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Just a Flesh Wound? A Detailed Review of Modern Dressings

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Abstract

Dressings are employed across the world as a ubiquitous form of wound treatment in the 21st century. However, the differences between the thousands of wound dressing products currently available on the market can be difficult for clinicians to understand. Common categories of dressings include bioactive, hydrocolloids, hydrogels, alginate-based gels and semi-permeable films among others. However, understanding each dressing's characteristics is crucial for clinicians to providing the highest standard of care to their patients. This review will highlight the important compositional differences among the most common variants of modern wound dressings and discuss the implications on their clinical applications and antimicrobial properties. As new material is introduced and novel concepts in microbiology are illuminated, more researchers will seek to apply their knowledge to the research and development of modern wound dressings. This review hopes to inspire and guide future studies of wound dressings in an interesting and meaningful direction.

Keywords: Dressings; Wound; Modern wound dressings

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Introduction

Wound dressing is certainly no new topic in the world of medicine. Evidence suggests that over two thousand years ago, Egyptians were already using bandages soaked with grease to manage flesh wounds [1,2]. In the two millennia that followed, newer and more effective tactics have evolved, all the while keeping two central goals in mind [3]. First, dressings should aid, or at least not interfere with the body's intrinsic healing process. Second, dressings should protect the wound from further external damage. The most common cause of such external damage, as clinicians learned through the microscope, turns out to be infection.

These two central concepts remain the basis of moist-wound healing in the 21st century. A dressing that keeps the wound moist can contribute to more rapid healing, less agony for the patient, and better tissue integrity during recovery [4]. To prophylactically combat infection, clinicians have tried integrating various antibiotics, and more recently, metals as well as antimicrobial peptides into wound dressings [5,6]. The continual updates to dressing materials, renewed understanding of microbiology and of the physiology of healing as culminated in a greater confidence in wound treatment. Modern clinicians have countless choices in dressing the various wounds they encounter in their practices, each with their own advantages and drawbacks [7].

This review seeks to illuminate the major types of modern wound dressings and their respective applications, with a focus on their unique material and compositional characteristics. In this rapidly evolving field, it is imperative for future researchers to have an open mind and a special vision. This review hopes to inspire innovation and continual progress in the field of trauma and wound care.

Bioactive dressings

Bioactive dressings are designed to enhance wound healing in addition to being biodegradable. To better fulfill this purpose, researchers used material that are well adapted and compatible with human tissue. Common materials used include collagen

and elastin, hyaluronic acid and chitosan [7]. The first three are some of the most abundant connective tissue proteins found in the human body. Chitosan is derived from chitin, a natural polysaccharide commonly found in arthropods. Chitin is extracted and deacetylated to become the more soluble chitosan, which is also cationic [8]. Like many other polysaccharides, chitin and chitosan were quickly applied to many areas of pharmacological research [9,10].

As early as the 1980s, researchers studied chitin for its use in non-woven wound dressings [11]. There are several advantages to chitin as a dressing material, the first being its role in accelerating wound healing [12,13]. Chitin accomplishes this by adhering cut edges of skin together, tighter than fibrin glue. In addition, chitin-treated wound sites experienced more rapid granulation and subsequent epithelization. It should be noted that a more significant migration of inflammatory cells was present at chitin-treated sites, with no evidence of phagocytosis of chitin itself [12]. Furthermore, chitin and quaternized chitosan-containing nanofibers were also shown to be effective at killing *S. Aureus* and *E. Coli* [14]. Electron microscopy evidence shows that these nanofibers' antimicrobial mechanism includes hindering the adhesion of *S. Aureus*. Additional chemical modifications of chitin resulted in dibutyrylchitin (DBC), in an attempt to further improve biocompatibility [15]. Structural analysis of DBC revealed that it was less crystalline and had higher thermal stability than native chitin [16]. Perhaps the most important improved aspect of DBC is its high resistance to enzymatic degradation, which was studied via challenge by amylase, collagenase, and lysozymes [17]. Having both healing-enhancing properties and antimicrobial effectiveness makes chitin and its derivatives popular material candidates in modern non-woven, bioactive wound dressings. Researchers have also combined chitosan with collagen [18] and hyaluronic acid [19] in newer synthetic materials and studied their enhanced biocompatibility characteristics.

One of the most successful bioactive dressings currently available is the Aquacel Ag®, produced by ConvaTec [20]. The composition and the various properties of Aquacel serves as prime examples of the current advances in the bioactive wound dressing field and serves as a beacon that may help inspire an even better path forward. The current iteration of Aquacel is the culmination of advancements in two key technologies, Hydrofiber® and Advantage®[20]. The dressing is made of non-woven sodium carboxymethylcellulose (NaCMC) infused with ionic silver (Ag+) [20,21]. NaCMC forms the basis of the Hydrofiber® technology, as its fibers absorb wound exudate upon contact to form a moist gel, which promotes wound closure and healing [22]. It should be noted that NaCMC is also commonly used in hydrocolloid dressings [23], which will be discussed in a later section. Meanwhile, the ionic silver is combined with Ethylenediaminetetraacetic (EDTA) and Benzethonium Chloride (BEC) using the Advantage® technology, which is designed to achieve sustainable action against microbes [24].

The NaCMC fibers achieves the goal of enhancing wound healing by three major mechanisms. The first is through exudate and fluid absorption. The NaCMC fibers will form a moist gel soon after adhering to the wet surface of a wound. Importantly, the absorption of exudate is achieved vertically only, lowering the risk of maceration [25]. With traditional bandages and dressings, the moisture absorbed often spreads beyond the area of the wound. Over an extended period, the wound and the area surrounding it becomes wrinkly and edematous. This macerated state of the surrounding skin is not conducive towards healing [26]. By limiting absorption to the vertical direction, Aquacel can ensure that while the wound itself is kept moist, the surrounding tissue is kept dry and non-macerated. The left half of the Figure 1 demonstrates the wide diffusion of moisture in traditional dressings, resulting in maceration and edema of surrounding tissue, hindering wound healing [26]. The right half of the Figure 1 demonstrates the vertical absorption of exudate in Aquacel Ag® as a result of Hydrofiber® technology, keeping the wound site moist, minimizing maceration of normal tissue and promoting healing. Diagram not drawn to actual scale.

See Figure 1 for a demonstration of the unique vertical absorption mechanism that Aquacel employs. The second mechanism of NaCMC fibers to promote healing is through neat contouring of the wound [25]. With traditional dressings, dead space is quite commonly seen between the wound and the dressing fibers. Fluid and tissue debris that accumulate in this dead space creates the perfect environment for microbes to thrive, causing infections [27]. Aquacel's neat contouring to the wound surface helps minimize dead space and thus ensure a smoother, uncomplicated recovery process. The last mechanism of NaCMC fibers in enhancing healing lies in the dressing removal process. The gel-like nature of the Hydrofibers® minimally stick to the granulation tissue of the wound, thus preventing secondary damage common in the removal of traditional dressings [28].

The strategy that Aquacel employs to combat bacteria is ionic silver, which has long been proven to be an effective antimicrobial agent [29]. Silver does so through several mechanisms, including binding to bacterial DNA to prevent cell division, blocking nutrient transport and inhibiting energy production at the bacterial cell wall [30]. In Aquacel, ionic silver is compounded with EDTA and BEC, which enhances silver's antimicrobial efficacy [24,31]. EDTA is often used to enhance antibiotic effects via prevention of bacterial aggregates and promoting the access of antimicrobials to the bacterium [32]. BEC reduces the surface tension of the dressing-wound gel interface, allowing EDTA and ionic silver better access to bacteria [33]. Aquacel compounds ionic silver with EDTA and BEC using Advantage® technology to achieve great efficacy against microbes, even *Pseudomonas* biofilms, commonly seen in nosocomial infections [34].

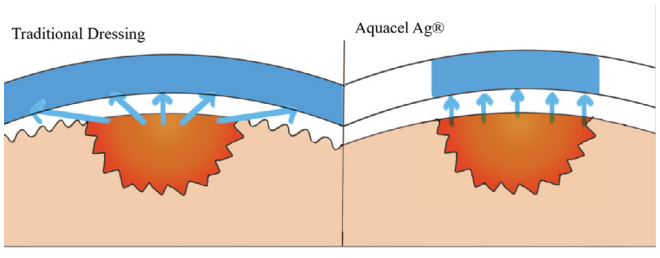

Figure 1 Mechanism of Aquacel Ag® in reducing maceration.

Aquacel can act as a great benchmark for the future development of bioactive wound dressings. Two central development strategies will likely still revolve around actively promoting wound healing and preventing infection. Aquacel is based on NaCMC, but future bioactive dressings may choose to employ chitin, collagen or elastin as adjunct in a new synthetic material [35]. If these components are indeed compatible, the ideal dressing would combine the controlled vertical absorption of NaCMC fibers with the greater biocompatibility of chitin and collagen. In terms of antimicrobial considerations, there are even more possibilities and opportunities. In addition to prophylactic antibiotics and silver nanoparticles, antimicrobial peptides are an interesting direction to explore [36]. In the setting of rapidly developing drug resistance among bacteria, treatment methods like antimicrobial peptides that can circumvent this resistance will be promising. Certain studies have already began exploring possibilities of incorporating these peptides into wound dressings among other applications [37,38].

Hydrocolloid dressings

A hydrocolloid (HCD) is a two layered dressing surface that is opaque, transparent, biodegradable, and breathable. It can adhere over a wound with no separate taping to promote healing as a primary or secondary dressing [39]. The inner layer consists of self-adhesive gel-forming carboxymethylcellulose polymer, pectin, gelatin or an elastomer. The outer layer consists of polyurethane film that seals the wound to protect it from bacteria, foreign debris, and shearing [40,41]. This outer layer can either be occlusive or semi occlusive [42]. There are many types of HCD dressings. The fibrous type is the most popular and composed of sodium carboxymethylcellulose which form to become a gel when it comes into contact with any fluid [41]. Shapes and sizes vary for HCDs and they also are presented in paste, powder, or granule form [40].

In general, the mechanism of HCDs in wound healing is effective because the inner layer provides a moist environment, which promotes autolytic debridement, and the outer layer prevents contamination from bacteria and fluids. First, the HCD dressing is placed in contact with the wound. As the wound produces exudate, the inner layer absorbs the fluids and swells due to increased oncotic pressure to form a gel-like matrix structure. The retention of moisture facilitates an acidic environment to inhibit bacterial growth. Moreover, the inner layer pushes down on the wound, thus promoting fibrinolysis, angiogenesis, and healing without breaking down or softening the patient's skin. Furthermore, the exudate that is absorbed will exert a pressure back onto the wound to reduce further exudate production. See Figure 2 for a simplified demonstration of this mechanism. The outer layer is speculated to play a role in trapping white blood cells that liquefy and prevent necrosis [39,40,42-45].

Indications of using HCDs include healing of partial and full thickness acute or chronic wounds by promoting autolytic debridement [42]. These wounds can include high friction areas (i.e. sacrum, heels) and prevent device-related pressure injuries in intubated ICU patients [42,46]. Although HCDs assume the shape of whatever they are placed onto, they should still be used in line and not to fill a wound cavity. This is because the HCD dressing may strip peri-wound skin if not changed frequently [44]. It is not recommended to use HCDs for healing of dry wounds or wounds with heavy exudation [40,42]. If a patient were to receive HCD dressing for a wound with excess exudate, it is important to remove the HCD prior to the occurrence of hypergranulation [47].

Reviewing literature suggests that the application of HCD dressings were most commonly associated with treatment of ulcers, but may also be beneficial for burns, skin donor sites, surgical/traumatic wounds, and pediatric/neonatal wounds. Some literature concludes that HCD is far superior to other conventional gauze dressings in healing ulcers [48-53]. However, other studies found no statistical significance between dressings in healing ulcers [54-57]. For burn treatment, HCD should be used for superficial burns without necrosis [58]. For skin donor sites, HCD offered better cosmetic results and accelerated healing rates compared to those of conventional dressing [59]. In addition, HCD can reduce pain and heal surgical and traumatic wounds faster than conventional dressing can [60]. Finally, for pediatric/neonatal wounds, HCD is excellent for protecting pediatric skin and can mold into patterns suitable for smaller neonatal sizes [61,62].

Hydrogel dressings

Hydrogel wound dressings are hydrophilic polymers crosslinked by in-situ processes such as electrical fields, magnetic fields, temperature shift, pH shift, light intensity shift, radiation, addition of solvent, and shift in pressure [63,64]. Addition and removal of these processes causes a volumetric shift in the hydrogel, which can swell and reversibly compress back to original size [63]. They are highly flexible dressings with a water content similar to that of the body's own soft tissues. The outer mesh of hydrogel dressings prevents microbial entry. Hydrogels serve as beneficial wound dressings because they control water loss from the wound, keep the wound moist, exchange gases with the atmosphere, are similar in consistency to soft tissue, and can be removed more easily than alternative dressings due to their non-adherent nature [64]. Hydrogels are set apart from alternative wound dressings by their 60-78% water capacity, which can rehydrate wounds to aid in autolytic debridement without the need for significant exudate release to maintain a gel composition [65-67]. Because they absorb only 14-28% of moisture from the wound, hydrogel dressings perform best when placed on lightly exuding or dry

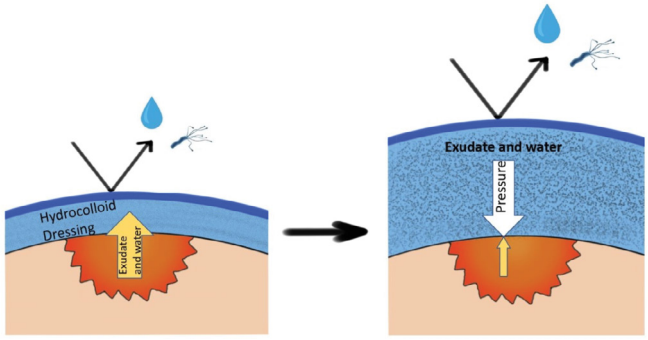

Figure 2 Mechanism of wound healing for HCD surface dressing.

wounds, such as radiation wounds, ulcers, post-surgical incisions, a wide variety of burns, and even meningococcal purpuric macules [66,68]. Hydrogels can absorb some exudate; they also aid in fibroblast proliferation and keratinocyte migration in the wound site [64].

However, many hydrogels suffer from a low mechanical stability due to a tradeoff of viscosity for easy application and elasticity for continued flow after initial application [69]. Because of this tradeoff, as well as inconsistencies in macromolecular structure and low friction between polymer chains, Hydrogels tend to leak more than alternative wound dressings [70]. Water capacity, flexibility, and mechanical stability are major points of differentiation between extant hydrogels on the market [6]. Many hydrogels have improved their stability through an innovative composition. Double network hydrogels are a more stable gel which overlaps two distinct polymer networks, which can synergize to enhance factors like stability, tensile strength, and biocompatibility [71].

Since their invention by Wichterle and Lim in 1960, hydrogel composition has evolved to increase stability and to function as an effective delivery mechanism [72]. Poly (vinyl alcohol)-hydrogel hybrids, which combine natural and synthetic polymers, are very common on the market [73]. Additionally, chitosan bioactive dressings and alginates, which are often utilized in hydrogels, are becoming increasingly popular. Manufacturers are moving away from propylene glycol, which can be a mildly irritating to certain patients [66]. Because the macromolecular network of hydrogel composition can replicate the extra-cellular matrix, biological components or antibiotics can be paired with hydrogels to be delivered to the wound in a time-release manner. Drugs can be added during the gelation process via entrapment, covalent linkage, or use of a micelle/liposome carrier [74]. As the hydrogel swells with moisture and exudate, or as a stimulus is applied, drugs are released from the gel into the wound site, as shown in Figure 3. The hydrophobic polymer chains (green) with cross-linkages (red) undergoes gelation with the drug (blue), which becomes entrapped in the hydrogel. The bottom half of the figure demonstrates three delivery mechanisms from left to right: Stimulus-mediated drug release, simple diffusion through the mesh and swelling release. The first mechanism involves a stimulus (magnetism, glucose, enzymes, electricity, light, radiation, pH, ultrasound, or temperature) applied to the hydrogel, which then promotes drug release. The second depiction shows the drug as it slowly diffuses out of the polymer chains in a time-release format. The last mechanism involves the hydrogel swelling with moisture and exudate from the wound. The influx of water then flushes out the drug from the now loosened polymer chains. This can be particularly beneficial in increasing patient compliance, thus improving therapeutic outcomes for those with chronic wounds [75]. With this advantage, hydrogel dressings can be further modified to be an effective mechanism for delivery of drugs, nanoparticles, enzymes, stem cells, or growth factors [76-78]. Because of this addition mechanism, some modern hydrogels such as DermaGel and Intrasite Gel have been proven to have a higher efficacy against *Candida*, *Pseudomonas*, and *Staphylococcus* infections than traditional dressings [66]. Other hydrogels even have enzymatic mechanisms built-in to fight antibiotic resistance in bacteria [79,80].

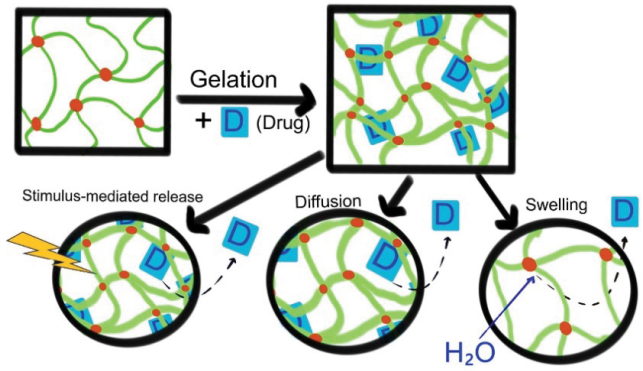

Figure 3 Hydrogel dressing drug delivery mechanism.

Alginate dressings

Alginate is another biopolymer frequently used in wound dressings. Derived from the cell walls of brown algae species (*Ascophyllum nodosum, Laminaria Hyperborean, Macrocystis pyrifera, Laminaria japonica, Laminaria digitate)* as well as from some bacteria (*Azotobacter vinelandii, Pseudomonas spp.*) [81], alginate is a linear polysaccharide composed of β-(1,4) linked D-mannuronic acid (M) residues and α-(1,4)-linked L-guluronic acid (G) residues [82]. Alginate monomers are arranged of consecutive M-residues (M-Blocks), G-residues (G-Blocks), or alternating M and G residues (MG-Blocks) depending its source material [82]. The unique arrangement of these blocks is demonstrated in Figure 4 and determines the physical and biomechanical characteristics of the alginate polymer. The left side of the image illustrates the egg-box structure that forms from the binding of G-residues on opposite sides of the alginate polymer in the presence of divalent cations. This crosslinking of alginate polymers leads to the formation of alginate gels. The right side of the image illustrates the structure of M-Blocks, G-Blocks, and M-G Blocks that make up alginate monomers and give alginate its biologic and mechanical properties [82]. Increasing the M:G ratio stimulates cytokine production, leading to a greater immunogenic effect. Decreasing this ratio leads to a stiffer, more stable structure [83]. The monomeric units come together to form linear, unbranched polymers of alginate, which can then crosslink with divalent cations (Ca^{2+} and Ba^{2+}) via ionic bonding to form alginate gels. In this process, G-residues on opposite sides of the polymer bind to each other, forming a diamond shaped "egg-box" structure with a hydrophilic center that binds the divalent cations.

Alginate dressings are formed from polymers of alginate coated in calcium and sodium salts [84], and ionic exchange between the dressing and wound exudate leads to crosslinking and the formation of alginate hydrogels [85]. Alginate is well suited for wound care because its features resemble those of the human tissue extracellular matrix while being naturally biocompatible [86], non-immunogenic [85] (if properly purified [83]), and affordable [87]. The strongly hydrophilic nature of alginate increases its capacity for wound exudate absorption (absorbs

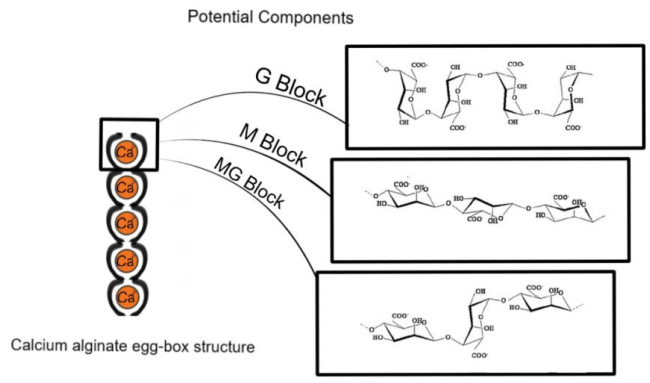

Figure 4 Molecular composition of calcium alginate dressings' egg-box structure.

15–20 times its weight in fluid) [88]. It provides the wound with a moist microenvironment to promote healing [89], and confers protection against bacteria [90,91]. The high absorption capacity makes these types of dressings useful for minimally, moderately, and heavily exudative wounds [92-96] as well as chronic wounds [97,98]. The release of calcium ions in alginate dressings activates platelets, improving alginate's hemostatic capabilities and making it effective for the management of bleeding wounds [99,100]. These biological and chemical properties of alginate work together to increase the efficacy of wound healing [90,101].

Different nanomaterials can also be added to alginate gels to increase their antimicrobial capabilities or to promote tissue growth. Alginate has been combined with nano zinc oxide [102], silver nanoparticles [103,104], ammonium salts [105], chitosan [106], or loaded with antibiotics such as moxifloxacin [107] and ampicillin [108]. Simvastatin-incorporated alginate has shown an ability to upregulate hypoxia-inducible factor-1α and vascular endothelial growth factor, leading to increased angiogenesis [109]. Amniotic fluid loaded into alginate led to greater wound healing by increasing cell proliferation and spreading. It also led to a greater degree of collagen secretion at the wound site [110].

Despite is many advantages, alginates' relatively poor mechanical properties [111,112] necessitate that they be combined with synthetic and natural polymers to improve their stability [113,114]. One ionic polymer that is frequently combined with alginate is chitosan, and ionic crosslinking between the two polymers leads to increased hydrogel structural stability [97,115-118] as well as stronger antimicrobial properties [106,119]. Alginate has also been combined with gelatin [120-122], nanocellulose [123], bioglass/agarose [124], carboxymethyl chitosan [125,126], and polyacrylamide [127] to improve its mechanical stability. Another biomechanical limitation of alginate is that higher molecular weight alginate strands cannot be broken down due to a lack of mammalian alginate-degrading enzymes. Oxidizing the M and G residues of alginate has been shown to increase the biodegradability of alginate [128].

While alginate hydrogels are the most commonly used form of alginate wound dressing, additional forms of alginate-based dressings include foams, wafers, films, membranes, nanofibers, and sponges [85]. All these different forms of alginate contain its innate properties of biocompatibility, non-immunogenicity, and high absorption capacity. Alginate foams are also easy to apply, with minimal discomfort to the patient and conveniently removable from the wound site [129]. They also have an extended hydration time, large surface area, a high degree of porosity, and can be loaded with bioactive agents [130]. Freeze-drying alginate polymer solutions via the lyophilization method results in solid, porous wafers whose structure resembles foam dressings but turn into a gel upon coming into contact with wound exudate [131,132]. Alginate based films and membranes can be used as dressings, but are not effective for wounds with high levels of exudate [7,99]. Nanofibers have shown some potential as an alginate-based wound dressing due to their ability to improve epithelial cell proliferation and tissue formation [35], promote hemostasis [133], and their strong biomechanical [134] and antimicrobial [135,136] properties, but they are currently both difficult and expensive to produce [137,138].

The future of alginate dressings is likely going to focus on testing the loading and releasing of various bioactive molecules to wound sites to better optimize the dressing's tissue repair and antimicrobial effects. Currently, alginates loaded with a single antibiotic show much faster rates of drug delivery than dual-antibiotic loaded alginate dressings, but microfluidic technology could produce pH-responsive alginate composites with a greater ability to deliver dual-antibiotics [139]. Modification of alginate to be more biomechanically stable and biodegradable while maintaining its absorptive capabilities will also likely be a key area of focus in the bioengineering of novel alginate dressings [89]. Lastly, if the clinical effectiveness of alternative forms of alginate dressings can be increased while simultaneously decreasing their production cost, their usage may become significantly more widespread [85].

Semi-permeable film dressings

Semi-permeable film dressings are non-porous, flexible, thin, and transparent, sheets of polyurethane covered with an adhesive layer that allows the dressing to adhere to the skin. These polyurethane sheets are permeable to gas such as O_2 and CO_2, but impermeable to liquid and microbial organisms. Semi-permeable dressings prevent microbial migration and protect the wound. They are intended for simple superficial injuries such as lacerations, burns and abrasions.

As a flexible sheet, semi-permeable film dressings: (i) easily adhere to the skin, (ii) allow for evaporation of moisture, (iii) relieve pain, (iv)act as barriers from the external environment (v) allow for easy inspection of wound without dressing removal [140]. In terms of disadvantages, semi-permeable films can cause injuries on removal and can pool exudate on the wound when used as a secondary dressing. Furthermore, semipermeable films are non-absorptive dressings, and inappropriate dressing choices can lead to the damage of the surrounding skin and, increasing risk of infection.

Semi-permeable films can be used as primary dressing or secondary dressings when applied simultaneously over an exudate, such as a foam. When applied as a secondary dressing, semi-permeable films act as a protective cover for the wound. In surgery, semi-

permeable films can be used to protect postoperative wounds and have been more cost effective and efficient compared to traditional gauze dressing [84]. The use of semi-permeable films serves as a barrier to external contamination. Further, this barrier prevents microbials entrance and infection. As a result, the wound can easily self-heal without the infringement of external factors. Additionally, semipermeable film dressings are beneficial in preventing and managing of radiation-induced skin reactions, such as radiation dermatitis of different grades [141].

Some semi-permeable film dressings currently on market are Biofilm, Biooclusive, Hydrofilm, Mepilex Film, OpSite, OpSite Flexifix Gentle and Tegaderm [142]. These products are used for light abrasions or postoperative sutured wounds. Films can be maintained in place for up to seven days, and the replacement period may depend on the size and type of the wound.

A future enhancement of semi-permeable film dressing is an ozone generating system film dressing [143]. Wearable and flexible ozone (O_3) generating system has been suggested to treat non-healing and critically infected wounds by providing strong antibacterial properties while accelerating local tissue regeneration. Ozone is known to inactivate bacteria, viruses, fungi, yeast, and protozoa through the oxidation of phospholipids and lipoproteins in the cell envelope, which can weaken or destroy bacterial walls [143]. Further, the presence of ozone activates fibroblast growth factors, triggers angiogenesis, and promotes tissue regeneration [144]. The ozone generating system proposes a multilayered patch that utilizes the characteristics of ozone against microbials and treat chronically infected wounds. This system works by uniformly dispersing a small amount of ozone to the site of infection or wound via a portable device, which is demonstrated in Figure 5. This figure demonstrates the various layers of the ozone-enhanced wound dressing system as outlined by Roth *et al*. PDMS is the abbreviation for Polydimethylsiloxane, an organosilicon compound that confers hydrophobicity. This patch thus incorporates a hydrophobic and highly ozone-permeable outer layer and an inner dispersion layer for more a more uniformed gas distribution [143]. Figure is not drawn to actual scale.

Research has shown that a small amount of ozone is cytotoxic to antimicrobial resistant strains bacteria, *P. aeruginosa* and *S. epidermidis*, but noncytotoxic to human basal skin cells [143]. However, a drawback of such a system is that it requires a sizable portable device that is only likely to be available in clinic settings [143]. In prospect, the development of a portable ozone semi-permeable film would significantly enhance the management of chronically infected wounds against resistant microbes.

Another notable approach to semi-permeable films would be incorporating it with nanomaterials-based film dressings [84]. Nanomaterials (NMs) can be designed to have antibacterial, anti-inflammatory, proangiogenic, and proliferative properties [84]. Additionally, NMs can modulate the expression of essential proteins and signal molecules to improve wound healing processes. Research has proposed that a nanofiber-based semi-permeable film dressing can be used at the site of injury. Nano-

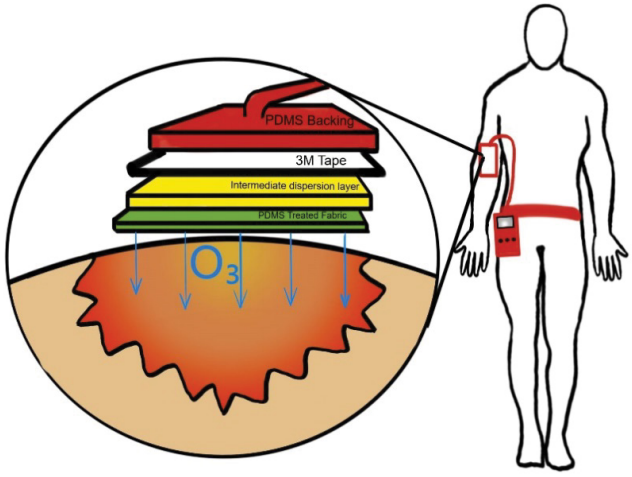

Figure 5 Enhancement of semi-permeable film dressings using ozone production system.

fibrous membranes can detect changes in pH of an injured site and release antibiotics and other drugs to enhance wound healing.

Concluding Remarks and Outlook

Understanding the subtle differences between wound dressings can potentially help the clinician achieve a better outcome for his/her patient, whether that is a less painful recovery, a shorter hospital stay, or in the most emergent of cases, decreased mortality [145]. However, it is also impossible for every practicing physician to memorize information about every type of wound dressing available in the market. Thus, this review aims to inform clinicians about the most significant aspects of each major category of trauma dressing. It goes into detail regarding their material and compositional characteristics for those that are more concerned.

The preeminent goal in the development of trauma dressings would be to create one that is highly adaptable and effective for the widest range of wound conditions. For example, combining the biocompatibility of bioactive dressings with the non-irritant properties of hydrogels and exudate-suppressing qualities of the hydrocolloids [7,12,146]. This may be impossible at present due to the inherent limits of material synthesis technology, but may become a reality soon, with the advent of novel methods of creating more complex composites. Currently, most advancement in the field comes from discoveries of new materials that enhance healing or inhibit microbial activity [43]. This serves as a solid foundation for the next significant phase in wound dressing research- the mixing and matching of such materials in search for the most efficacious composite or synthetic. Given the dire current situation regarding the Covid-19 pandemic [147-149], investments in the biotech field is surging, helping to accelerate microbiology research in the near future.

There will be tense competition in the arena of future trauma dressing research. However, this competition can be “synergistic”

and help the industry flourish. The copious number of materials studied now can will translate to countless future opportunities. Creation of newer, better and more affordable wound dressings will benefit millions of patients around the world and perhaps even revolutionize acute trauma care.

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Conflict of Interests

The authors have no conflict of interests to declare.

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