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REVIEW

Foam Dressings for Wound Healing

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Abstract

Purpose of Review Chronic, non-healing wounds affect millions of people globally and demand significant healthcare spending. One of the most important aspects of wound care is the appropriate selection and placement of a wound dressing. One of the key roles of a wound dressing is the optimization of a moist wound environment for healing. A moist wound environment facilitates wound healing by encouraging interaction of growth factors with their targets, epithelialization, angiogenesis, and autolytic debridement of dead tissue. However, while some chronic wounds are highly exudative and require absorptive dressings in order to minimize maceration, other wounds are drier and require more occlusive dressings with the capability of preserving moisture. Given the compelling global demand for wound care, foam dressings have been continuously innovated over the past several decades. Some foam dressings are manufactured to be highly adherent, while others are manufactured with minimal adherence in order to preserve peri-wound skin during dressing changes. Foam dressings are also manufactured within a spectrum of absorptivity and pliability. As such, foam dressings are applicable in a variety of clinical settings. Pressure injuries/ulcers, diabetic foot ulcers, and venous ulcers are a few examples of chronic wounds that have demonstrated clinical improvement with the utilization of foam dressings.

Recent Findings Given the compelling global demand for wound care, foam dressings have been continuously innovated over the past several decades. Some foam dressings are manufactured to be highly adherent, while others are manufactured with minimal adherence in order to preserve peri-wound skin during dressing changes. Foam dressings are also manufactured within a spectrum of absorptivity and pliability. As such, foam dressings are applicable in a variety of clinical settings. Pressure injuries/ulcers, diabetic foot ulcers, and venous ulcers are a few examples of chronic wounds that have demonstrated clinical improvement with the utilization of foam dressings.

Summary Foam dressings are frequently utilized in wound care due to their ease of use, often (relatively) low cost, pliability, fluid absorptivity, and ability to deliver anti-microbial substances, such as silver, to the wound bed. Overall, foam dressings are one of the most useful tools in wound care.

Keywords Foam dressings · Chronic wound · Polyurethane dressing · Silver foam · Pressure ulcer/injury · Venous leg ulcer

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Introduction: Wound Healing and the Role of Dressings

Non-healing wounds are a significant challenge facing millions of people around the world and requiring large healthcare spending globally. Up to $28 billion dollars in American Medicare spending is allocated to chronic wounds annually [1]. This number illuminates the substantial need for wound care materials in the USA. While it is generally accepted that acute wounds heal within 4 weeks [2], a wound that remains open for months or even years is considered to be non-healing or chronic [3, 4]. A myriad of reasons, including patient-related factors, wound characteristics, and environmental factors, may play a role in delayed wound healing and the development of a chronic, non-healing wound in

any one patient. The chronic wound environment has been studied extensively, and an imbalance of pro-inflammatory versus anti-inflammatory mediators have been found, including elevated TNF-α, IL-1β, reactive oxygen species, matrix metalloproteinases, and other proteases [5•]. Inflammation is necessary in acute wounds and contributes to normal wound healing. However, non-healing wounds contain higher quantities of inflammatory mediators and are thought to be "stuck" in a prolonged and elevated inflammatory state [6, 7]. In addition to the physiological state of inflammation, factors such as infection in the wound bed, patient medications such as corticosteroids or blood thinners, and minimal lifestyle modifications also play a role in delayed healing [8]. Wound care, including topical cleansing, debridement, topical medications, and dressing application, aims to promote healing and resolve the chronic inflammatory state. Here, we will focus on one of the key pillars of wound care, wound dressings. First described in 1962, topical dressings promote wound healing through the ability to foster a moist wound environment [9]. A moist wound promotes the interaction of growth factors with their targets, faster epithelialization, faster angiogenesis, improved autolytic debridement of dead tissue, and reduced pain [10]. One of the most important tools in wound healing is maintenance of a moist wound environment through the appropriate selection of wound dressing.

The performance of wound dressings, as for any other medical device, are constituted by their product-specific structure, in particular the microstructure of the materials that they are composed of. The structure-function relationship constituting the performance of wound dressings is a foundational concept underpinning the development, understanding, and utilization of any dressing type. For example, foams used in dressings (e.g., polyurethane foams) are materials characterized by a cellular structure, composed of air-filled voids within a solid polymer matrix. The microstructural aspects of foams, such as the size, shape, and distribution of these voids and their interconnectivity properties, play a foundational role in determining the function of the dressing, such as its fluid handling metrics, compressibility, stiffness, and conformity which are all directly influenced by the arrangement, density, and connectivity of the voids. Open-cell foams, with interconnected voids, which are used in the dressing industry, allow for fluid absorbency and further provide excellent cushioning and impact resistance, while closed-cell foams, with isolated voids (i.e., so that air cannot escape the voids), offer superior thermal insulation but are not useful at all for exudate management (and are therefore not used in wound dressings). The thermal insulation properties of foams, which are a key factor in the function of wound dressings, are also highly dependent on their structure. Foams with smaller, dense, and uniform voids tend to exhibit superior thermal insulation due to reduced heat conduction through the structure (because air is a poor heat conductor). Accordingly, the structure-function relationship in foams is crucial for tailoring these materials to specific applications in wound care, from simple single-layer dressings to multi-layer dressings and also foam materials used in negative pressure wound therapy. By manipulating the cellular structure of foams, biomedical engineers can optimize its performance to meet a wide range of clinical needs and wound etiologies.

Wound dressings are manufactured to optimize the wound environment, taking into account the physical and biochemical limitations and needs of various types of wounds. While the wound exudate may be very little in some wounds which may delay wound healing due to lack of moisture, other wounds may produce excess exudate which increases the risk of peri-wound skin maceration. Wound healing may also be limited by the presence of overt infection and biochemical factors such as biofilms. Wound dressings must therefore be absorbent in highly exudative wounds so that the wound is moist rather than wet to avoid maceration, and occlusive in drier wounds to maintain an adequate level of moisture. Wound dressings must also conform to the wound edges, minimize infection, minimize mechanical destruction of the wound, control pain, control odor, and be able to stay adherent to the skin between dressing changes. Dressings may also be designed to work well with other devices, such as compression wraps and offloading casts [5•]. Wound dressings fall into three categories, the first designed to manage the physical symptoms of the wound such as exudate and pain, the second designed to manage infection through occlusive properties or the ability to deliver anti-microbial substances to the wound, and the third designed to alter the wound environment in order to promote healing [5•]. The microarchitecture of dressings are constructed with intention in order to meet a specific need within wound care. For example, some foam dressings are manufactured in order to wick away fluid in highly exudative wounds, while others are manufactured with qualities that allow the preservation of fluid in wounds that are less exudative. Therefore, all dressings are not manufactured to be suitable for all wounds. In order to select a dressing with the best performance for a specific wound, it is necessary to take into account the etiology of the wound, patient limitations and lifestyle factors, and the clinical requirements of the wound bed.

Foam Dressings

While the use of wound coverings began in ancient civilization, the beginnings of modern sterile wound dressings took root in the late nineteenth century, following the discovery of microorganisms [11•]. Early sterile wound dressings served as a wound barrier to the outside world, absorbing fluid and

protecting the wound from infection. Gauze and cotton dressings were some of the first dressings to enter the market (dressings made of cotton layers encased in gauze appeared at around the first world war). However, these dressings, while functional, are not appropriate for all wounds. After several hours of contact with the wound bed, gauze and cotton dressings can adhere to highly exudative wounds. This can complicate wound dressing changes in highly exudative wounds. The removal of these partially adhered dressings can disrupt wound healing and damage epithelializing tissues. The need for better materials inspired innovation. Polyurethane (PU) foam dressings utilizing a single-layered foam design were developed in midtwentieth century and revolutionized wound care [11•]. Foam dressings possess the ability to absorb fluid while maintaining moisture in the wound environment and offer mechanical pliability, cushion, and thermal insulation. In the later twentieth century, foam dressings transitioned from a single foam to a multi-layer design in order to prevent adhesion and facilitate wound dressing changes [11•]. Since this time, several modifications have been added to foam dressings in order to improve function for varying indications. Some foams have been modified with a bordered design, in which a sticky, adherent rim of silicone is manufactured along the borders of the foam dressing in order to maximize the strength of wound dressing adherence. These foams are appropriate for wounds that necessitate barrier protection and may benefit from a higher level of dressing adherence. Other foam dressings are designed to contain silicone without an adherent border in order to minimize damage to the wound and peri-wound skin during dressing removal. In addition, foam dressings may also be manufactured with imbedded medications and anti-microbial substances, such as silver, which can confer anti-microbial protection to the wound bed. Overall, foam dressings are easy to place and remove and offer comfortable wound protection. Foam dressings are commonly utilized in wound care because of their ability to absorb fluid, provide anti-microbial substances directly to the wound, minimize damage to wound skin during removal (for those with embedded silicone adhesive layer for attachment to skin), and protect against premature dressing detachment [11•].

Mechanical Properties/Stiffness

The fundamental functions of wound dressings are strongly correlated and dependent upon the microstructure of the dressing and the material components therein. There are a variety of wound dressings available across a spectrum of absorptivity. A level of absorptivity of a certain wound dressing is very intricately linked to its specific microstructure. The forces that first draw fluid from the wound into the dressing include the capillary bed pressure, gravity, and capillary action harnessing the intermolecular forces between the fluid and the solid surface of the dressing [12]. However, once the fluid has been transferred into the dressing, the microporous structure of the dressing and any superabsorbent polymer particles or fibers embedded in the dressing, if exist, are responsible for the capacity of absorption and dispersion of fluid within the dressing and its retention within the dressing.

Foam dressings possess a system of micropores linked through interconnecting channels [11•]. The design of these pores allows for fluid absorbency and can be optimized through engineering analyses and material manufacturing processes to meet specific needs of the wound etiology such as a high exudation volume or viscous exudate characteristics. The absorbency of a foam is defined by the combined porosity, or volume of the micropores within it and the extent of their interconnectivity, together with the moisture-vapor transmission rate (MVTR) which is largely affected by the properties of the backing material layer (also called the backing film). Foams are available with a range of pore volume, from 25 to about 1000 μm [13]. Smaller volume micropores will allow for less fluid absorption, while a larger volume micropore allows for a higher absorption. However, there are advantages and disadvantages of each. While the larger pores hold more fluid, they also accept the transfer of cells necessary for wound healing, such as fibroblasts, and lack the stiffness necessary to prevent damage in the setting of mechanical forces such as accidental microtraumas at the wound site [14, 15]. While small pores may limit the absorption of cells, the foam dressing will possess a stiffer quality than foams with larger volume pores and may leave an indent in highly edematous skin, especially when paired with overlying compression devices [16]. In addition, such a (stiffer) dressing will be less conforming to curved body parts and more difficult to apply to small and irregular surfaces (concave or convex) at certain body regions (e.g., the knee or arm pits). Similarly, a more permeable backing material will allow a higher rate of evaporation of fluid from the foam, but will not protect as well from invading pathogens and potential infection. While a less permeable backing may limit MVTR, the wound will be more protected from pathogens in the outside world [17]. Therefore, clinicians must analyze each wound on its own in order to select the appropriate wound dressing. A wound which is highly exudative and requires a dressing with a high absorptivity may desire a foam dressing with a relatively large pore volume and with a more permeable backing material. However, this dressing will also place the wound at various risks, such as losing cells, e.g., fibroblasts to the wound dressing and risk of infection from the surrounding environment. A wound which is less exudative may require a foam dressing with smaller pore volume and a more impermeable wound backing. This wound may be more

protected from the surrounding environment and pathogens; however, the smaller pores confer an increased stiffness to this type of foam dressing. Accordingly, such dressings may not be suitable under a compression device.

Foam dressings also have the capability to be embedded with anti-microbial substances such as silver that release slowly over time or can serve as a structural basis for an anti-microbial treatment agent, e.g., medical-grade honey. This capability allows foam dressings to limit both infection in the wound bed and the spread of infection to other areas of the body via leakage of the wound fluid [11•]. One of the key considerations in wound dressing changes is the balance of properties that allow a dressing to stay in place, versus those that limit skin peeling during removal. There are foam dressings available with a layer of silicone, as mentioned previously, which helps to limit adherence to skin and facilitate wound dressing changes with minimal damage to the wound bed and peri-wound skin. Finally, there is a risk of premature detachment inherent to all wound dressings. Wound exudate may weaken the attachment of a dressing to the skin before intended removal. If a dressing absorbs fluid but traps these fluids at the edges of the wound dressing and does not allow adequate evaporation, that fluid will eventually break down the adhesiveness and cause detachment. Foams demonstrate adequate fluid retention and evaporation, therefore reducing the risk of premature detachment, reducing the frequency of dressing changes, and improving undisturbed healing [18, 19].

Foam Dressings: Types

There are many variations of foam dressings on the market. However, the majority of foam dressings are manufactured with polyurethane, a polymer that provides flexibility, biocompatibility, gas permeability, and water absorptivity, among other qualities that facilitate wound healing [20, 21]. Polyurethane foams possess spherical, interconnecting pores in a cell layout which is called an open-cell format [22]. Polyurethane confers no resistance to bacteria, and often anti-microbial compounds are added to the foams during manufacturing. Foam dressings are also manufactured with the capability of delivering medication to the wound bed in a slow-release mechanism. Silver-releasing foam dressings are frequently utilized in wounds for which anti-microbials would benefit healing. For example, venous leg ulcers (VLUs) are wounds that require a dressing with absorptivity, but which would also benefit from a dressing with anti-microbial properties. Of note, VLUs are at risk for infection due to many factors, and foam dressings imbedded with silver are appropriate in this setting. Silver foams have demonstrated clinical, patient-reported, and economic benefit over other dressings for wounds which require bioburden management [23]. In addition, future directions for foam dressings may include imbedding rhEGF directly into the dressing. Foam dressings with recombinant human epidermal growth factor embedded in the polyurethane foam (rhEGF) have already been developed; however, this rhEGF-embedded foam dressing has not yet been studied in humans. The biological activity of rhEGF is maintained once released into the wound bed, evidenced by improvements in wound contraction, epithelialization, and collagen deposition in mouse models [24]. One cohort study investigated the application of foam dressings followed by spray of rhEGF in patients with head and neck cancers experiencing radiation-induced dermatitis. Seven patients diagnosed with oropharyngeal ($n=3$), nasopharyngeal ($n=2$), hypopharyngeal ($n=1$), and laryngeal ($n=1$) carcinoma who had been treated with radiotherapy were included. Patients were treated with topical wound cleaning and debridement followed by rhEGF spray and new foam dressing placement daily. This method was successful in achieving wound healing in all patients. After 14 days (median = 8 days), each patient achieved complete wound healing without further need for wound dressings [25]. The benefits reported in this cohort study and the clinical improvement seen in mouse models with the novel growth factor-releasing foam support potential for future innovation in foam dressings and wound healing.

Foam Dressings — Indications + Contraindications

Chronic Wounds

Pressure Ulcers/Injuries

Pressure ulcers/injuries develop in the setting of prolonged immobilization, which can occur in various settings, including during hospital admissions, prolonged bedrest at home, and prolonged time spent in a seated position for wheelchair-bound patients. The prevention of pressure ulcer/injury development is of utmost importance, because these wounds add significant comorbidity and loss of quality of life and are also costly to treat and manage. Foam dressings may be utilized in the setting of prolonged immobilization as a prophylactic measure in order to prevent the development of a pressure wound through redistribution of pressure and reduction in friction [26–28]. One study investigated the pressure of the left heel versus the right heel of a supine patient on a viscoelastic foam mattress. This study analyzed 50 healthy patients at a community hospital with an average age of 39.6 years and average body mass index of 26.6. Of the 50 volunteers, 70% were female. Patients were randomized to receive a silicone-bordered foam dressing on one of the

heels. Interface pressure measurements were taken of both heels. The heel with the foam dressing demonstrated a statistically significant decrease in pressure as compared to the heel without a dressing, suggesting the basis for foam dressings in the prevention of pressure ulcers due to added cushioning leading to pressure redistribution [29]. In two randomized controlled trials, data suggests a statistically and clinically significant reduction in the development of pressure ulcers/injuries of the sacrum, heel, and elsewhere with the use of silicone foam dressings versus standard of care [28, 30, 31].

Venous Ulcers

Venous leg ulcers (VLUs) are painful, highly exudative, malodorous, and at risk for infection. Treatment of a VLU requires the use of absorbent dressings which may be utilized in conjunction with compression devices. Foams are one of the most commonly utilized dressings in venous leg ulcers. Due to the nature of VLUs and their proclivity to infection, foam dressings that are manufactured with anti-microbial properties may offer more clinical benefit than foam dressings without anti-microbial properties. In chronically colonized venous leg ulcers, silver-release foam dressings have demonstrated a statistically significant decrease in wound area, odor, leakages, and maceration after 4 weeks than when compared to non-silver foam dressings [32]. In addition, in a study investigating 24 patients with locally infected, stalled, painful, and draining VLUs, foam dressings with both silver- and ibuprofen-releasing capabilities demonstrated a reduction in wound pain after 12 h measured by an 11-point numerical box scale. Pain reduction remained at a low level thereafter across dressing changes. In this study, an improvement in overall wound healing was also found with an average reduction in wound area of 42% [33]. While there is evidence to support that silver-containing dressings improve wound healing in the setting of VLU when compared to dressings without silver [34], there is very limited evidence to support the efficacy of one dressing type over another for a venous ulcer [35, 36].

In some cases of a highly edematous leg requiring the daily use of compression therapy, foam dressings may be contraindicated for VLUs. A stiff foam dressing may leave an imprint in the leg underneath a compression bandage, which can lead to increased inflammation in the wound, decreased viability of the peri-wound skin, and subsequent delayed wound healing [37•]. Overall, while silver-releasing foam dressings absorb exudate, manage odor, decrease pain, and limit infection in the setting of VLUs, the stiffness of the foam dressing should be considered if the patient receives concomitant compression therapy.

Diabetic Foot Ulcers

Another example of a chronic wound that may be treated with foam dressings is a diabetic foot ulcer (DFU). Diabetic foot ulcers respond well to offloading procedures. Topical dressings are used concomitantly to protect the wound bed and encourage a moist wound environment. While foam dressings are utilized for DFUs, little difference in effectiveness has been found when comparing foam dressings to basic wound contact dressings, alginate dressings, or hydrocolloid dressings in the healing of a DFU across randomized control trials [38]. However, in a case series, silver foam dressings have demonstrated significantly improved clinical outcomes in DFUs, including reduced mean ulcer size and reduced wound exudate, and a decreased bioburden of pathogenic organisms [39]. Similar results were seen in another non-comparative study utilizing non-adherent silver-releasing foam dressings [40]. However, improvement in wound healing for diabetic foot ulcers has also been seen with silver-containing hydrofiber dressings. This may indicate that when selecting a wound dressing in the setting of DFUs, different types of silver-containing dressings may be equivocal [41].

Other Indications

Foam dressings are helpful clinically for a variety of indications and are not limited to chronic wounds. Surgical wounds and trauma wounds as well as wounds caused due to radiation therapy can all be treated by means of foam dressings. For example, foam dressings are utilized in the prevention and treatment of radiation dermatitis following radiation for various cancers such as sarcomas, ear nose and throat, breast, cervix, and lung cancers. In one study, 20 patients with radiation dermatitis, including some receiving active radiation therapy, were treated with a management protocol involving preventative measures, topical creams, and non-adhesive, silicone contact layer foam dressings. Radiation dermatitis resolved in 100% of patients within 1 to 2 weeks without evidence of infection [42]. In this study, foam dressings achieved praise from patients indicating ease of use, convenience, and comfort. In a separate case study investigating foam dressings in patients with oncology treatment-related wounds, including radiation dermatitis, silicone bordered foam dressings conferred a reduction in wound exudate levels, an improvement in peri-wound skin, and a reduction in wound pain [43]. While foam dressings have demonstrated improvement in radiation dermatitis wound healing in on their own, another study investigated foam dressings in addition to recombinant human epidermal growth factor (rhEGF) spray in radiation dermatitis [25]. Seven patients with head and neck cancer and a history of radiation dermatitis were

treated with daily debridement, cleansing, rhEGF spray, and finally a foam dressing. All patients achieved complete healing within 2 weeks (median 8 days).

Foams are also utilized for post-surgical wound healing. One study investigated the use of foam dressings to protect newly reconstructed nipples following breast reconstruction. The aim of the study was to test if the addition of multilayered hydrocellular polyurethane foam dressing could help achieve post-surgical healing through the mechanisms of (1) applying adequate pressure to the nipple and (2) maintaining a moist wound environment. In this study, areola skin grafts following reconstructive breast surgery demonstrated improved clinical outcomes with the addition of the multilayered hydrocellular polyurethane foam dressings [44].

The therapeutic use of foam dressings in combination with negative pressure wound therapy (NPWT) has been documented in the setting of a high-energy soft tissue injury. In one case report, a 21-year-old male with a history of a high-energy soft tissue injury of the lower extremity was treated with surgical debridement followed by 2 weeks of traditional NPWT without improvement and with persistent bone exposure. The patient was then treated with a novel reticulated open-cell foam dressing in collaboration with negative pressure wound therapy with instillation and dwell time (NPWTi-d). After 9 days, the patient experienced new granulation of the non-healing, necrotic wound, including over the bone [45]. A split thickness skin graft was then used, and complete healing was achieved. The universally beneficial characteristics of foam dressings make them widely applicable across medical disciplines.

Summary and Conclusions

Foam dressings, as other types of dressings, possess the physical and biochemical characteristics that allow easy application and removal, skin adherence, fluid absorption, evaporation, pliability, and the ability to release anti-microbial silver into the wound bed. These are just a few of the reasons why foams are one of the most often utilized dressings for wound prevention and healing. Diagnoses such as pressure ulcers, venous ulcers, diabetic foot ulcers, and radiation dermatitis have all demonstrated improvement in wound healing with the appropriate selection and placement of foam dressings. However, the indications for foam dressings are not limited to these conditions. Foam dressings have also demonstrated improvements in cost effectiveness when compared to other dressings or standard of care alone. In a study conducted in the United Kingdom, a silver-containing foam dressing consisting of soft, absorbent polyurethane foam bonded to a semipermeable film was evaluated for cost effectiveness when compared with three other silver-containing non-foam dressings. This study evaluated the cost of relative wound area reduction during a 4-week treatment period. Cost-effectiveness analysis revealed that the silver-containing foam dressing achieved the most cost-effective treatment in both wound area reduction and complete wound healing for venous leg ulcers when compared with the other silver-containing non-foam dressings [46]. In a separate study conducted in Spain, polyurethane foams demonstrated a reduction in mean number of dressing changes and a 59% reduction in weekly costs when used for wounds versus standard of care [47]. Foam dressings may provide an economically advantageous tool in wound care. Future directions for foam dressings include the development of various slow-release formulations embedded with growth factors and the potential for collaborative dressings such as a foam gel designed to optimize hemostasis [48]. In conclusion, polyurethane- and silver-releasing foam dressings are manufactured within a range of functionality, including absorptivity and anti-microbial properties, in order to be appropriate for a wide variety of indications. Foam dressings are manufactured to be simple for patients to use and to minimize damage to the wound bed during dressing changes. While foam dressings have been linked with a promotion of wound healing across several clinical indications, more research is needed in order to further quantify the role of foam dressings in wound healing. Further research is necessary in order to elucidate the potential for growth factor embedded foam dressings.

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Compliance with Ethical Standards

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