CLINICAL MANAGEMENT

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The Role of Moisture Balance in Wound Healing

CME CATEGORY 1
1 Credit

CE ANCC/AACN
3.5 Contact Hours

Denis Okan, BHSc, MD (cand) • Medical Student • Memorial University of Newfoundland • St. John's, Newfoundland, Canada

Kevin Woo, MSc, RN, ACNP GNC(C) • Clinical Scientist/Nurse Practitioner • Wound Healing Clinic, The New Woman's Hospital • Toronto, Ontario, Canada

Elizabeth A. Ayello, PhD, RN, APRN,BC, CWOCN, FAPWCA, FAAN • Faculty • Excelsior College of Nursing • Albany, NY • Senior Advisor • The John A. Hartford Institute for Geriatric Nursing • New York, NY • President • Ayello, Harris & Associates • New York, NY • Clinical Associate Editor • *Advances in Skin & Wound Care* • Ambler, PA

R. Gary Sibbald, BSc, MD, FRCPC (Med) (Derm), FAPWCA, MEd • Professor of Medicine and Public Health Sciences • University of Toronto • Toronto, Ontario, Canada • Director • Wound Healing Clinic, The New Women's College Hospital • Toronto • Clinical Associate Editor • *Advances in Skin & Wound Care* • Ambler, PA

PURPOSE

To provide an overview of moisture balance and its importance in wound healing.

TARGET AUDIENCE

This continuing education activity is intended for physicians and nurses with an interest in wound care.

OBJECTIVES

After reading this article and taking the test, the reader should be able to:

1. Discuss the wound healing process and wound assessment.

2. Describe the types of dressings available and how they meet the needs of the individual patient.

ADV SKIN WOUND CARE 2007;20:39-53; quiz 54-5.

The wound bed preparation concept described by Sibbald et al[1] and Falanga[2] in 2000 is a systemic approach to optimizing wound healing. The Sibbald et al[1] model emphasizes treating the cause or causes of wounds and acknowledging patient-centered concerns. Factors affecting the *whole* patient must be addressed before assessing the local wound and applying the principles of moist wound healing (Figure 1).

This article focuses specifically on moisture balance and its importance in moist wound healing, and it is the third in a 4-part series that will address the wound bed preparation model of DIME—**D**ebridement, **I**nflammation or infection, **M**oisture balance, and **E**dge effect for the introduction of advanced therapies in wounds not healing at the expected rate. The wound bed preparation model is used to develop an approach to product selection for optimum moisture balance. The current understanding of the biochemical environment in wound fluid and approaches to contemporary wound care dressing selection are discussed.

MOISTURE BALANCE

Prior to the animal model work of Winter[3] and the human validation of Hinman and Maibach,[4] it was widely accepted that successful wound healing depended on maintaining a dry wound bed. Subsequently, a paradigm shift toward moist wound healing has revolutionized acute and chronic wound care. It is now commonly accepted that a moist wound environment hastens the healing of both acute and chronic wounds and promotes the growth of new tissue.[5–7] A balanced moist wound environment facilitates cellular growth and collagen proliferation within a healthy noncellular matrix. The identified factors in chronic wound fluid that can delay healing have been clarified recently, allowing for a better understanding of ideal conditions for repair.[8,9]

The balance of moisture is critical to wound healing. In acute wounds, a balanced moist surface facilitates the action of growth factors, cytokines, and chemokines, thus promoting cellular growth and the establishment of a provisional wound matrix.[3,7]

From another standpoint, excess moisture in the wound bed can impair the healing process and damage the surrounding skin, leading to periwound maceration.[5,6] If the excess moisture is left unchecked, healing can be impeded, and there may also be subsequent breakdown and further deterioration of the wound bed. Inadequate moisture in the wound environment, related primarily to exposure of the wound environment to air, promotes wound desiccation, necrosis, and eschar formation, and results in poorer wound healing rates. The formation of eschar, therefore, slows the ability of regenerative cells (keratinocytes) to migrate from the wound periphery into the wound center.[10] Epithelialization is ideal on a flat surface. Optimal migration and re-epithelialization is hindered by eschar formation.

BIOLOGIC CHARACTERISTICS OF ACUTE AND CHRONIC WOUNDS

Recent advances in the understanding of the basic mechanisms of wound healing have set the stage for optimal treatment of chronic wounds.[4,11] The fluid exuded from a wound bed is not inert. It has specific biologic and chemical properties that can serve to hasten or to prolong the healing time of a wound.[12] Recent research trials using topical administration of specific growth factors, such as platelet-derived growth factor (PDGF), to pressure, venous, and diabetic wounds have had limited success when combined with optimal treatment of the causation of a specific wound.[13–16] These experimental data suggest that growth factors are multifunctional and act to facilitate or impede healing depending on the wound bed matrix and cellular conditions. A single biologic factor in a fixed concentration without the ideal local wound bed properties will often fail unless an appropriate mix of growth factors in flexible concentrations within a responsive matrix can be reproduced.

Acute wound exudate is rich in growth factors—specifically, PDGF, fibroblast growth factor (FGF), and epithelial growth factor (EGF)—that serve to promote the proliferation of

Figure 1.
NEW WOUND BED PREPARATION MODEL
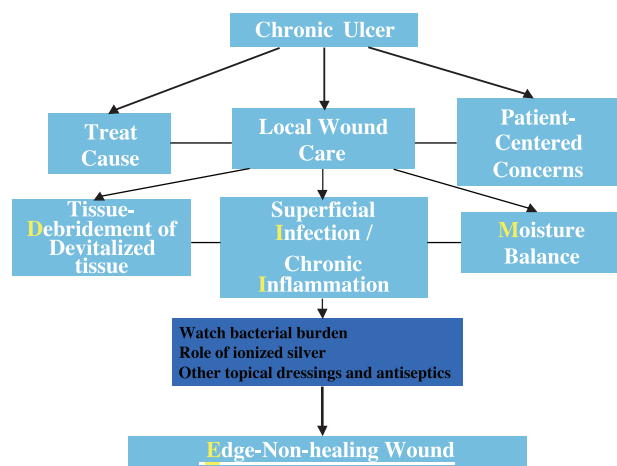
Source: Reprinted courtesy of Wound Care Canada, the official publication of the Canadian Association of Wound Care, http://www.cawc.net. Copyright 2006. All rights reserved.

fibroblasts, keratinocytes, and endothelial cells in both in vitro[17] and in vivo studies.[18] Acute wounds have a finite organized inflammatory stage for proteolytic and fibrinolytic agents to break down debris. Their concentration subsequently decreases to set the stage for the proliferation and re-epithelialization of cells. Furthermore, endogenous proteolytic and fibrinolytic enzymes break down components of the wound bed. The ensuing products then act as chemotactic messengers to attract more inflammatory cells that expedite the re-epithelialization process.

Chronic wound exudate has a different composition, with studies[8,9,11,19] showing decreased cellular mitogenic activity in the chronic wound bed. This may be associated with higher concentrations of matrix metalloprotease (MMP) pro-enzymes that serve to degrade the wound matrix necessary for optimal healing.[9] In chronic wounds, there is often a competing prolonged inflammatory stage that inhibits a nascent proliferative stage.[9,11] Therefore, the key to healing chronic wounds becomes not only balancing moisture levels in the wound bed, but also sequestering those compounds in chronic wound exudate that may be barriers to normal healing. In theory, a proper moisture balance can help to inhibit the actions of these matrix-destroying enzymes while promoting prohealing messengers and proteins that act on the wound bed (Figure 2).

A moist wound environment also provides an increased electrical gradient between the wound and the wound margin and base, promoting the migration of keratinocytes into the center of the wound base.[20] Animal studies[21,22] have shown that this natural electric gradient increases PDGF and FGF receptor density on fibroblasts, thereby facilitating healing rates.

A moisture-balanced wound environment can be maintained primarily by appropriately applying newer generation wound dressings. Depending on exudate levels from the wound bed, the appropriate dressing could have occlusive, semiocclusive, absorptive, hydrating, autolytic debriding, or hemostatic characteristics.

Figure 2.
ACUTE VS. CHRONIC WOUNDS
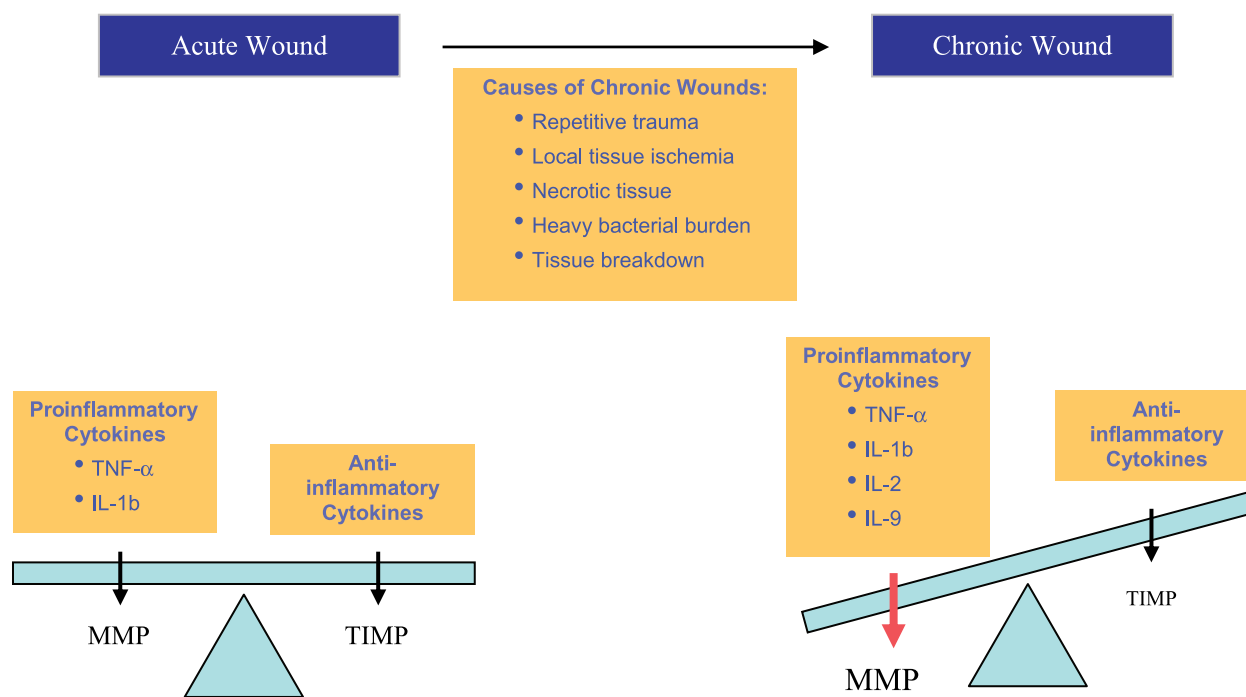
MMP = metalloprotease enzyme; TIMP = tissue inhibitor of metalloprotease enzyme

Some of the newer active dressings and ionized silver dressings offer additional anti-inflammatory actions, going one step further and literally soaking up the harmful substances in chronic wound fluid. By inhibiting destructive enzymatic action in the wound bed, which could lead to infection, these protease-modulating matrix dressings significantly accelerate healing time.[23]

PRACTICAL APPLICATION

To facilitate the clinical use of the above conceptual knowledge about wound moisture balance, the authors have constructed an enabler (Table 1) that lists the best practices. These practices are discussed in more detail below.

1. Diagnose and correct or modify treatable causes of tissue damage. Maintenance of a moist wound environment is optimal for wound healing after the cause of the wound is identified and appropriately treated.

An accurate diagnosis must be made to correct the cause of a given wound and to identify factors such as infection that will negatively influence wound healing. Kannon and Garrett[24] suggest that occlusive dressings, which maintain a moist wound environment, may be harmful on clinically infected wounds, diabetic neuropathic foot ulcers, or ischemic wounds because the moisture will facilitate bacterial proliferation. Without adequate host resistance, bacteria will then invade adjacent tissue, leading to deep tissue infections such as cellulitis or osteomyelitis.

An easy way of remembering this approach, particularly for persons with neuropathic foot ulcers, is through the use of the mnemonic **VIPS.** The clinician should consider **V**ascular supply, **I**nfection, **P**ressure offloading, and using **S**harp surgical debridement to remove any necrotic tissue.[25] After these preliminary factors are considered and managed, the principles of moist wound healing can be applied.

2. Differentiate the wound's ability to heal: healable, maintenance, or nonhealable wound. A moist wound environment may be contraindicated in nonhealable or maintenance wounds.

Determining the ability of a wound to heal is an important first step in assessing a person with a chronic wound. Healable wounds are those that have sufficient blood supply and that can have the underlying cause or causes corrected while addressing patient-centered concerns. Maintenance wounds have sufficient blood supply but present challenges in patient adherence to treatment due to personal health or systemic factors. The presence of a palpable pulse is evidence that blood supply to the area is adequate for healing (80 mm Hg and higher in the foot and 60 mm Hg and higher in the arm).

Nonpalpable pulses require further patient workup using Doppler ultrasound to determine the ankle-brachial pressure index (ABI). An ABI greater than 0.5 is sufficient pressure to consider a wound healable. However, caution must be used, especially in patients with diabetes, as calcified medium-sized vessels in the leg (present in 20% of all patients and in 80% of persons with diabetes) may produce a falsely elevated ABI. Any Doppler ABI ratio greater than 1.2 indicates noncompressible vessels and is inaccurate due to arterial calcification of the vessel wall.

Any suspicion of a falsely elevated result warrants a full arterial Doppler of the lower extremity with toe pressures. The smaller arteries of the large toe lack a circumferential adventitial layer that is necessary for the calcification process to occur. A toe pressure greater than 50 mm Hg is ideal for healing; however, patients with toe pressures between 30 and 50 mm Hg are considered healable as long as all other factors are optimized. If these results are questionable, more intensive and laborious transcutaneous oxygen saturation testing can be used to determine blood supply. With this type of testing, values greater than 40 mm Hg are ideal, with 30 to 40 mm Hg indicating some arterial compromise. Patients with values between 20 and 30 mm Hg (indicating moderate arterial impairment) or below 20 mm Hg (indicating severe ischemia) are unlikely to heal.

3. Assess and support the management of patient-centered concerns to enable healing. Minimize pain and trauma during dressing change by maintaining a moist wound environment to reduce the risk of dressing material adhering to wounds.

Most patients are concerned about the pain and frequency of dressing changes.[26] However, patient discomfort and concern are exacerbated if moisture balance is not optimal. Addressing this important patient concern is critical to proper healing of an ulcer and patient-centered care. Occlusive dressings that promote a moist wound environment and are less adherent to the wound bed preserve the developing fragile layer of surface epithelium over the wound base. This helps reduce pain and trauma during dressing removal. A moist wound environment diminishes pain, although the mechanism is not fully understood. One possible explanation is that the fluid will surround exposed nerve endings to prevent painful tissue drying and necrosis of the nociceptors.[10]

Many moisture-retentive dressings are available in adhesive and nonadhesive forms. Strong adhesives have a strong tear force with dressing removal and can cause pain and trauma with removal. Some of this can be avoided by pulling the dressing laterally to break the adhesive bond before pulling vertically or upward to remove the dressing. An alternate approach is to use a soft silicone surface for dressing

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Table 1.

ENABLER FOR BEST PRACTICES FOR MOISTURE BALANCE

CAWC Guidelines	Implications for Moisture Balance
Identify and Treat the Cause	
1. Diagnose and correct or modify treatable causes of tissue damage.	The maintenance of a moist wound environment is optimal for wound healing after the cause of the wound is identified and appropriately treated.
2. Differentiate the wound's ability to heal: healable, maintenance, or nonhealable wound.	A moist wound environment may be contraindicated in nonhealable or maintenance wounds.
Address Patient-Centered Concerns	
3. Assess and support the management of patient-centered concerns to enable healing.	Minimize pain and trauma during dressing change by maintaining a moist wound environment to reduce the risk of dressing material adhering to wounds. Consider the quality of life of individuals with chronic wounds in the management of exudation.
4. Provide patient education and support to increase adherence to treatment plan.*	
Provide Local Wound Care	
5. Assess and monitor the wound history and physical characteristics (location and measure).*	
6. Debride healable wounds, removing nonviable, contaminated or infected tissue (surgical, autolytic, enzymatic, mechanical, and larval).	Consider a moist wound environment to promote autolytic debridement of the wound when appropriate.[†]
7. Cleanse wounds with low-toxicity solutions (eg, normal saline or water). Topical antiseptic solutions should be reserved for wounds that are nonhealable or those in which the bacterial burden is of greater concern than the stimulation of healing.*	
8. Assess and treat the wound for increased bacterial burden or infection. (Distinguish from persistent inflammation of nonbacterial origin.)*	
9. Select a dressing that is appropriate for the needs of the wound, the patient, and the caregiver or clinical setting.	Match the dressing absorbency characteristics and wear time to the wound surface moisture.
10. Monitor the quantity and quality of wound exudation to prevent periwound maceration.	
11. Evaluate expected rate of wound healing. If suboptimal, reassess patient according to recommendations 1 to 9.	
Provide Organizational Support	
12. For improved outcomes, education and evidence base must be tied to interprofessional teams with cooperation of health care systems.*	

*These steps are not referred to in this article, but remain important in the overall schema of wound bed preparation.

[†]Nonhealable wounds should have only nonviable tissue removed and active debridement to bleeding tissue is contraindicated.

stability on the periwound margin and decreased pain at dressing removal.

Dressings that absorb exudate and those that are dry at the interface of the wound surface will adhere to the wound bed, causing further trauma during dressing changes (eg, saline wet-to-dry dressings). Most literature favors moisture-balance dressings with long wear time (approximately 3 to 7 days vs daily to twice-daily dressing changes for saline wet-to-dry

dressings), depending on the amount of exudate present.[27–29] Other dressings, including alginates and hydrogels, maintain the moisture balance in a wound because they possess a gel-forming, high-viscosity characteristic on contact with exudate that does not dry the wound bed.[30] This soothing effect is dramatically observed clinically with hydrogel dressings in burns[31,32]; however, there would be a similar mechanism of pain relief for other chronic ulcers.

The NICE[©] model for dressing decision making, developed by Ayello and Sibbald,[33] helps clinicians choose an appropriate dressing. It attempts to match and manage specific characteristics of a wound. The clinician should look for any Necrotic tissue that should be debrided, signs of Infection or Inflammation, specific Characteristics of the wound or the patient (ie, particular location of the wound), and the presence of and amount of Exudate. Although all 4 of these components are important, the level of exudate is the most significant constituent for moisture balance. The other elements should also be considered as they contribute secondarily to the exudate and moisture in the wound environment (ie, increased exudate with infection or exposure to moisture from lymphedema or incontinence). The NICE[©] model ensures that a wound has adequate moisture balance, and this will decrease the frequency of dressing changes that are often painful and traumatic to the wound bed. Adequate moisture balance increases patient adherence to treatment and enhances the rate of healing of an ulcer.

4. Consider the quality of life of individuals with chronic wounds in the management of exudate.

Inadequate moisture balance can cause fluid leakage from the dressing, odor, and periwound maceration that can lead to an increase in wound size and pain. This excess exudate often requires more frequent dressing changes and numerous visits to health care providers, presenting even more challenges for the health care system, as well as for the patient (and his or her caregivers, if the patient is incapacitated). If the patient encounters exudate strikethrough (exudate leaks from the sides and top of the dressing) between dressing changes, leakage from the wound may soil clothing and produce an unpleasant odor. Patients with highly exuding and malodorous wounds often experience embarrassment and retreat into seclusion and segregation from society.[34] Ideal moisture balance enhances patient satisfaction and quality of life while the patient is living with a chronic wound.

5. Debride healable wounds to remove nonviable, contaminated, or infected tissue. Consider a moist wound environment to promote autolytic debridement of the wound when appropriate.

Autolytic debridement is the promotion of liquefaction of wound slough and granulation through dressing-facilitated endogenous enzymes. A moist wound environment accelerates autolytic debridement of the wound bed because the proteolytic and fibrinolytic enzymes involved in autolytic debridement function solely in an aqueous milieu.[35] A wound fluid study by Chen et al[11] identified various peptide growth factors and chemotactic molecules that stimulate cellular turnover, regeneration, and autolytic breakdown. The establishment of a fibrin clot serves as a temporary hemostatic plug or provisional matrix for cells to migrate. Furthermore, it is a reservoir of soluble factors that are released on its dissolution by fibrinolytic for subsequent cell activation events (eg, chemotaxis, wound angiogenesis, cell proliferation, etc).[18] These chemical messengers become inactive in a dry environment.

Therefore, it is beneficial to use occlusive dressings to maintain a moist wound environment and to preserve the quality and efficacy of these enzymes and molecules. Further hastening of the autolytic process can be achieved by fenestration of a firm eschar surface with a scalpel blade, making superficial parallel grooves on the surface in a grid pattern (crosshatching).[19] Bleeding from the grooves should be absent or minimal because viable tissue should not be penetrated. Nonhealable wounds should have only nonviable tissue removed; active debridement to bleeding tissue is contraindicated, as it only worsens the ulcer.

Autolytic debridement is most prominent with moist interactive dressings, specifically hydrogels, hydrocolloids, alginates, and transparent films.[19] The benefits of moist wound healing have been demonstrated in many studies comparing the efficacy of autolytic debridement with hydrogel dressings to mechanical debridement with wet-to-dry dressings. Gates and Holloway,[36] Mulder,[37] and, more recently, Trudgian[38] all note that autolytic debridement with a hydrogel is more time- and cost-effective, less painful, and results in faster healing when compared with wet-to-dry dressings. In addition to maintaining a moist wound environment, the gels formed by hydrocolloids and calcium alginates have their own enzymatic activity that further facilitates tissue breakdown.[19]

6. Select a dressing that is appropriate for the needs of the wound, the patient, and the caregiver or clinical setting. Match the dressing absorbency characteristics and wear time to the wound surface moisture.

A moisture-balanced wound environment promotes wound healing and can potentially increase the rate of re-epithelialization by 50%.[3] Dressings can be divided into absorbent and hydrating classes. The properties of moist

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Table 2.

CONTEMPORARY CLASSES OF WOUND CARE DRESSINGS[18,19,30,39,41,44,71]

Generic Categories		Care Considerations	
Class	Description/ Mode of Action	Advantages/Disadvantages	Indications/Contraindications
Absorbent 1. Foam	Nonbioresorbable bilaminate opaque dressings with absorbent porous hydrocellular polyurethane center laminated with a semiocclusive outer layer	A: Permeable to gas and water, allowing exudate absorbency. Provides thermal insulation. Easily cut/shaped to fit awkward wounds. High absorbency and long wear time. D: Nonadherent; requires tape or secondary dressing to adhere. Does not allow continuous inspection of wound. Causes strikethrough and adherence to wound.	I: Venous ulcers with exudate, deep cavity wounds C: Dry wounds
2. Hydrofiber	Nonadhesive dressing composed of sodium carboxymethylcellulose gelling agent available in sheets or ropes	A: High degree of absorption. Provides moisture-balanced milieu promoting slow autolysis. Good fiber strength allows loose packing into wounds. D: Nonadherent; requires tape or secondary dressing to adhere.	I: Moderate to heavy exudate, partial- and full-thickness cavernous wounds with increased bacterial burden C: Dry or nonexuding wounds
3. Calcium alginate	Nonadherent calcium alginate polysaccharide kelp derivative available in fiber or nonwoven form. Sodium-calcium ion exchange between exudate and dressing promotes formation of sodium alginate gel. High content of mannuronic acid promotes gelling, and high galuronic acid content promotes fiber integrity for packing.	A: Hemostatic and autolytic properties. Can be used to pack deeper cavernous wounds. D: Nonadherent; requires tape or secondary dressing to adhere. Foul odor and appearance of gel may be confused with infection. Infection may be increased with retained dressing.	I: Moderately exudative wounds, hemostasis postdebridement C: Diabetic foot ulcers
4. Hydrogel	Semipermeable (O_2, CO_2, gases), nonadherent, semitransparent cross-linked hydrophilic polymers	A: Allows for continuous inspection of wound. Cooling/ soothing effect. Facilitates autolytic debridement. D: More frequent dressing changes and selective Gram-negative bacterial proliferation.	I: Dry, sloughy wounds with mild exudate; partial-thickness wounds C: Ischemic ulcers

Table 2.
CONTEMPORARY CLASSES OF WOUND CARE DRESSINGS, CONTINUED[18,19,30,39,41,44,71]

Generic Categories		Care Considerations	
Class	**Description/ Mode of Action**	**Advantages/Disadvantages**	**Indications/Contraindications**
5. Hydrocolloid	Outer polyurethane foam bonded to a middle hydrocolloid CMC/pectin gelling agent and inner adhesive layer	A: Does not require secondary dressing. Gel contains endogenous enzymes that aid autolytic debridement. Dressing changes relatively painless. D: Impermeable to gases and water vapor, causing overhydration, leakage of exudate and periwound maceration. Foul odor and appearance of gel may be confused with infection. Reported allergic dermatitis to Pantalyn H linked with allergy to colophony.	I: Chronic venous ulcers, decubitus ulcers, burns, partial-thickness wounds, diabetic foot ulcers C: Ischemia, infection, vasculitis
6. Adhesive film	Semipermeable (O_2, CO_2, gases) 0.2 mm sheet of polyurethane or synthetic polymer coated on one side with adhesive	A: Highly elastic and transparent, allowing continuous inspection of wound. D: Difficult to apply; self-sticking. Reports of some increased rates of infection.	I: Most commonly used in IV, catheter sites, and partial-thickness wounds C: Clinical infection, highly exudative wounds
7. Nonadhesive film	Permeable (O_2, CO_2, gases) 0.2 mm sheet of polyurethane or synthetic polymer bonded to acrylamide, a synthetic monomer	A: Transparent, allowing continuous inspection of wound. Conforms to wound shape. Non-self-adhesive. Direct absorption of antimicrobial agents. D: Nonadherent; requires tape or secondary dressing to adhere. Least capacity to balance moisture. Leakage channels may lead to fluid accumulation and subsequent critical colonization.	I: Can be used in exuding and infected wounds
8. Crystalline sodium chloride gauze		A: Mechanical debridement; antibacterial properties. D: Requires daily dressing change.	I: Highly exudative wounds

Hydrating Dressings (vertical label, left margin)

Table 2.

CONTEMPORARY CLASSES OF WOUND CARE DRESSINGS, CONTINUED[18,19,30,39,41,44,71]

Generic Categories		Care Considerations	
Class	**Description/ Mode of Action**	**Advantages/Disadvantages**	**Indications/Contraindications**
Miscellaneous 9. Hydropolymers	Composed of 4 layers: hydropolymer wound contact layer, nonwoven/ woven acrylate, permeable polyurethane backing, and a border of water-soluble polyurethane backing	A: Two forms; nonwoven acrylate for mild to moderate exudate and woven acrylate for moderate to large exudate. Water-soluble adhesive border makes dressing changes less painful and less traumatic. Hydropolymer wound contact layer conforms to irregular surface of wound.	I: Highly exuding venous leg ulcers
10. Acrylics	Semipermeable polyurethane membrane coated with acrylic adhesive layer	A: Protective barrier; scab formation is prevented in shallow wounds, allowing for enhanced rate of re-epithelialization.	I: Can be used on wounds that need easy visibility for assessment without dressing removal.

interactive dressings are summarized in Table 2 as the basis for appropriate selection and clinical monitoring. These dressings are discussed in more detail below. The clinician should keep in mind that no dressing can control or meet all the specific needs of the different stages of a particular wound, chronic or otherwise, and some clinical creativity and trial and error are needed to find a treatment plan that works best for the wound and, ultimately, for the holistic care of the patient.

ABSORBENT DRESSINGS

Foam

Simple foam dressings have an absorbent porous hydro-cellular polyurethane center laminated with a semiocclusive outer layer.[19] Different foams have outer layers with differing moisture vapor transmission rates (MVTRs). Dressings with higher MVTR backings are considered semiocclusive and permit evaporation of moisture. They have a greater absorptive capacity and have longer wear times when compared with more occlusive backings with lower MVTRs. Second-generation foam dressings may have variable sizes of the pores, allowing partial fluid retention along with fluid exchange. Larger pore sizes allow for moisture exchange between the ulcer base and the dressing. Smaller pore sizes become saturated and retain moisture from the wound. Moisture is retained under the polyurethane backing in the lacunae of the cells. Foam dressings are particularly useful in highly exuding wounds to keep periwound maceration and associated tissue damage to a minimum.[39] They are considered nonocclusive, and thus, are permeable to gases and water. This allows the wound bed to breathe and excess moisture to evaporate readily.[18] If a foam dressing does not have an occlusive backing, excess moisture from a highly exuding wound is free to slowly evaporate from the exposed surface, or the fluid may be transferred to a superabsorbent secondary dressing.

Foam dressings are nonbioresorbable and usually nonadherent. They can be easily shaped to fit wounds of any size, including deeper cavities. Some specific dressings have a secondary coating at the dressing/wound surface junction and may have an adhesive or soft silicone layer. The silicone layer reduces trauma to the wound bed and pain during dressing removal. A prospective, open-label study to assess the clinical performance of foam dressing in chronic wounds by Zoellner et al[40] found a significant decrease in the level of exudate from the wound bed, the proportion of patients with periwound skin problems, and the percentage of patients with wound pain. Foam dressings are indicated in venous ulcers with high levels of exudate. They are contraindicated in dry wounds where absorbency of moisture is not required to maintain balance. The opacity of the dressing makes inspection of the wound impossible without removal. The major advantage of foam dressings is the high absorbency with long wear time.

Hydrofiber

Hydrofiber dressings, available as either sheets or ropes, are composed of highly absorbent sodium carboxymethylcellulose (CMC).[41] This material has both hydrophilic and hydrophobic properties in the carboxy and methylcellulose regions, respectively. The exudate is bound in the center of the fiber and CMC is not bioresorbable. Carboxymethylcellulose binds to the glycoproteins on cell surfaces, allowing absorption and sequestering inflammatory cells, particularly neutrophils, to hasten re-epithelialization.[42] These dressings provide a moisture-balanced milieu that can promote slow levels of autolysis, as well as excellent control of exudate due to the gelling properties of the dressing, core. A retrospective study of chronic venous ulcers with CMC dressings versus gauze favored the use of CMC dressing, with a 130% increased chance of healing within 18 weeks and reduced health care costs from decreased nursing and physician costs associated with dressing changes.[43]

Hydrofiber dressings are indicated for moderate to heavy exudate and can be used with increased surface bacterial burden. They are contraindicated in dry wounds or wounds with little exudate. They have good fiber strength and can be packed loosely into sinuses (fluff, not stuff). Like nonadherent foams, hydrofibers are also nonadhesive and require a tape or a secondary dressing to stay in place.[24]

Calcium alginate dressings

Calcium alginate dressings are derived from kelp and composed mainly of calcium alginate polysaccharides.[19] This class of dressing works through a sodium-calcium ion exchange between the wound exudate and the dressing. The interaction produces a sodium alginate gel with moisture-retentive properties and autolytic debridement potential, making these dressings another candidate for moderately draining wounds.[44]

The varied composition of units of mannuronic and galuronic acid determines the physical properties of the dressing. Higher levels of mannuronic acid encourage gelling, whereas increased concentrations of galuronic acid promote fiber strength and allow for easier packing.

The calcium ions released by this type of dressing are a natural co-factor in the coagulation pathway.[45] Their increased concentration in the wound bed during the gelling process results in the hemostatic properties of the dressing, and they are particularly efficacious in stopping bloody exudate postdebridement.[19,46] Alginates containing zinc ions have the greatest potentiating effect on prothrombotic coagulation and platelet activation.[46] This type of dressing is not intended for hemostasis from acutely bleeding vessels.

Calcium alginates can be coated with antiseptics (eg, betadine or chlorohexadine) for maintenance or nonhealable wounds or combined with antibacterial creams (eg, silver sulfadiazine or mupirocin) in wounds with the ability to heal. When an alginate dressing is hydrated with wound fluid, the odor and appearance of the wound after dressing removal may resemble infection.[18]

On removal of the dressing, the presence of undissolved fibers indicates a lack of exudate; a different dressing should be selected in that case. Undissolved fibers left in the wound bed can be hydrated with compresses to dissolve them.

HYDRATING DRESSINGS

Hydrogel

Hydrogel dressings are semiocclusive and composed of a cross-linked network of hydrophilic polymers.[18] A hydrogel dressing is predominantly water with polymers to increase the viscosity and allow the dressing material to adhere to the wound surface. These polymers may consist of repeating units of monomeric polyvinyl pyrrolidone, polyacrylamide, or polyethylene oxide. The dressing derives its strength from noncovalent and free-radical interactions between the polymers. The hydrophilic side-chains serve to bind water molecules to their surface. Semiocclusive dressings help facilitate autolytic debridement by maintaining an environment rich in moisture.[47] Hydrogels are recommended for wounds that range from dry to mildly exuding and can be used to slowly degrade slough on the wound surface. Clinical trials show that hydrogels have a soothing effect,[48] especially on burns,[32] due to their ability to bathe exposed nerve endings with gel. They are contraindicated in ischemic ulcers.[30]

Hydrogels are usually applied as viscous amorphous gels with the ability to adhere to the wound surface without sliding off. Pharmacists refer to this property as the amount of tack. Hydrogels may be covered with films of varying MVTRs to form a sheet rather than an amorphous gel. Modifications of the sheet structure include an adhesive border. Some hydrogel sheets have a top film that may be removed to decrease the hydration properties of the gel and allow greater moisture release. All hydrogels have a semitransparent nature, permitting continuous monitoring of the wound without removal of the dressing.

Different manufacturers have produced hydrogel dressings with different physical and chemical properties. One hydrogel is composed of 20% hypertonic normal saline and is a strong agent for autolytic debridement. Another hydrogel is composed of 0.9% isotonic normal saline that softens eschar and provides an environment unfavorable to microorganisms. A third hydrogel is an aqueous gel that contains a modified CMC polymer and propylene glycol, which acts as a humectant and preservative.

Studies have been unsuccessful in showing a significant difference in the efficacy of these dressing subtypes in the treatment of chronic ulcers, despite their differences in chemical composition.

Hydrocolloid

Hydrocolloid dressings were the first class of ''modern'' moist wound healing dressings, marketed in the 1970s and 1980s. These dressings have an inner hydrocolloid gelling agent made of CMC combined with pectin and sandwiched between an inner adhesive layer that abuts the wound surface and an outer coating, such as a polyurethane coating of foam or a film.[24] The hydrocolloid gelling center absorbs moisture in the presence of wound exudate and forms a gel. The structure and properties of the gel depend on its composition. Some gels are more cohesive and retained within the adhesive matrix, whereas others are more mobile. As hydrocolloids absorb increasing amounts of moisture, they become progressively more water permeable. This ability to transmit moisture explains the dressing's ability to manage exudate. The adhesive layer component may be composed of a hydrogenated rosin ester under the trademark Pentalyn H. Pentalyn H is a common allergen, especially in patients with leg ulcers, and sensitized patients generally have a cross-sensitivity to colophony.[49,50] Hydrocolloids have a variable ability to melt when exposed to wound exudate and may leave a residue on the skin surface.

A prospective multicenter study of chronic venous ulcers treated with compression demonstrated that after 7.2 weeks, ulcers treated with a hydrocolloid dressing had a faster healing rate and decrease in size when compared with controls treated with conventional wet-to-dry saline dressings.[51] Patients also experienced a greater reduction in pain with hydrocolloid dressings. A longitudinal study by Kerstein and Gahtan[52] reported similar results. They found hydrocolloid dressings to be the most cost-effective dressing studied with the lowest frequency of ulcer reoccurrence. A Korean chronic pressure ulcer study established that the time required for complete healing was 5.4 days shorter in the hydrocolloid dressing group than in the wet-to-dry dressing group (18.9 days vs 24.3 days, respectively).[53]

Due to their hydrating properties and the mixture of the liquefied dressing with the patient's endogenous enzymes contained in the gelling layer, hydrocolloid dressings are useful in autolytic and enzymatic debridement of the wound bed.[39] They have limited absorption and in the presence of heavier exudate, they will have a shorter wear time than more absorptive foam dressings. Impermeability to gases and water vapor may cause overhydration of the wound and surrounding tissue, resulting in messy leakage around the dressing and periwound maceration.[47] The gelling agent, as in alginate dressings, can

have an acrid odor and appearance that may be confused with a clinical infection.[18] Dressings with higher residues are particularly malodorous. However, infection is generally not an issue with hydrocolloid dressings, perhaps because of the slightly acidic wound environment that discourages bacterial proliferation. In a study by Hutchinson and Lawrence,[54] hydrocolloid dressings were associated with a lower rate of infection than traditional wet-to-dry saline dressings.

Hydrocolloids are indicated for chronic wounds, including venous, pressure, and diabetic foot ulcers.[55] They should be used with caution in wounds of an ischemic or vasculitic nature or when infection is suspected. Hydrocolloid dressings may be combined with calcium alginate dressings to increase their absorptive capabilities or with silver to add an antibacterial component.

Films

Film dressings are manufactured in either adhesive or non-adhesive forms. They consist of polyurethane or synthetic polymer sheets. Adhesive films are semipermeable and have an adhesive coating on the wound side. They are, on occasion, difficult to apply and may adhere to themselves even in the hands of an experienced clinician.

Some studies describe increased rates of infection associated with adhesive film use.[56] However, the study results did not distinguish between bacterial colonization and infection. As a result, film dressings should be used with more caution in situations where clinical infection is suspected. They are most commonly used to cover intravenous catheter sites, as well as partial-thickness wounds.[24,47] Film dressings are also used to cover newly healed wounds that have 20% of the tensile strength of skin that has never had a wound. They provide a layer of added protection to the wound bed to minimize further damaging trauma.

Unlike the other dressing types discussed above, film dressings possess no properties to absorb wound exudate and cannot support any significant amount of moisture. They have the lowest capacity of the discussed dressing classes to handle wound-derived exudate. These dressings are indicated for wounds with absent or a low level of exudate. The wound healing capabilities may depend on whether the specific MVTR of the dressing can handle the amount of wound exudate present. Bolton et al[57] measured the MVTR of a variety of dressings and determined that an MVTR of less than 35 g of water vapor transmitted per square meter of dressing per hour is low enough to maintain a moist wound surface. Most film dressings are semipermeable, in that they are permeable to water vapor and oxygen but impermeable to water and microorganisms. Leakage channels developing from the periphery or fluid accumulation under the dressing

due to excess exudate production can lead to a relatively alkaline environment of the wound surface, which is a risk factor associated with bacterial proliferation, critical colonization, and infection. The dressing must be changed if the adhesive bond is compromised.

MISCELLANEOUS DRESSINGS

Crystalline saline

Crystalline saline dressings are also considered absorptive due to the moisture-wicking effects of the salt crystals impregnated into the gauze.[19] They are useful when debriding, as friction between the wound bed and the crystals creates a perfect environment for mechanical debridement. The sodium crystals may also absorb excess debris and bacteria from the wound surface. They are changed every 24 to 72 hours.

Hydropolymer foam

Hydropolymers are a newer class of dressings that attempt to combine the absorbent characteristics of foams with the nonadhesive characteristics of hydrogels. They are composed of 4 separate layers.[58] The wound contact layer is a hydropolymer—a polyurethane polymer with a strong affinity for water. When this layer absorbs wound exudate, it enlarges in size and conforms to the rough and uneven surface of the wound bed. The second layer is available in either a nonwoven acrylate or a woven acrylate viscose/rayon material. The former is intended for mild to moderately exuding wounds and wicks fluid vertically from the wound bed. The latter is absorbent foam that allows for vertical and horizontal wicking, locking fluid in the core and allowing it to transpire through the upper semipermeable polyurethane backing. The island dressing is surrounded by a border of polyurethane adhesive that is water-soluble, facilitating nontraumatic removal of the dressing from the wound.

Venous ulcer clinical trials have demonstrated that the hydropolymer dressings are most effective at controlling wound exudate and reducing periwound maceration in comparison with hydrocolloids that often cause leakage and maceration.[59–62]

Acrylic dressings

Acrylic dressings are semipermeable polyurethane membranes coated with a thin layer of acrylic adhesive. Although moisture and oxygen are free to diffuse across the membrane, microorganisms are not. Like film dressings, acrylic dressings perform a protective barrier function, shielding against external contamination and adding strength against shear and tensile forces that risk damaging the weaker, newly formed epithelium. The acrylic dressings help remove moisture from the wound bed at a controlled rate, maintaining wound surface moisture an ideal level. Excess fluid can escape through the porous membrane. In shallow wounds, eschar formation is prevented and epidermal regeneration takes place at an enhanced rate, compared with traditional dry dressings.

WOUND POUCHING AND NEGATIVE PRESSURE THERAPY

Wound pouching systems are appropriate for wounds that drain more than 50 mL of fluid a day or are associated with fluid that is especially damaging to skin, such as pancreatic enzymes.

Negative pressure wound therapy is based on the generation of subatmospheric topical air pressure to eliminate the presence of exudate from the wound bed, reduce edema, and increase blood flow.[63] This is achieved by covering the wound with a foam dressing in contact with the wound surface; the dressing is embedded with tubing connected to a vacuum pump. An airtight seal is created by covering the foam, tubing, and surrounding healthy tissue with an adhesive drape dressing. Fluid is drawn from the wound bed, through the foam and tubing, into a disposable canister. Negative pressure wound therapy may be employed for patients with healable and nonhealable acute and chronic wounds, including diabetic neuropathic, neuroischemic, and pressure ulcers. Criteria for use are often set by payers based on cost of the modality compared with other alternatives and the amount of exudate in the wound.

Negative pressure wound therapy should not be initiated in patients with low serum albumin levels as the loss of proteinaceous fluid from the wound bed can result in further hypoalbuminemia. It is also contraindicated when the ulceration is in direct communication with organs or body cavities or is the result of a malignancy. Wounds that require hemostasis or patients treated with anticoagulants are not candidates for therapy as the negative pressure can exacerbate bleeding and lead to blood loss and potential hemodynamic compromise.

This treatment is not a replacement for antimicrobial therapy and should not be used primarily to treat infections. It is one method to manage excess exudate produced by wounds that are critically colonized or infected.

MORE PRACTICAL APPLICATIONS

7. Monitor the quantity and quality of wound exudate to prevent periwound maceration. Maceration is the softening and damage to periwound tissues with increased exposure to moisture and inflammatory exudate.

Wound exudate can be classified in 2 different ways. The first approach is to look at the *quantity* of exudate, as well as

its color and consistency. The quantity of exudate is difficult to judge, but examining the dressing on removal can allow the clinician to classify the exudate into one of the following groups: none, small, moderate, or large.[64] No exudate on the dressing implies that the wound is nonexudative and has no discharge. A small or mild amount means that exudate will cover less than 33% of the dressing's surface area. Exudate covering 33% to 67% of the dressing's surface indicates a moderate amount. A large or high level of exudate covers more than 67% of the dressing surface.[64]

The *quality* of the exudate is also important to moisture balance. Serous exudate is clear and is indicative of serum or transudate. Sanguinous exudate is bright red to dark brown and indicates blood loss from the area and a potentially friable wound bed. Purulent exudate indicates the presence of inflammatory cells and is usually the result of infection, necrosis, or sterile inflammation. These types of exudate may exist singularly or concurrently (ie, serosanguinous exudate) in the wound. If not controlled, exudate and its components may retard healing and even cause damage to surrounding tissues.

Optimal moisture balance can be ensured by choosing appropriate dressings based on the guideline in this article. Clinicians must always remember to remove the causes of increased production of exudate through compression and elevation for venous and lymphedematous leg ulcers. Using antimicrobials for infection will remove excess exudate and often periwound maceration damage.

Clinical trials with venous ulcers have demonstrated that hydrogel dressings are efficacious to control wound exudate and reduce periwound maceration, but they have a shorter wear time than hydrocolloids that may cause leakage and maceration.[59–62] Overextending the time between dressing changes decreases the absorptive ability of dressings and causes maceration of the wound edges. Hydrogels also outperformed calcium alginate and film dressings for venous ulcers despite shorter wear time in the latter.[61] Periwound maceration may also be a problem with exposure to external sources of moisture, such as water during washing and feces and urine from incontinent patients.

Special care is important for patients with diabetes who develop wounds on their feet related to sensory neuropathy. Exudate and increasing moisture on the plantar surface must be controlled by absorptive dressings to prevent maceration and possible secondary fungal infection, especially in the toe-web spaces.

The LOWE© model developed by Ayello and Sibbald[64] is a simple mnemonic that can help clinicians remember the different ways of protecting periwound tissues from maceration. In addition to the use of absorbent dressings over exuding wounds, **L**iquid acrylates that form a film with skin application, **O**intments (ie, petrolatum or zinc oxide), **W**indowed dressings framing the wound margins with a protective adhesive (ie, hydrocolloid, film, acrylate, silicone), and **E**xternal collecting devices such as those used in the perirectal area can be utilized to prevent contact of healthy epithelium with excess moisture.

8. Evaluate the expected rate of wound healing. If suboptimal, reassess the patient according to recommendations 1 to 7.

Flanagan[65,66] noted that a 20% to 40% reduction in 2 and 4 weeks is likely to be a reliable predictor of healing. According to Sheehan et al,[67] a 50% reduction at week 12 is a good predictor for persons with diabetic foot ulcers. A more recent study by Jessup[68] compared 3 mathematical formulas used to predict the rate of wound healing. An equation measuring linear advancement of the edge to the wound center, also known as the Gilman equation,[69] was the best indicator of wound healing after 4 weeks of healing.[68]

If the wound edge is not migrating after appropriate wound bed preparation, including moisture balance, and healing is stalled, then advanced therapies should be considered to reinitiate the healing process, but only after reassessment of the patient and other causes and treated cofactors have been ruled out. Clinicians need to remember that wound healing is not always the primary outcome. Consider other wound-related outcomes, such as reduced pain, reduced bacterial load, reduced dressing changes, or an improved quality of life.

9. Empower the patient through education about wound bed preparation, coherent treatment plans, and the ability to practice prevention. Treatment plans that are developed without patient involvement will likely fail.

Empowerment of patients requires educational initiatives that are evidence based. Treatment plans need to be tailored to meet individual needs and abilities. The clinician should be sensitive to socioeconomic, cultural, psychosocial, and other individual factors when planning all interventions with the patient.

The model of Keller et al[70] encourages clinicians to enhance patient communications by including the 4 ''E's'' with every patient visit: engage, empathize, educate, enlist. The following are examples of how to apply this model:
• Engage: Know something about the patient other than the reason for his or her visit.
• Empathize: Demonstrate true concern for the patient's well-being.
• Educate: Ensure that the patient fully comprehends his or her disease process and agrees with the treatment plan.
• Enlist: Mutually decided on a treatment plan and follow-up outcome.

SUMMARY

Dressings have come a long way from the original gauze materials clinicians previously used to cover wounds. As science has provided new understanding of the dynamic nature of fluid in acute and chronic wounds, dressings have been created that absorb exudate and remove harmful components in wound fluid. With the large number of modern moisture balance dressings available, clinicians are also challenged to match the best dressing for the specific characteristics of the wound, as well as for the pain, quality of life, and dressing frequency requirements of the patient. ●

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