydrocolloids are generally opaque and are slightly bulkier than films. This increased size may provide more protection for the wound, although it may interfere with function to a greater degree. Examples of hydrocolloid dressings are Duoderm (Convatec, Princeton, NJ), NuDerm (Johnson and Johnson Medical, Arlington, NJ), Comfeel (Coloplast, Holtedam, Denmark), Hydrocol (Dow Hickham, Sugar Land, TX), Cutinova (Smith and Nephew, Largo, FL), and Tegasorb (3M, New York, NY).

Alginites

Alginate dressings are composed of soft, nonwoven fibers of a cellulose-like polysaccharide derived from the calcium salt of alginic acid (seaweed) [24]. They have their primary utility in exudative wounds. When in contact with wound exudate, the insoluble calcium alginate is partially converted to a soluble sodium salt. This conversion generates a hydrophilic gel as
a by-product. The gel creates an occlusive environment that facilitates healing. The characteristics of the environment under alginate dressings have not been evaluated as completely as that under films and hydrocolloids. When the alginate becomes engorged and begins to “bleed,” a dressing change is indicated. Alginates are packaged in a variety of forms, including ropes for packing cavities, ribbons for narrow wounds or sinuses, and pads. Examples of alginate dressings include Algiderm (Bard, Murray Hill, NJ), Algosteril (Johnson and Johnson Medical, Arlington, TX), Kaltostat (Convatec, Princeton, NJ), Curasorb (The Kendall Company, Mansfield, MA), Carasorb (Carrington, Irving, TX), Melgisorb (Mölndal, Sweden), SeaSorb (Coloplast, Holstedam, Denmark), Kalginate (DeRoyal, Powell, TN), and Sorbsan (Dow Hickham, Sugar Land, TX).

Hydrogels

Hydrogel dressings consist of a starch polymer, such as polyethylene oxide, or a carboxymethylcellulose polymer and up to 80% water. They are available as gels, sheets, or impregnated gauze. They function as rehydrating agents for dry wounds. Because of their high water content, they do not absorb large amounts of wound exudate. They do create an occlusive environment underneath them, although the characteristics of the environment have not been well worked out. Examples of hydrogels include Vigilon (Bard, Murray Hill, NJ), Nu-gel (Johnson and Johnson Medical, Arlington, TX), Tegagel (3M, New York, NY), FlexiGel (Smith and Nephew, Largo, FL), Curagel (The Kendall Company, Mansfield, MA), and Flexiderm (Dow-Hickham, Sugar Land, TX).

Comparisons of nonbiologic occlusive dressings

There are significant differences between different types of nonbiologic occlusive dressings. There are also differences between different products in each category. Thomas and Loveless [25] evaluated the absorbency, fluid-handling characteristics, and other physical properties of 12 hydrocolloid dressings. Their results showed that although similar in appearance, the dressings differed markedly. Thickness, absorption, moisture vapor permeability, conformability, residual supernatant pH, fluid retention, and gel cohesion all varied from product to product. Bolton and colleagues [7] compared six hydrocolloid dressings and two film dressings and noted significant differences in the levels of occlusion produced. Bradley and coworkers [6] performed a meta-analysis of dressings and topical agents used for pressure sore treatment. No significant differences were noted between polyurethane foam dressings, film dressings, hydrocolloid dressings, or various membrane dressings in their effects on healing.

Using a standardized partial-thickness wound model in domestic pigs, Angren [26] conducted a study comparing four different calcium alginate dressings, Algosteril, Comfeel Alginate, Kaltostat, and Sorbsan. He
considered their ability to retain wound exudative fluid and adhere and their effect on dressing residues, epithelialization, and inflammatory cell infiltration. Although there were differences in handling characteristics, adherence, dispersion of wound exudate, and amount of dressing residue left on the wound, they did not differ significantly in their effect on epithelialization or dermal healing.

There is evidence that each of the occlusive dressings facilitates healing and limits pain to a greater degree than nonocclusive dressings. It is difficult to state that one occlusive dressing provides these attributes better than another, however. The choice of which occlusive dressing to use for a particular wound is predicated primarily on other factors. Hydrocolloid and alginate dressings generally provide more absorption than either hydrogel dressings, which provide limited absorption, or films, which are nonabsorptive. Films are transparent and allow wounds to be visualized. None of the other occlusive dressings provide this benefit. The film and hydrocolloid dressings include adhesives. They generally adhere better than hydrogels or alginites but require surrounding skin that is intact to which to adhere. This ability to adhere allows films and hydrocolloids to protect wounds better from contamination by bacteria and foreign materials but may contribute to more disruption of healing tissues with dressing changes.

Biologic occlusive dressings

As mentioned, biologic dressings include homograft, xenograft, and amnion. Homograft is a graft transplanted between genetically unique humans, whereas a xenograft is a graft transplanted between species. Pigskin is the most commonly used xenograft. Homografts and xenografts are temporary dressings in that both are rejected if left on a wound for an extended period [27]. Amnion is derived from human placenta and is another effective biologic wound dressing [28]. Its use has diminished with increased concern regarding biologic materials.

There are a rapidly expanding number of synthetic biologic dressings. Some, such as Alloderm and Integra, include components that are incorporated into healing skin and are more appropriately considered skin substitutes. Skin substitutes are not considered in detail in this section. One of the first synthetic biologic dressings was Biobrane (Dow Hickham, Sugar Land, TX). Biobrane is a biosynthetic dressing constructed of a silicone film with a nylon fabric embedded into the film. The nylon fabric is constructed of a trifilament thread to which collagen is chemically bound [29]. When used on donor sites, Biobrane proved superior to Scarlet Red with respect to control of pain, accumulation of exudate, and healing time [30]. TransCyte (Smith and Nephew, Largo, FL) is a newer but related biologic dressing material. TransCyte includes human neonatal fibroblasts cultured on the silicone membrane bonded nylon mesh of Biobrane. This product has been used clinically with success on partial-thickness burns [31].
Apligraf (previously known as Graftskin) is a living, bilayered biologic dressing that has been designed to simulate normal skin. Initially, neonatal-derived dermal fibroblasts are cultured in a collagen matrix for 6 days. Human keratinocytes subsequently are cultured on top of this neodermis. The dressing needs to be used at the specific time cellular proliferation has produced an adequate amount of cells. The dressing contains matrix proteins and expresses cytokines; however, it does not contain melanocytes, Langerhans’ cells, macrophages, lymphocytes, or adnexal structures normally present in human skin. It has been shown to be efficacious for the treatment of venous stasis ulcers [32,33].

Creams, ointments, and solutions

Many topical wound treatments are available in the form of creams, ointments, and solutions. This is a broad category that extends from time-honored materials, such as zinc oxide paste, to cutting-edge preparations containing growth factors. Many of the creams, ointments, and solutions are designed to have antibacterial properties. Others include enzymatic débriding agents. Still others include free radical scavengers (allopurinol, dimethyl sulfoxide), agents to decrease platelet aggregation (iloprost), and growth factors (platelet-derived growth factor) or agents that bind growth factors (sucralfate). An encyclopedic discussion of all of these materials is beyond the scope of this article. Discussion is limited to some of the more commonly used antibacterial and enzymatic débriding agents.

Antibacterial agents

Bacteria colonize essentially all chronic wounds, and a distinction must be made between colonization and infection. In contaminated wounds, host defenses are able to keep bacterial counts effectively in check. Infection results when bacterial proliferation outstrips the ability of host defenses to contain it. Bacteria can spread into surrounding unwounded tissue as well. The indications for antibacterial therapy rest on the diagnosis of an infected wound. Subjective signs, such as increased wound exudate, cellulitis in the surrounding tissues, or lack of progress in healing, may raise the suspicion of infection. The gold standard for diagnosis of wound infection is a quantitative bacterial count. It has been shown conclusively that greater than $10^5$ organisms per 1 g of tissue results in clinical infection [34]. This holds true for essentially all bacterial species other than β-hemolytic streptococci, which can cause infection at lower concentrations. Antibacterial agents commonly are used to treat infected wounds. Commonly used materials include acetic acid, Dakin’s solution, silver nitrate, mafenide (Sulfamylon), silver sulfadiazine (Silvadene), and a variety of ointments.

Acetic acid

Dilute acetic acid (vinegar) is an ancient therapy still used today. It is primarily effective against gram-negative organisms, such as *Pseudomonas*. 
Clinical antibacterial efficacy requires at least a 0.5% concentration. Lineaweaver and colleagues [35] showed that a 0.25% acetic acid solution killed 100% of exposed fibroblasts in an in vitro model so that impaired healing would be expected at any clinically effective concentration of the acid. Acetic acid has been shown to slow wound epithelialization and to limit polymorphonuclear neutrophil function [35,36].

**Dakin’s solution**

The antibacterial properties of hypochlorite solution initially were described by Labarraque in 1820, although its use was popularized by Dakin in 1915 [37]. Dakin described the use of hypochlorites for infected wounds after a friend and colleague, Carrel, wrote to him for suggestions to improve the treatment of trench wounds during World War I. Essentially dilute bleach, Dakin’s solution has a broad antibacterial spectrum, although it is also toxic to fibroblasts [38]. Kjolseth and associates [39] showed that wounds treated with Dakin’s solution were significantly slower to epithelialize and neovascularize than wounds treated with less toxic solutions.

**Iodine-containing antibiotics**

Iodine-containing antibacterial preparations include 5% and 10% povidone-iodine ointment and cadexomer iodine gel (Iodosorb and Iodoflex, Healthpoint, Fort Worth, TX). Povidone-iodine ointment provides a broad antibacterial and antifungal spectrum. Experimental human wounds inoculated with *S. aureus* and treated twice daily with povidone-iodine cream or polymyxin B sulfate/neomycin sulfate (Neosporin) ointment showed significantly reduced bacterial counts (*P* < .001) compared with untreated wounds [40].

In evaluating the toxicities of common topical antimicrobial agents, such as polymyxin B/bacitracin (Polysporin), bacitracin, polymyxin B, neomycin, gentamicin, mafenide, acetic acid, Dakin’s solution, genitourinary (GU) irrigant, and povidone-iodine (Betadine), Cooper and associates [41] showed that Betadine (Purdue Frederick, Stamford, CT) solution tested at multiple dilutions was “the most toxic of all agents tested on fibroblasts.” In a meta-analysis evaluating the toxicity versus effectiveness of povidone-iodine, Kramer [42] established that in most instances, povidone-iodine did not effectively promote good wound healing; most studies showed that it impaired wound healing, reduced wound strength, or promoted infection.

Iodosorb, a cadexomer iodine gel, is composed of a three-dimensional lattice of starch molecules formed into microspheres [43]. Iodine atoms are trapped within this lattice at a final concentration of 0.9%. Because the substrate is a starch, Iodosorb has a high absorptive capacity. As wound exudate is absorbed, the lattice pore size increases, allowing the controlled release of iodine. This slow-release formulation delivers a constant, low-level concentration of iodine to the wound, which minimizes the toxic
effects of iodine, while maintaining antibacterial properties. Efficacy has been shown in the treatment of venous leg ulcers with small or no risk of skin irritation [44].

**Silver-based dressings**

*Silver nitrate.* Silver nitrate initially was used in the Middle Ages for cautery and, in high concentrations (3% to 8%), for hypertrophic granulation tissue. In the early 1800s, lower concentrations (0.2% to 2%) were used for burn treatment. Moyer and colleagues [45] popularized its use in a continual irrigation of 0.5% solution in the mid-1900s, and this method was at one time a mainstay of the treatment of burns. Advantages of silver nitrate include its broad antibacterial spectrum. It can slow epithelialization [46], however, and it can produce hyponatremia and hypochloremia secondary to hypotonicity. It also stains bedclothes and all it touches black. *Aerobacter cloacae* can convert the nitrate to nitrite and cause methemoglobinemia. Its use has diminished as other agents have become available.

*Mafenide acetate.* Mafenide acetate (Sulfamylon; Dow Hickham, Sugar Land, TX) first attained broad usage in Germany during World War II. It has a broad antibacterial spectrum and has the ability to penetrate eschar [47]. Its disadvantages include occasional pain on application, inhibition of epithelialization [46], and inhibition of carbonic anhydrase, which can lead to a metabolic acidosis. More recently, these disadvantages have been minimized while maintaining antibacterial efficacy by using a 5% solution of mafenide that is placed on dressings three to four times a day [48].

*Silver sulfadiazine.* Silver sulfadiazene (Silvadene; Hoechst Marion Roussel (now Aventis), Strasbourg, Germany) was developed in the 1960s by Fox [49–51]. Silvadene has a broad spectrum of antibacterial, antifungal, and antiviral activity. Its limitations are its occasional association with a transient neutropenia and its occasional topical sensitivity. Although fibroblast toxicity has been shown for Silvadene and Sulfamylon in culture [52], it has been noted to accelerate epithelialization of partial-thickness wounds [53], suggesting that some of the toxicity may be buffered by other wound components in vivo. In other studies, an increase in neovascularization was noted [39]. Silvadene has become the most commonly used antibacterial agent in burn wound management.

**Acticoat**. Acticoat (Smith and Nephew, Largo, FL) is a silver-impregnated dressing that is occlusive and promotes a moist healing environment. It has a broad spectrum of antibacterial activity that persists for 3 days, eliminating the need for frequent dressing changes. It was noted to be a more effective antibacterial than silver nitrate in a comparative study of burn wounds [54].
Bacitracin, polymyxin B, neomycin, Neosporin, Polysporin. Topical bacitracin, polymyxin B, and neomycin and their combined forms Neosporin and Polysporin are antibiotic preparations whose delivery systems are in the form of ointments. Ointments are soothing to apply, comfortable to wear, lubricating to the wound surface, and occlusive in nature. These mixtures deliver the antibiotic directly to the wound surface and limit scab formation. Their antibacterial activity lasts approximately 12 hours. Ointments, which are suspensions of water in oil, are not water miscible, and they can be difficult to clean off wounds. They are of limited benefit after epithelium heals.

Bacitracin is a branched cyclic peptide antibiotic effective against gram-positive cocci and bacilli. It is derived from the bacteria *Bacillus subtilis*, and its mechanism of action is by inhibiting cell wall synthesis [55]. Neomycin is primarily effective against gram-negative bacteria and functions primarily through inhibition of protein synthesis [56]. Polymyxin B sulfate is produced by *Bacillus polymyxa* [56]. It is a cationic detergent, which disrupts the bacterial cell membrane. It is primarily effective against gram-negative organisms. Its disadvantages are that it limits epithelial proliferation and polymorphonuclear cell function [57]. Polysporin is a blend of polymyxin B sulfate and bacitracin zinc, whereas Neosporin is a blend of polymyxin B sulfate, bacitracin zinc, and neomycin [58]. Triple antibiotic ointment is a combination of polymyxin B sulfate, bacitracin, and neomycin [58]. These combinations are advantageous because they possess broad antibacterial spectra, including gram-positive and gram-negative bacteria. Geronemus and colleagues [53] noted that Neosporin ointment significantly increased the rate of reepithelialization of experimental wounds by 25% compared with wounds with no dressing. For uncomplicated wounds presenting to the emergency department, Dire and coworkers [59] showed that bacitracin and Neosporin ointments significantly and equally decreased the rate of wound infection compared with petrolatum controls.

Mupirocin. Mupirocin (Bactroban; SmithKline Beecham, Research Triangle Park, NC) is derived from *Pseudomonas fluorescens* and inhibits protein synthesis within bacteria. It was isolated in the 1970s and is currently manufactured as 2% mupirocin in polyethylene glycol base [60]. It is primarily active against aerobic gram-positive cocci, including streptococcal species, *S. aureus*, *Staphylococcus epidermidis*, and methicillin-resistant *S. aureus* [61]. It does not impair epithelialization or wound contraction.

Wound débridement

Healing is retarded if necrotic tissue is present in a wound. Eschar can create an environment that facilitates bacterial proliferation. Treatment with topical antibacterials is frequently unsuccessful in eschar-covered wounds because the active ingredient is unable to penetrate the necrotic debris. Sharp débridement is the time-honored approach to removing devitalized...
and necrotic tissue from wounds. Clearly demarcated areas of living versus dead tissue are required to avoid damaging healthy tissue and to minimize patient discomfort. To complement or limit sharp débridement, a wide variety of débridement methods and products have been developed.

Biologic débridement with sterile maggots (fly larvae) is a centuries-old technique that is enjoying a resurgence in popularity [62–64]. Sterile maggots have peculiar feeding habits whereby they fiercely consume necrotic tissue and reject viable tissue [64]. By secreting peptide antimicrobials (defensins), they may provide an antimicrobial benefit [65].

The wet-to-dry débridement technique is a surgical standard that is used frequently. With this technique, the wound is cleansed and packed with saline-moistened gauze. As the wound and gauze dry, the fibrinous exudate generated by the wound hardens and adheres to the gauze and surrounding tissue. With gauze removal, any adherent material also is removed from the wound. This method is not discriminating, and newly formed granulation tissue and epithelium are removed with necrotic debris. This removal of tissue and epithelium can slow the progress of the healing wound and cause pain.

Nonmechanical débridement can be provided by absorptive and enzymatic agents. Dextranomer polysaccharide is an example of an absorptive agent and is provided as anhydrous, highly porous beads or as a paste. The beads have a diameter of 0.1 to 0.3 mm. The beads and the paste are highly hydrophilic and rapidly absorb wound exudate. Small molecules become trapped in the matrix of the polysaccharide, whereas bacteria and debris become adherent to the dextranomer layer at the wound/dressing interface. These unwanted substances are washed away when the dressing is changed. Dressing changes effectively diminish the bacterial counts in wounds [66].

Enzymatic débridement takes advantage of naturally occurring compounds that degrade complex molecules. Enzymes induce chemical reactions without being changed or consumed themselves. Sutilains is an enzyme derived from the bacterium Bacillus subtilis. Sutilains digests soft necrotic tissue that is composed primarily of denatured collagen. Collagenase is also a bacterial product, derived from Clostridium histolyticum. Collagenase (Santyl) digests denatured collagen and native collagen. Papain is a vegetable pepsin prepared from the juice of the fruit and leaves of carica papaya (papaw) [67]. Papain is effective against collagen in the presence of a cofactor containing a sulfhydryl group (−SH). Common preparations include urea (papain/urea, Accuzyme; Healthpoint, Fort Worth, TX), which doubles the enzymatic action of papain alone [68]. Fibrinolysin degrades fibrinous tissue, and deoxyribonuclease degrades DNA and nuclear proteins. The combination of the two complement each other in their effect on wound débridement [69].

A cornucopia of studies provide no clear consensus as to the superiority of one agent over another. Rodeheaver and colleagues [70] evaluated the
fibrinolytic capacity of a host of enzymes and determined that sutilains was more effective at clot lysis (96%) than fibrinolysin-deoxyribonuclease (15%) or papain (35%). Hobson and associates [71] compared enzymatic agents in vitro and found papain/urea débrided approximately 27% of heat-denatured proteins in a 24-hour period, whereas collagenase débrided about 5% and fibrinolysin/deoxyribonuclease débrided about 2%. Alvarez and coworkers [72] compared papain/urea (Accuzyme) with collagenase (Santyl; Smith and Nephew, Largo, FL) for the treatment of pressure sores requiring débridement. The papain/urea formulation was significantly more effective at all time points than collagenase. There was no significant difference in the rate of wound closure between the two, however.

Mechanical devices

Mechanical devices have been developed to augment functions normally provided by dressings in wound management. A complete review of this area is beyond the scope of this article. The device that has gained most widespread utility to date is the VAC device (KCI). The VAC device uses a reticulated foam dressing that is cut to conform to an individual wound. The foam is covered by an occlusive drape under which a vacuum tube is placed. The tube is connected to a pump, which provides 50 to 125 mm of negative pressure to the occluded wound environment. The device has been shown to enhance local blood flow, diminish edema, limit bacterial proliferation, and accelerate granulation tissue formation in wounds [73]. It has been used successfully in a wide variety of wounds either to facilitate complete wound closure or to prepare the wound for a reconstructive procedure.

Choosing a dressing

Incisional wounds

For incisional wounds, it is desirable to have a dressing that protects the wound from contamination by bacteria or foreign material and absorbs any exudate. The epithelial edges of incisional wounds are millimeters apart, but a limited amount of epithelialization is required, and a dressing that encourages this is desirable. Some compression and immobilization are also beneficial. It is useful to have a dressing that minimally interferes with function and is esthetically appealing. These dressing characteristics can be provided in a variety of ways. Each method provides some functions to a greater degree than others, so the practitioner must choose which dressing attribute is most desirable for a particular wound.

The traditional approach to incisional wounds is to use a dressing with three layers—a contact layer, an absorptive layer, and a binding layer (Table 2). The contact layer is the layer in contact with the wound itself.
A nonadhering, hydrophilic material, such as Xeroflo or N-terface, is optimal to facilitate drainage into the overlying dressing layers and minimally interfere with healing tissues. The second dressing layer is the *absorptive layer*. It generally consists of gauze and wicks wound exudate away from the wound to limit maceration. The outer *binding layer* fixes the dressing in place and may provide compression and immobilization. Tape is most commonly used.

The advantages of the three-layer dressing are that it protects the wound and absorbs wound exudate well. Wound compression and immobilization can be provided to a variable degree depending on the binding layer used. There are several disadvantages to this approach, however. The relatively dry environment is not optimal for wound reepithelialization. The dressings frequently are bulky and cumbersome for the patient. The dressings cannot handle an unlimited amount of drainage and lose their effectiveness if they soak through.

A simpler approach, often used on the face, is simply to apply an antibacterial ointment, such as Neosporin. The primary advantage to this approach is that it is simple and does not interfere with function. Ointment also provides a moist environment, which facilitates epithelialization and limits scab formation. The disadvantages of this approach are that it provides limited absorption, protection, immobilization, and compression. Also the ointment can be wiped off inadvertently. If excessive ointment is applied to a wound, it sometimes can become macerated as well.

A third alternative for incisional wounds is to apply an occlusive dressing. Such a dressing creates a moist environment that facilitates epithelialization and prevents desiccation. It protects the wound from bacteria and foreign materials. The primary disadvantage of occlusive dressings is that they provide limited or no absorption depending on what

### Table 2

<table>
<thead>
<tr>
<th>Incisional wound</th>
<th>Three layer dressing</th>
<th>Ointment</th>
<th>Occlusive dressing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial thickness wounds (e.g. abrasions, donor sites)</td>
<td>No dressing (scab)</td>
<td>Impregnated gauze</td>
<td>Creams/ointments</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Occlusive dressings</td>
</tr>
<tr>
<td>Full thickness wounds (e.g. pressure sores)</td>
<td>Alginates or hydrogels- rarely applicable</td>
<td>Creams/gels (e.g; Silvadene silver sulfazine [Silvadene])</td>
<td>Wet-to-wet dressing changes</td>
</tr>
</tbody>
</table>
material is used. Michie and Hugill [74] compared Xeroform with Duoderm on surgical incisional wounds. Patient satisfaction with Duoderm was high; at the 4-week visit, the patient and the surgeon rated the scar segments covered with the hydrocolloid dressing (Duoderm) better with respect to color, evenness, and suppleness. These differences were no longer apparent 7 months after surgery, however.

**Donor sites and other partial-thickness wounds**

For partial-thickness wounds, such as skin graft donor sites, abrasions, and superficial burns, the primary goals for a dressing are to facilitate epithelialization, absorb exudate, protect the wound from bacteria and other contaminants, and be esthetically appealing. A variety of approaches are possible for wounds of this type. The simplest approach is to allow a scab to form and let the wound heal underneath it. The primary advantages of this approach are that it is simple and it does not cost anything. There are many disadvantages, however. Wounds treated in this manner epithelialize more slowly. There is nothing to absorb wound exudate. Until the scab dries and becomes solid, there is no protection from bacteria or foreign materials. Open wounds can be unattractive and uncomfortable. This approach has primary utility for smaller wounds.

A second approach is to apply a plain or impregnated gauze dressing and allow it to dry on the wound. When used in this manner, the dressings serve as a matrix for scab formation. The dressings are peeled off as the wound reepithelializes. This approach has many of the advantages and disadvantages mentioned for the no dressing approach. Gemberling and colleagues [75] compared Vaseline, Scarlet Red, Xeroform, and hydrophilic petrolatum with unimpregnated fine mesh gauze of identical weave and porosity in a series of skin graft donor sites. The infection rate and the rate and quality of healing were virtually the same for all materials tested, suggesting that the fabric additive did not affect healing. The primary advantage of this approach is simplicity in that no dressing changes are required. It has great utility in extremely large or circumferential wounds, which provide limited unwounded surfaces for affixing more involved dressings. Wound contraction also is facilitated by this approach compared with biologic dressings [76] and some antibacterial agents [77]. The primary disadvantages of this approach are slower healing and more pain than under an occlusive dressing [4].

A third approach is to change a dressing regularly using creams or ointments and gauze. These dressings generally are fixed in place with tape or circumferential wraps on extremities. They maintain a warm, moist environment to facilitate epithelialization. The wound is protected and can be compressed or immobilized depending on how the binding layer is applied. The wound is relatively pain-free when the dressing is in place. Antibacterial creams are commonly used, and these provide protection against infection. The regular dressing changes required may be uncomfortable for
the patient, however, and this approach creates more expense in dressing materials.

The fourth approach is to use one of the occlusive dressings discussed earlier. The rate of epithelialization is maximized, and patient comfort also is greatest. This is the preferred approach for most partial-thickness injuries. It may not be possible to use these dressings effectively, however, in large or circumferential wounds that provide limited uninjured skin to which to affix the dressing. It also is difficult to use these dressings in certain anatomic locations, such as the axilla or perineum. One of the previously mentioned methods is preferred in these situations.

**Full-thickness wounds**

The healing of large open wounds, such as pressure sores, is optimized by a warm, moist environment, such as that created by an occlusive dressing. These wounds frequently are irregular in contour, and occlusive dressings rarely conform to them. Alginates or foam dressings sometimes can be used if the wounds are not too irregular or extensive. More commonly, however, one must rely on alternative dressing modalities. Dressing changes with creams such as Silvadene or some gel products can maintain a reasonable environment for healing, as can wet-to-wet dressing changes with saline-moistened gauze. These approaches are labor and dressing intensive. Mechanical devices, such as the VAC, have utility in this type of wound as well. These wounds can harbor either excessive numbers of bacteria or necrotic tissue. In these clinical scenarios, antibacterials or débriding dressings are preferred.

For most bacterially contaminated wounds, Silvadene is the preferred antibacterial in that it is effective against a broad spectrum of bacteria and has minimal toxicity. Sulfamylon is useful if eschar penetration is needed. Iodosorb is a good alternative antibacterial choice that also has limited toxicity. Bactroban has specific efficacy for methicillin-resistant *S. aureus*–infected wounds. Acticoat is useful for relatively flat wounds with limited exudate and has the advantage of limiting dressing changes. Polysporin and Neosporin are useful when one needs an ointment to stay in a limited area. Ointments commonly are used on the face, where creams have a greater tendency to run into the eyes or mouth.

For wounds requiring extensive débridement, nothing surpasses surgical débridement in terms of effectiveness. In wounds in which the surgical approach cannot be used because of coexisting morbidities or in which the tissue requiring débridement is less defined, wet-to-dry dressing changes or enzymatic agents have utility. Enzymatic débridement may be slightly more comfortable for the patient, but it involves additional costs.

**Summary**

There are currently hundreds of dressings on the market to aid in wound management. Before selecting a dressing for a particular wound,
a practitioner must assess carefully the needs of the wound to understand which dressing would provide maximal benefit. Frequently, there is not one clear best choice, and it is crucial that the pros and cons of each dressing modality be understood. This article has provided a framework to assist in dressing assessment.

References


