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REVIEW ARTICLE / DERLEME MAKALE

PROPERTIES OF IDEAL WOUND DRESSING

İDEAL YARA ÖRTÜSÜNÜN ÖZELLİKLERİ

Seçil KAYA[1], Serap DERMAN[1]*

[1]Yıldız Technical University, Faculty of Chemical and Metallurgical Engineering, Bioengineering Department, 34220, Istanbul, Turkey

ABSTRACT

Objective: *Many substances have been used for wound-burn treatment to date. Recent studies have focused not only on covering the wound but also on the production of dressings that will provide patient comfort at the highest level. This review mentions the types of dressings and the expected features of an ideal wound dressing. An ideal wound dressing should close the wound and protect against external factors such as microorganisms. It must have an appropriate absorption capacity for the exudate level in terms of not drying the wound. It should mimic healthy skin with mechanical strength and flexibility. Wound dressing is expected to accelerate healing by supporting cell proliferation and migration.*

Result and Discussion: *One or more of these features come to the fore when the patient's age and chronic diseases, wound depth, degree, and stage are considered. As a result, since many factors are influential in wound dressing selection, it is crucial to examine the properties of materials. Wound dressings should be developed by considering tissue debridement, infection control, moisture balance, and epithelization.*

Keywords: *Hydrogels, nanofibers, wound, wound dressing, wound healing*

ÖZ

Amaç: *Yara ve yanık tedavisinde günümüze kadar birçok madde kullanılmıştır. Son yıllardaki çalışmalar yaranın yalnızca kapatılmasına değil hasta konforunu en üst düzeyde tutacak malzemelerin üretilmesine de odaklanmaktadır. Bu derleme makalesinde yara örtüsü türlerinden ve ideal bir yara örtüsünden beklenen özelliklerden bahsedilmektedir. İdeal bir yara örtüsü yarayı kapatmalı, yarayı dış faktörlerden ve mikroorganizmalardan korumalıdır. Yarayı kurutmaması açısından eksuda düzeyine uygun emilim kapasitesine sahip olmalıdır. Mekanik mukavemet ve esneklik konusunda sağlıklı cildi taklit etmelidir. Yara örtüsünün hücre çoğalmasını ve göçünü destekleyerek iyileşme sürecini hızlandırması beklenmektedir.*

Sonuç ve Tartışma: *Hastanın yaşı ve kronik hastalıkları, yaranın derinliği, derecesi ve evresi dikkate alındığında bu özelliklerden bir veya birkaçı ön plana çıkmaktadır. Sonuç olarak yara örtüsü*

* **Corresponding Author / Sorumlu Yazar:** Serap Derman
e-mail / e-posta: serapacar5@gmail.com, **Phone / Tel.:** +902123834643

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seçiminde pek çok faktör etkili olduğu için malzemelerin özelliklerinin incelenmesi büyük önem taşımaktadır. Yara pansumanları doku debridmanı, enfeksiyon kontrolü, nem dengesi ve epitelizasyon dikkate alınarak geliştirilmelidir.
Anahtar Kelimeler: *Hidrojeller, nano lifler, yara, yara iyileşmesi, yara örtüsü*

INTRODUCTION

The skin is composed of three layers: the epidermis, dermis, and subcutaneous layers. The skin accounts for approximately 15% of an adult's body weight. The epidermis, which contains 95% keratinocyte cells, is the outermost layer of the skin [1]. There are collagen fibers, elastic tissue, fibroblasts, plasma cells, lymphocytes, dendritic cells and blood vessels in the dermis layer. The dermis layer contains free nerve endings and nerves that are responsible for touch and pressure sensations. The subcutaneous layer is the innermost layer of the skin and consists of lipocytes. Around 80% of the body's fat is stored in the subcutaneous layer [2].

A wound is defined as the deterioration of skin and tissue integrity as a result of physical or thermal factors [3]. Wounds are classified as acute or chronic based on their natural healing time and depth. Wounds that heal spontaneously within 8-12 weeks are called acute wounds, while those that do not heal normally and require surgical operation are called chronic wounds [4]. Wound healing is a complex process that involves a series of signal transduction and cellular activities in the body, starting with injury. It occurs in four phases: hemostasis, inflammation, proliferation and remodeling. The necessary condition for wound healing is the correct timing and succession of these processes as soon as possible. Factors such as the patient's age, chronic conditions, the wound's stage, and the wound's depth should be considered when selecting the appropriate dressing [5].

In the hemostasis phase, the coagulation process begins with the activation of platelets and the release of clotting factors at the injury site. The hemostasis and inflammation phases begin within a few seconds at the time of injury. The inflammation phase involves purifying the injured area from pathogens and dead cells. Inflammation occurs due to the response of the immune system. The prolonged duration of this phase or high degree of infection can cause painful processes that seriously reduce patient comfort [6]. Cellular activities taking place at the inflammatory stage prepare the wound bed for new tissue formation. Neutrophils are the first blood cells that migrate into the wound to destroy bacteria and remove dead tissue. Neutrophils decrease in number after about 2-3 days, leaving their place to macrophages. Macrophages attract other immune system cells to the area by secreting growth factors and proteins, thus accelerating tissue repair [5]. The proliferation phase begins with the formation of new tissue in the cleaned areas. Granulation tissue is formed during the accumulation of new cells in the wound bed. This granulation tissue can provide the filling of the wound with connective tissue and the formation of new blood vessels. The epithelial tissue around the wound is stretched simultaneously because the cells are pulled toward the center of the wound. This phase continues for 4-20 days until the wound bed is completely covered. The new tissue formed when the remodeling phase begins is weak in terms of mechanical strength and flexibility compared to healthy tissue. Collagen fibers differentiate, and the process of gaining elasticity and strength of the newly formed tissue continues for a long time. This stage can continue for years depending on the patient and the condition of the wound. As a result, scar tissue with a strength of approximately 80% of healthy tissue is formed [6,7].

The literature contains numerous studies on wound dressings, each of which generally focuses on a specific feature. For instance, one study may emphasize the physicomechanical properties of wound dressings [8], while another may examine their antimicrobial effectiveness [9]. In a brief comment, Carta et al. [10] outlined the characteristics of an ideal burn cover. In this review, the properties of an ideal dressing have been explained for the first time in the literature. This review aims to draw attention to the selection of the ideal wound dressing by providing information about modern dressing types. The different types of dressings are explained under the title of "Wound Dressing," followed by a discussion of the general characteristics of an ideal wound dressing under various headings.

Wound Dressings

Wound therapy has come a long way in recent years, with modern wound dressings playing a key role in current approaches to wound management [11]. Modern wound dressings offer a range of benefits, including improved healing rates, reduced risk of infection, and enhanced patient comfort. In this context, it is essential to understand the applications of these dressings in wound therapy. This topic is of great importance for healthcare professionals, patients, and their families, as it can provide insights into the latest trends and developments in wound care. Wound dressings have been used for centuries to protect wounds from infection and promote healing. However, modern wound dressings have become increasingly sophisticated and effective with advancements in technology and materials science. Today, a wide variety of wound dressings are available to meet the specific needs of different types of wounds and patients. These modern wound dressings have revolutionized the approach to wound therapy, providing improved outcomes, reduced healing times, and greater patient comfort. In this context, it is essential to understand the various applications of modern wound dressings and how they are used in current wound therapy approaches [12].

Wound dressings can be produced from a variety of materials including starch, dextran, chitosan, alginate, polyurethane, cellulose derivatives, hyaluronic acid, polysaccharide derivatives, collagen and gelatin [13,14]. Based on the production method and materials used, modern wound dressings can be classified into several categories: films, foams, nonwovens (including electrospun and blow spun), 3D printed dressings, and hydrogels [15].

Film Dressings

Film dressings are typically made by creating a thin film through the process of solvent evaporation, using a natural or synthetic polymer or a combination of both [16]. One of the notable characteristics of film dressings is their mechanical properties, such as strength, tensile strength, softness, flexibility, and elasticity [17]. Additionally, film dressings possess a transparency feature that allows for the monitoring of the wound without having to remove the dressing [18]. Paramylon (β-1,3-glucan), a natural compound synthesized by Euglena gracilis, is used in the production of film dressings. Paramylon film dressings, similar to bacterial cellulose, keep the wound moist and support the continuity of cellular activities. Furthermore, it has been observed that paramylon films promote a greater closure of the wound compared to cellulose films [19].

Foam Dressings

Foam dressings, made of polyurethane foams, are produced by reacting organic compounds (polyols) containing multiple hydroxyl groups with diisocyanate [20]. Polyurethane foams have various advantages, including softness, flexibility, air permeability, and high exudate absorption (about 1500%). Research has indicated that the absorption capacity and resistance to pressure of foam dressings increase when natural polyols such as alginate and hydroxypropyl methylcellulose are used in foam synthesis [21]. However, a disadvantage of foam dressings is that they can dry out wounds with very little exudate, making them more suitable for use in highly exuding wounds [22].

Nonwoven Membrane Dressings

Nonwoven materials are composed of fibers ranging in thickness from a few microns to several hundred nanometers. While various methods can be used to produce nanofibers, the electrospinning technique is preferred due to its simplicity and cost-effectiveness. This technique involves delivering a polymeric melt or solution under high electrical power to a collector at a specific flow rate as fibers [23]. By modifying the basic electrospinning device or adjusting conditions, fibers with a wide range of properties can be produced [24]. In a study by Yang et al. [25], natural and synthetic polymers were used to produce Ag nanoparticles and ciprofloxacin-loaded nanofibers using a side-by-side spinneret without dissolving them in the same solvent. An alternative method for nanofiber production is the blow-spinning process, which uses a compressed air unit instead of high voltage. Unlike electrospinning, fibers can be deposited on any surface without the requirement of being conductive. It has been reported that blow spinning can be used to cover intra-body wounds during surgery [26,27].

Nonwoven wound dressings also possess several characteristic properties that make them unique and well-suited for wound care: absorbency, breathability, conformability, comfort, biocompatibility, and cost-effectiveness. Nonwoven wound dressings are designed to absorb and retain exudate from the wound bed, which helps to keep the wound moist and promote healing. Nonwoven dressings are typically made from porous materials that allow for proper ventilation and oxygenation of the wound site [28]. They can conform to the contours of the wound bed, ensuring that the dressing stays in place and providing protection against further injury or infection. They are typically lightweight and comfortable to wear, reducing discomfort for the patient. Nonwoven dressings are made from materials that are biocompatible and non-toxic, which minimizes the risk of allergic reactions or other adverse events. They are often less expensive than other types of wound dressings, making them a cost-effective option for wound care. Overall, nonwoven wound dressings are a reliable and effective option for wound care, with a range of properties that promote healing, protect the wound from further damage or infection, and provide comfort for the patient [29].

3D Printed Dressings

The use of 3D printer technology enables the production of wound dressings with controlled micro-architecture and geometry. In recent years, 3D printing has emerged as an alternative method to produce biocompatible materials for wound care using polymers and bioactive materials. These materials are designed to support cell adhesion, migration and tissue regeneration [30]. The most important features expected from 3D materials are their ability to mimic skin, promote cell growth, enhance blood circulation, and deliver nutrients to tissues [31]. Long et al. [32] produced a dressing material based on chitosan-pectin (CS-PEC) using the 3D printing method. The CS-PEC hydrogel formulations were shaped into a 3D structure with a cubic lattice made of polylactic acid (PLA). The CS-PEC dressing materials are biodegradable, temperature-sensitive, absorbent, flexible and can be integrated into the tissue, according to the authors [32].

Three-dimensional (3D) wound dressings possess several characteristic properties that make them unique from traditional flat dressings. One of the key features of 3D dressings is their ability to create a three-dimensional structure that conforms to the contours of the wound bed. This allows for improved contact between the dressing and the wound, which can enhance the delivery of therapeutic agents and promote faster healing. In addition, 3D dressings can also provide increased mechanical support to the wound bed, which can help to protect the wound from further damage and promote tissue regeneration. The porous nature of many 3D dressings also allows for better ventilation and moisture management, which can help to prevent infection and improve wound healing. Overall, the special characteristic properties of 3D wound dressings make them a promising option for wound care, offering improved outcomes and greater patient comfort compared to traditional flat dressings [33].

Hydrogels

Hydrogels are commonly used in the biomedical field as drug delivery systems, for cell adhesion support, as a barrier, contact lens, absorbent, and scaffold. Their three-dimensional polymeric network structures allow them to absorb high amounts of exudate and other body fluids. Additionally, hydrogels cool the wound surface and reduce pain. Bacterial cellulose is one of the natural polymers used in hydrogel production, and although it does not possess antimicrobial properties, its cross-linked fibrous structure allows it to carry antimicrobial agents. PVA hydrogels have the advantage of absorbing exudate, but their low elasticity and mechanical strength require support from carbon-based materials such as graphene or graphene oxide (GO) [34-37].

The dressing produced with calcium alginate hydrogel is an affordable option that provides a moist healing environment. However, its mechanical properties weaken after swelling due to the absorption of wound fluid. Additionally, it does not have antimicrobial properties and does not contain sites suitable for cell adhesion. Therefore, it is often used in combination with antibiotics, nanoparticles, or natural antibacterial molecules [38]. Chitosan is a natural polymer that has wound healing properties and can inhibit the growth of microorganisms. PVA/chitosan hydrogels can be produced through a simple freeze-thawing process without the need for aldehyde-based crosslinkers. The material has strong intramolecular and intermolecular hydrogen bonds and is non-toxic [39].

Hydrogel wound dressings have several unique characteristic properties that make them suitable for wound care. Some of these properties include moisture retention, cooling effect, biocompatibility, non-adhesive, non-occlusive, and long-lasting. Hydrogel dressings are highly absorbent and can retain large amounts of fluid. This helps to maintain a moist wound environment, which is important for wound healing [40]. The dressings have a cooling effect when applied to the wound, which can help to reduce pain and inflammation. They are biocompatible, meaning they are not toxic to living tissue. This makes them safe to use on all types of wounds, including those that are sensitive or fragile. Hydrogel dressings are non-adhesive and do not stick to the wound bed. This makes them easy to remove without causing additional trauma to the wound. They are permeable to gases, which allows for the exchange of oxygen and carbon dioxide. This helps to maintain a healthy wound environment and promotes healing. They can be left in place for extended periods, which reduces the need for frequent dressing changes and minimizes the risk of infection. Overall, hydrogel wound dressings provide a gentle and effective way to manage a wide range of wounds, making them a popular choice for healthcare professionals and patients alike [41].

Properties of Ideal Wound Dressing

When selecting a wound dressing, several factors are considered, including the patient's age and chronic disease history, as well as the depth, stage, infection level, and exudate amount of the wound. Although the definition of an ideal dressing may vary depending on the patient and wound type, there are common desirable features. An ideal wound dressing should protect the wound from the environment and microorganisms while also being comfortable, biocompatible, and durable. It should not irritate the wound and should be non-adherent, although it may have a frame that adheres to the surrounding tissue. Additionally, it should allow for gas exchange and maintain a moist wound bed [42,43]. The European Wound Management Association (EWMA) has established a wound care strategy that includes four key points: tissue debridement, infection control, moisture balance, and epithelialization [44,45].

An ideal wound dressing should promote and accelerate the natural healing process of the wound while protecting it from external factors. It should maintain a moist environment to prevent the wound from drying out, but at the same time, it should not create excessive moisture that can lead to maceration or bacterial growth. The dressing should be able to absorb excess exudate while preventing leakage to the surrounding healthy skin. It should also be easy to apply, remove, and dispose of. An ideal dressing should have antimicrobial properties to prevent or manage infection in the wound area. The dressing material should be biocompatible, non-toxic, and non-allergenic, without causing any adverse reactions in the body. Finally, the ideal dressing should be cost-effective and readily available in different forms suitable for various wound types and stages. The combination of these properties can help promote healing, reduce pain, and improve the quality of life of patients with wounds [46].

The properties of the ideal dressing are explained under the headings of mechanical properties, infection control, moisture balance, epithelialization, gas exchange, and cost-effectiveness.

Mechanical Properties

Since the primary purpose of wound dressings is to cover and protect the wound, their mechanical strength is an important consideration. To determine the mechanical properties of dressing material, factors such as elasticity modulus (Young's modulus), tensile strength, and stability (thermal and chemical) are investigated [47,48]. The elasticity modulus (stress/strain) refers to a material's resistance to deformation when subjected to applied stress. When the applied tensile force exceeds the elastic limit, the material becomes irreversibly deformed. Tensile strength (force/area) is the maximum tensile force a material can withstand before breaking [49]. In a study [50], the effects of adding graphene oxide (GO) to alginate/PVA nanocomposite sponges on the sponges' tensile strength and elasticity modulus were investigated. The results showed that the addition of GO at a rate of 2% significantly increased the tensile strength and elasticity modulus of the nanocomposite sponges. It was suggested that GO improves the mechanical properties of alginate and PVA by increasing the crosslink density [50].

Flexibility is an important feature sought in wound dressings to provide ease of movement to patients and to allow for adaptation to various joints and folding areas. Flexible materials are characterized by high elasticity modulus and tensile strength [51]. Silk fibroin dressing materials [52] are reinforced with dextrose to increase flexibility and mechanical strength. While the elongation of silk fibroins at rupture was $3.2 \pm 0.7\%$, the addition of 15% dextrose increased this ratio to $40.1 \pm 2.5\%$ [41]. One flexible dressing on the market is Foam Lite™, which is a foam dressing designed for use on low-exudate wounds. It has been noted that this dressing can adapt perfectly to a patient's body movements and posture positions [53]. Biatain® is another flexible dressing produced in suitable forms for different parts of the body [54]. Acticoat® Flex 3 and 7 are made from a single braided polyester material that promises to minimize discomfort and local trauma for the patient [55,56].

Infection Control

Patients with burns that cover more than 40% of the total body surface have a high risk of dying from infection, estimated to be 75%. Orthopedic traumas and surgical wounds are also considered high risk for infection [57]. During the initial stages of wound healing, gram-positive bacteria such as S. aureus and *S. pyogenes* are the main microorganisms that cause infection, while in the chronic phase, gram-negative species such as *E. coli* and *P. aeruginosa* predominate. When infection occurs in a healthy individual, the immune system becomes active, and macrophages migrate to the wound site. In the later stages of infection, T lymphocytes secrete interferon-γ and CD40 ligands, which help in fighting the infection. However, if the immune system fails to destroy the pathogen, infection occurs, and extracellular matrix components (collagen, elastin, and fibrin), growth factors, and granulation tissue are disrupted, which can delay healing [58]. Therefore, it is crucial to develop a dressing that prevents microorganisms from entering the wound or inhibits microbial growth. Antimicrobial agents commonly used in dressings include antibiotics, nanoparticles, natural compounds, honey, essential oils, and chitosan [59]. Over the years, many antibiotics such as ciprofloxacin [60], streptomycin [61], vancomycin [62], and gentamicin [63] have been loaded into wound dressing materials. Infection Defense® is an adhesive bandage containing neomycin sulfate, bacitracin zinc, and polymyxin B antibiotics. This marketed antibiotic-loaded wound dressing is intended for large and minor wounds to prevent infection and promote healing [64].

The study investigated the antimicrobial activity of crosslinked films made of gelatin, chitosan, and cinnamaldehyde against various bacterial species, including gram-positive *S. aureus* and gram-negative *P. aeruginosa, Salmonella,* and *E. coli* [65]. Cinnamaldehyde is the main component of cinnamon oil and is known for its antimicrobial properties. While gelatin does not have antimicrobial properties, chitosan has been shown to have a broad range of activity against microorganisms. The addition of cinnamaldehyde to the films resulted in increased inhibition of bacterial growth, likely due to the interaction between the aromatic aldehyde groups in cinnamaldehyde and the amine groups in the peptidoglycan layer of the bacterial cell wall [65]. Aside from plant-derived compounds, extracts obtained from various parts of plants, such as leaves, flowers, roots, and stems, are also used as antimicrobial agents. For instance, the root extract of *Isatis tinctoria*, also known as woad or isatis, loaded onto polyvinylpyrrolidone (PVP), has been shown to inhibit the growth of many bacterial species [66]. Honey is another natural product with antimicrobial activity, which is attributed to its multiple components, including bee-derived defensin-1, an antimicrobial peptide, and polyphenols. Honey inhibits the growth of microorganisms through its high osmotic pressure and low pH [67]. A study has shown that incorporating Manuka honey, a type of honey produced by bees from *L. scoparium* flowers in New Zealand, into cellulose acetate nanofibers resulted in films with 2.74 ± 0.24 and 3.6 ± 0.35 mm inhibition zones against *S. aureus* and *E. coli*, respectively [68]. Roosin® is a wound dressing that contains Manuka honey and is designed for the treatment of second-degree burns, foot ulcers, and pressure ulcers [69]. Another example of commercial dressings with antibacterial properties is Mepilex® Ag, which contains silver nanoparticles. This dressing can inactivate wound-related pathogens within 30 minutes and maintain its effectiveness for up to 7 days. It is used for the treatment of low or moderate exudate wounds, such as leg and foot ulcers and partial burns [70].

Moisture Balance

The use of wound dressings can help maintain moisture balance, reduce pain and infection, and decrease wound care costs by shortening the healing period. It is important to create and maintain a moist wound environment but avoid excessive fluid accumulation. During the inflammatory phase, wounds produce a high amount of exudate which can cause surrounding tissues to soften, become unstable, and encourage microbial growth. Dressings should therefore absorb and remove excess fluid, without drying out the wound. Additionally, the dressing should be able to maintain its structure and remain in place for an extended period [71]. Hydrogels produced with hyaluronic acid and chitosan were found to have a swelling capacity of 4500%, making them "superabsorbents" [72]. Adding citric acid as a crosslinker to super absorbent dressing materials produced with carboxymethyl cellulose increased the swelling rate to 5000% at its highest concentration. Increasing the crosslinker concentration in hydrogels can improve their swelling capacity. Crosslink density is also important, as it allows hydrogels to absorb liquid while resisting high amounts of fluid [73].

Although nanofibers have a lower swelling capacity than hydrogels, they have potential use in wounds with little exudate. In a study by Mutlu et al. [74], swelling ratios were increased from 50% to 332% by adding curcumin to Poly (3-hydroxybutyric acid-co-3-hydroxyvaleric acid) (PHBV) nanofibers. In PVA/chitosan nanofibers [75], it has been observed that chitosan reduces the swelling rate. It has been reported that the addition of chitosan makes the structure more difficult to dissolve and firmer. Nanofibers were stabilized using methanol, glutaraldehyde, crosslinkers, and heating methods. The stabilized PVA and PVA/chitosan showed 800% and 300% swelling rates, respectively [75]. One synthetic polymer used to improve the swelling property of chitosan is PVP. The addition of 50% PVP increased the swelling rate of chitosan hydrogels from 400% to 1210% [76].

Cutimed® is an absorbent wound dressing made of sodium (80%) and calcium (20%) alginate that is derived from seaweed. When exposed to exudate, alginate transforms into a moist gel due to a chemical reaction between sodium ions in the exudate and calcium ions in the dressing. This dressing is particularly effective for highly exuding wounds as it absorbs exudate, which helps to keep the wound bed clean [77]. Mextra® is a super-absorbent dressing that is highly effective in managing wounds with high exudate. Its high fluid absorption rate can shorten treatment time and reduce costs. To ensure patient comfort, the edges of the dressing are made from soft materials. Additionally, the dressing is easily removable from the wound because it retains its structural integrity after absorbing exudate [78,79].

Epithelization

Epithelialization is the natural process of wound closure by the formation of new epithelial tissue. However, this process can be exceptionally prolonged in chronic wounds. An ideal wound dressing is expected to expedite wound healing by either accelerating epithelial tissue formation or indirectly promoting healing through antimicrobial and swelling properties. This is because cleaning the wound of microorganisms and absorbing exudate creates a conducive environment for healthy cell growth. While antimicrobial agents and substances that promote cell migration are effective in wound healing, their effectiveness is limited in duration. In addition, some antimicrobial agents, such as silver sulfadiazine, can cause damage to healthy skin and blood cells [80]. Peripheral neuropathy can increase skin damage, making the patient more vulnerable to microorganisms. A seemingly minor wound in a patient at high risk of infection can lead to organ loss or even death. Abnormal blood sugar levels can slow down the arrival of blood cells to the wound area. This is because peripheral neuropathy can damage signal transduction pathways, leading to a delay in cell migration signals and consequently, delayed arrival of blood cells. In the treatment of diabetes wounds, it is crucial to use effective wound care products and to maintain balanced blood sugar levels [81].

In a study conducted by Eğri et al. [82], a bilayer membrane was produced using a modified electrospinning process. The membrane consists of a PEG/PCL polymeric layer and a layer containing PEG-encapsulated *H. perforatum* (St. John's wort) oil. Cytotoxicity studies were performed on mouse fibroblast cells using the MTT assay, and wound closure was evaluated on mice with second-degree burns. The study concluded that wounds treated with *H. perforatum* oil-loaded membranes showed a high degree of epithelialization and closed quickly [82]. HydroClean® is an antibacterial product composed of polyacrylic acid (PAA) and cellulose fibers that accelerate wound healing. This product releases the drug in the wound for three days and inactivates matrix metalloproteinase (MMP) [83]. It has been reported that an increase in MMP levels can cause tissue destruction and slow healing in chronic wounds [84].

Gas Exchange

Gas exchange is an important property of wound dressings that allows for the exchange of oxygen and carbon dioxide between the wound and the surrounding environment. This exchange is important for promoting wound healing, as oxygen is required for many of the metabolic processes involved in tissue repair. Wound dressings that allow for gas exchange typically have a permeable membrane or mesh that allows for the passage of gases. These dressings may also have a hydrophilic coating or other surface modifications that help to facilitate gas exchange. In addition to promoting wound healing, dressings that allow for gas exchange can also help to prevent the accumulation of excess moisture around the wound, which can lead to maceration and delayed healing. By allowing for the exchange of gases, these dressings can also help to prevent the buildup of harmful gases, such as carbon dioxide, around the wound [85].

Tan et al. [86] developed electrospun wound dressings made of cellulose acetate and loaded with Pramipexole. The study reported that the wound dressing exhibited a water vapor permeation rate of around 256.18 ± 3.26 mg/cm^2/h. The researchers also noted that the porous structure of the nanofibers allowed for wound breathability. DuoDERM®, a semi-permeable film dressing, that allows the gas exchange of air and water vapor, is impermeable for bacteria and fluids, very flexible and conformable [87].

Cost-effectiveness

The cost of wound dressings can vary widely depending on the type of dressing, the size and severity of the wound, and the frequency of dressing changes required. Some wound dressings are more expensive than others but may be necessary for certain types of wounds or patients with specific healthcare needs. Some factors that can impact the cost of wound dressings include the type of dressing, frequency of dressing changes, size and severity of the wound, healthcare setting, and insurance coverage. Different types of wound dressings have different costs associated with them. For example, advanced wound dressings, such as hydrogels and collagen dressings, may be more expensive than traditional dressings like gauze or adhesive bandages. Dressings that need to be changed frequently may require more frequent purchases and can increase the overall cost of wound care. Larger and more severe wounds may require more dressing material, which can increase the overall cost of wound care. The cost of wound dressings may vary depending on the healthcare setting, such as inpatient versus outpatient care. The cost of wound dressings may be covered by insurance, which can help to reduce out-of-pocket costs for patients [88].

In addition to the cost of the dressing itself, there may be additional costs associated with wound care, such as healthcare provider time, medications, and other supplies. Patients and healthcare providers need to consider all of these factors when assessing the overall cost of wound care. In summary, the cost of wound dressings can vary widely depending on a variety of factors. While cost is an important consideration, it's also important to balance the cost of the dressing against its benefits and select the dressing that is most appropriate for the patient's wound and healthcare needs [88].

Li et al. [89] have designed MXene@polydopamine-decorated (PDA) chitosan nanofibers as a cost-effective wound dressing. The wound dressing demonstrated superior wound healing performance compared to Tegaderm™ film in a full-thickness skin defect model. It has been reported that this provides further evidence that the MXene@PDA material can promote the reformation of fibrinogen during the initial stages of the wound healing process [89].

RESULT AND DISCUSSION

There are thousands of commercially available wound dressings that can manage all aspects of wound care. However, there is no single superior product that provides complete healing for chronic ulcers, such as third-degree burns. Current research is focused on producing dressing materials that address the main intervention factors of the normal healing process, which can greatly assist patients and wound care professionals. Although it is not possible to identify an ideal dressing, the basic features expected from one can be explained. For example, hydrogels are superior in maintaining moisture balance, while nanofibers can mimic the components of the extracellular matrix and support epithelialization. Nanoparticles are taken into consideration for infection control with the development of nanotechnology. Natural-origin antimicrobial agents have become preferred due to their biocompatibility. Combining all of these features can be disadvantageous in terms of cost. Therefore, when selecting a wound dressing, factors such as the depth, type, stage of the wound, the age of the patient, and chronic diseases should be carefully analyzed, and the necessary features should be provided first.

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CONFLICT OF INTEREST

The authors declare that there is no real, potential, or perceived conflict of interest for this article.

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