WOUND DRESSING WITH TEXTILE DRESSING APPROACH: A REVIEW

SHAHIDI, SHEILA[1]; MOAZZENHI, BAHAREH[2,3]; KALAHROODI, HOSSEINI KIMIASADAT[4] AND MONGKHOLRATTANASIT, RATTANAPHOL[5*]

[1] Islamic Azad University, Arak Branch, Faculty of Engineering, Department of Textile, 38361-1-9131 6, Arak, Iran
[2] Amirkabir University of Technology, Textile Department, 15916-34311, Tehran, Iran
[3] Atiyeh Hekmat Abtin Company, Research and Development Department, 19496-35879, Tehran, Iran
[4] Alborz University of Medical Sciences, School of Pharmacy, 301-810 301-810, Karaj, Iran
[5] Rajamangala University of Technology Phra Nakhon, Faculty of Industrial Textiles and Fashion Design, Department of Textile Chemistry Technology, 10300, Bangkok, Thailand

ABSTRACT

To help healing, protect and care the wound from additional damage, a sterile dressing is applied to wound and injured area. Wound dressing can be a sterile pad or compress that directly contact with the wound area. Nowadays, different models of wound dressings are used in the medical field. In this review paper different wound dressings and efforts made on the textile based wound dressings discussed.

KEYWORDS

Wound; Dressing; Healing; Textile; Antibacterial; Nanofibers.

INTRODUCTION

For reducing infection in different wound types, various models of wound dressings are used. Wound dressings should stop bleeding and start clotting, absorb excess blood and other fluid from the injured area and eventually debridement the wound [1]. Wounds are classified as chronic or acute (Figure 1), due to the nature of the repair procedure [2].

Chronic wounds associated with tissue injury heal and heal very slowly and recur regularly as the trauma recurs, depending on the immunological problems, the patient's physiological situation and the persistent infection [3]. On the other hand, acute wounds are often tissue injuries that heal completely in the estimated time of 812 weeks with slight scarring. Acute wounds include mechanical injuries such as lacerations, abrasions, burns, cuts, and penetrations, as well as chemical injuries induced by chemical caustics [4]. In addition, wounds are categorized based on the number of layers of skin and the area of skin affected. In a superficial wound, the skin surface is only affected and contains the epidermis and the deeper layers of the skin with sweat glands, blood vessels and hair follicles, which is referred to as a partial wound [5]. Epidermis, dermis, and the underlying subcutaneous fat or deeper tissues are injured while full-thickness wounds occur. Based on physiological conditions and appearance, wounds are divided into five groups (Figure 2).

Necrotic wounds are dry, hard, and tend to shrink. Leg ulcers, burns, and pressure sores are types of greasy wounds. In this situation, the necrotic plaque is removed from the wound surface and a sticky yellow plaque is formed. This tissue is a mixture of protein, fibrin, serous exudate, leukocytes and bacteria and is not dead. Granulating tissue is the fresh matrix through healing which appear on the wound surface with bright color and moist condition with many tiny blood vessels. In epithelializing wounds, epithelium is made on a denuded surface and wound surface seems as pink colored. Infected wounds are green, cloudy with smelling fluid drainage [6]. There are many different types of wounds [7] such as burns, malignant wounds, radiation wounds, pressure ulcers, vasculitic ulcers that need treatment [5]. In an open wound, an internal or external break in the body's tissue caused that generally reasoned by accidents involving rough or sharp objects that cut through the skin and trauma created which can exposes the skin and body to dangerous bacteria and infections [8]. In open wounds, minor cuts can be self-treated, but severe cases need emergency services. Some types of open wounds include Abrasion (When the skin rubs in contradiction of a rough surface, abrasions occur. In most cases, wound is not deep

* **Corresponding author:** Mongkholrattanasit, R., e-mail: rattanaphol.m@rmutp.ac.th
Received September 18, 2023; accepted March 5, 2024

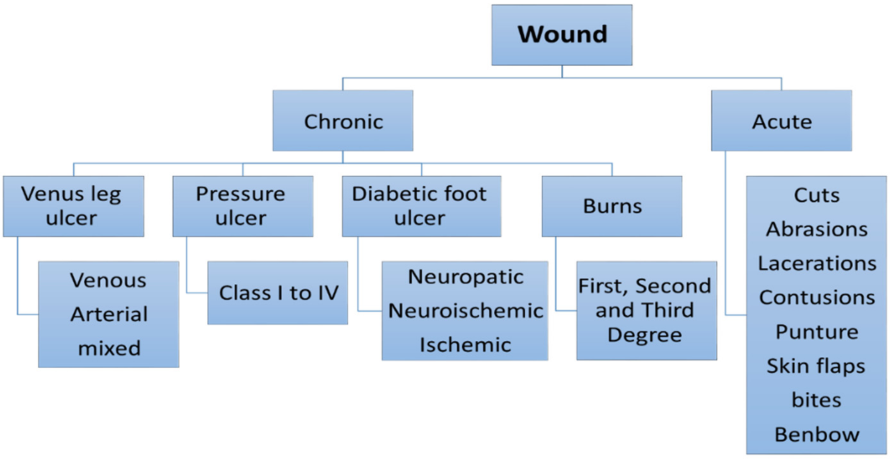

Figure 1. Wounds types due to the nature of the repair procedure.

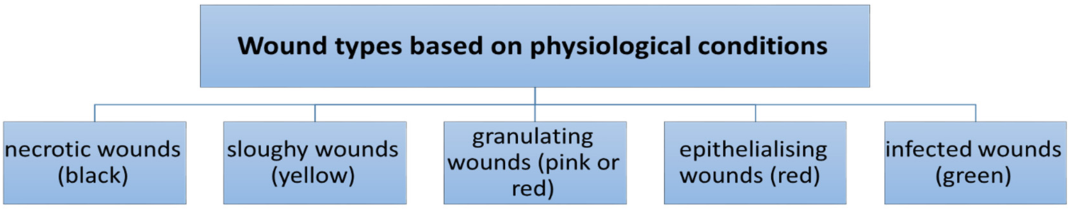

Figure 2. Wound types based on physiological condition.

and a little bleeding occurs), Puncture (There are hole-shaped wounds caused by pointy objects such as needles, gunshot and nails that called Punctures. Deep punctures necessitate urgent medical intervention.), Incision (A straight wound caused by any sharp object such as a knife or a broken glass is an incision), Laceration (A laceration is a sharp and deep cut those results in skin tears and caused heavy bleeding. Frequently it happens through machinery, mishandle knives, and other sharp tools.), Avulsion (A severe wound in the partial or complete tear of the tissues and skin that frequently occur during violent accidents like explosions, car crashes, and other incidents called avulsion that involve trauma.), Amputation (An amputation mentions to the loss of an extremity which can causes accidently or also be done in a medical procedure to manage certain diseases such as gangrene) [9-10]. An infection caused if a major wound is not treated correctly or left on its own. Some symptoms of infection are fever (body temperature rising above 37.5°C), malaise (tiredness, lack of energy and general feeling of being unwell), redness, swelling, temperature rise in the area, body aches (persistent pain in and around the wound), vomiting and unpleasant odor. It is difficult to know why some ulcers are not healing and occasionally out of many local wound dressing materials, some dressing material works wonders [11].

COMMERCIAL WOUND DRESSING TYPES

Wound dressings should have several properties (Figure 3) including absorb exudates, alleviate pain, sustain non-toxicity, moist environment, prevent infection and contaminant, permeability, ease of application, flexibility, comfortability, antibacterial properties and biodegradability [12]. Wound dressings should have antibacterial properties and the growth of microorganisms should be controlled or eliminated in the presence of antimicrobial agents resident in the fibrous structure [13]. In the wound healing process, the dressing defends the injury and restores skin and epidermal tissue. For this purpose, natural polymers such as proteoglycans and proteins (e.g. fibrin, collagen, gelatin and keratin), polysaccharides and derivatives (e.g. CMC, chitosan, alginates and heparin) [14] are widely used, that are biodegradable and biocompatible [15]. For effective and fast wound healing, using the correct dressing is important. Several features such as the type, size, position, and harshness of injury impressed on the type of used wound dressing [16]. Some of the most commonly used dressings are shown in Figure 4.

Hydrocolloid dressing

The word hydrocolloid was invented in the 1960s with the development of mucoadhesives made by combining carboxymethyl cellulose, tackifiers and adhesives used to treat mouth ulcers. To prepare

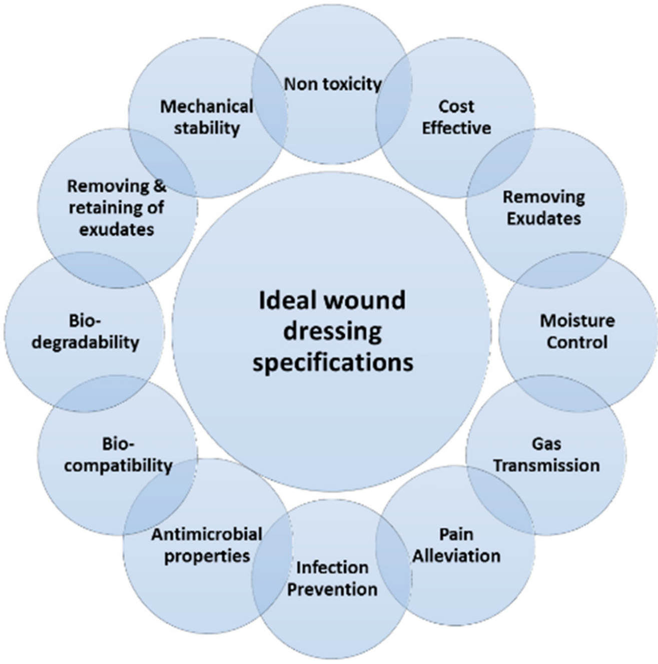

Figure 3. Ideal wound dressing specifications [17].

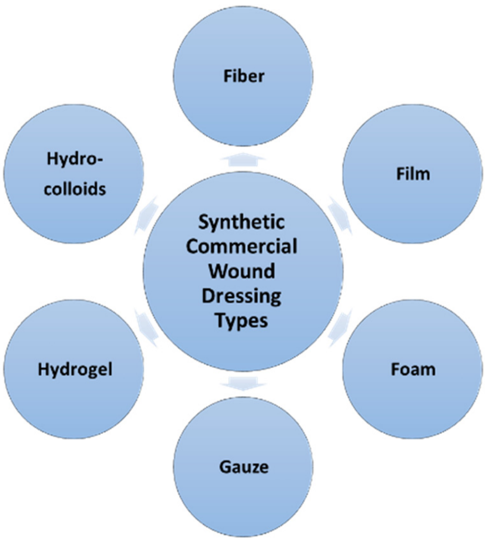

Figure 4. Synthetic commercial wound dressing type [16].

hydrocolloid dressings, a hydrophilic gellable mass in semi-solid form was applied to a flexible, semi-permeable support. The first formulation of this dressing was in the UK in 1982 and was later launched in 1983 as Duoderm in the US and other European markets. Hydrocolloid dressings are often associated with the treatment of chronic wounds. In addition, hydrocolloid dressings can be effective for treating various acute wounds. They can absorb excess fluid and help with debridement [18]. For wounds that are emitting liquid, burns, pressure and venous ulcers and necrotic wounds hydrocolloid dressings are useable. Hydrocolloid dressings are the most commonly used modern dressings and are self-adhesive, non-breathable, long-lasting, biodegradable, and easy to apply and need no taping. They made from comfortable and flexible materials that made them suitable for all skin types [19-21].

Hydrocolloid dressings made of a self-adhesive and hydrophilic colloid particle covered with a waterproof polyurethane film [22]. The surface of hydrocolloid dressings is coated with materials such as sodium carboxymethyl cellulose, pectin, gelatin, alginate or polysaccharides, which can absorb water and form a gel, which can protect the wound from infection and keep it clean and does not allow oxygen, water or bacteria entry on wounds. The outer layer protects the wound from environmental factors and bacteria and forms a gel-like phase on the surface of the wound, which preserves moisture and absorbs wound secretions and exudates [23]. The main advantage of hydrocolloid dressings is that they adapt to the patient's body and adhere well to different sites [24].

Hydrogel

In recent years there have been many advances in the management of wounds. Hydrogels are biocompatible with moisturizing properties and are widely used in wound dressings [25]. Hydrogel dressings are hydrophilic and semi-occlusive. They can hydrate wounds and re-hydrate eschar. Hydrogels are inexplicable polymers which are presented in different forms such as amorphous gel and sheet. Hydrogels absorb exudate and afford a moist environment for cell migration. One of the most benefit of hydrogel dressings is autolytic debridement deprived of damage and harm to granulation or epithelial cells [26].

This dressing allows moisture to stay at the surface of the wound. Hydrogel dressings can be a solution to these problems, exhibiting excellent properties such as tissue adhesion, swelling, and water absorption. In addition, these hydrogels can be formed in situ and, if necessary, dissolved by chemical or physical reactions. For second-degree and minor burns, donor sites, infected wounds, pressure ulcers, sore or necrotic wounds and a variety of wounds that are no fluid or leaking little, hydrogel can be used. To reduce bleeding in liver and aortic models, hydrogels can be used as a dressing, which can then be easily removed. Still, there are many researches on diverse methods to synthesize these hydrogels. Lu et al. in 2018, investigated four strategies for dissolvable crosslinked hydrogels, supramolecular self-assembling hydrogels, and environmentally sensitive physically crosslinked hydrogels. They concluded that these hydrogels offer cheap and effective methods for in vivo applications [27]. Hydrogels are usually used for drug delivery or tissue/organ repairs. They are water or glycerin based products; crosslinked polymeric networks extended in biological fluid. They can absorb 30-90% of their mass in water. Some cooling gels like burn soothe in hydrogels can reduce pain and help to heal wounds and burns and accelerate the healing process. Hydrogel wound dressings keep the moist wound environment clean and healthy. Hydrogels are available in different forms, like film, injectable gels and spray. Furthermore, smart hydrogel dressings included sensors can transport real-time information about the wound healing status. In recent times, sprayable hydrogel-based wound dressings have developed as appropriate scaffolds for wound care. Many researchers studied on synthesis and fabrication of hydrogels and emerging new smart hydrogels for several biomedical applications [2, 28]. In 2019, various types of injectable self-healing conductive hydrogels using dextran graft aniline tetramer graft 4-formylbenzoic acid and N-carboxyethylchitosan were synthesized by Guo et al. Hydrogels revealed superb self-healing. The conductive and injectable self-healing hydrogels are admirable candidates as scaffolds or as carriers for cell delivery that can be used for skeletal muscle repair or cell therapy [29]. Jin et al. in a review paper discussed about hydrogels dressings. They reported, by utilizing hydrogels as substrates, it is possible to design hydrogel dressings with pH-sensitive, temperature sensitive, glucose-sensitive, and pressure-sensitive properties. The hydrogel dressings using wound-monitoring utilities may ease treatment, by monitoring the results [25].

Foam dressings

Polyurethane foam dressings have been used for exudate management in moist wound healing for the past 30 years. Foams have a porous structure that can absorb liquids into air-filled spaces by capillary action. Silicone foam is also used in the wound dressing but is often applied as an adhesive wound contact layer. Various thicknesses of foam dressings are made, which can be adhesive or non-adhesive. They are rich in film-backing that has the resolution to provide a water and microbe resistant barrier to the environment. Overall, non-toxic and non-allergenic foam dressings are able to retain moisture at the wound bed and are easily removed, protecting the wound skin from bacteria. They can adopt and conform to body shape and maintained the temperature with a long shelf life. Foams can be used as a primary or secondary dressing [30]. Foam dressings are essential and important in the care of chronic and exuding wounds. Chronic wounds require the creation of a moist, warm wound healing environment and good exudate handling properties, and foam dressings are good candidates for treatment. Mostly, foams are made from polyurethane with smooth contact surface, thermal insulation, which are gas permeable. Foam dressings can absorb exudate in a number of ways. Some foams absorb exudate, some foams can breathe the moisture they absorb through a permeable backing. An absorbency and the moisture-vapor permeability are very important factors for foam dressings [31]. Kowalczuk et al. in 2020, focused on developing a possibly antibacterial polyurethane foam wound dressing that was loaded with bismuth-ciprofloxacin [32]. Wang et al. investigated the wound healing efficacy of silver-releasing foam dressings in competition with silver-containing creams in the outpatient treatment of patients with diabetic foot ulcers in 2020. They concluded that silver-releasing foam wound healing in infected diabetic foot was more actual and effective than traditional silver sulfadiazine cream [33]. Susy Pramod describes in 2021 the use of the Kliniderm foam silicone dressings for wound management in oncology. Kliniderm foam silicone dressing is safe, acceptable and effective for chronic and acute wounds [34]. Foam dressings play a key role in the medical management of chronic wounds and in moist wound healing.

Films (Transparent dressings)

Transparent dressings are more comfortable than bulky gauze and tape [35]. Semi-permeable sheet is a sterile polyurethane sheet coated with acrylic adhesive. Transparent dressings are breathable, flexible, impermeable to bacteria and comfortable to wear and keep the wound dry and clean. These dressings covered the wound with a clear film and wound healing can be monitored and detecting prospective problems much easier and earlier. Transparent dressings can be ideal for surgical incision sites, ulcers and burns and conform easily to the patient’s body. Due to the film-like structure, they are semi-blocking and can trap moisture. They can create a moist environment for wound healing [36]. Transparent polyurethane dressings have become popular cause of their consistently secures the catheter, it permits immediate visual inspection of the catheter insertion site. Transparent polyurethane dressings do not have to be changed repeatedly and enables the patient to wash and shower with no worry about wetting the dressing. They have significant adhesion, cost effective and easy to use [37]. Efficiency and success of a transparent film dressing for peripheral intravenous catheters was studied by Atay and Yilmaz Kurt in 2021. They concluded that the use of a transparent film dressing for addition of peripheral intravenous catheter may increase catheter indwelling time and reduce the incidence of complications [38]. The effectiveness of transparent compression bandages in inhibiting pain, discomfort and hematoma was reviewed by Sharma et al. checked. They reported that transparent dressing is a superior choice in patients with femoral/groin dressings after cardiac catheterization. Also, they reported that transparent dressings are more comfort and effective in prevention of pain [39].

Gauze dressings

Gauze dressings are produced in extensive range of shapes and sizes which made of non-woven or woven materials. These can be used for infected wounds, draining wounds, wounds which need packing and very frequent dressing changes. Gauze dressings are available readily and are cheaper than other wound dressing types and can be used on almost all wound types. In the other hand, gauze dressings should frequently combine with another wound dressing and often is not effective for moist wound healing. Gauze dressing is still routinely used for long-term wound care in hospitals and clinics [40]. Balasubramanian et al. in 2013 studied about carboxymethylated cotton gauze dressing. Moist conditions are maintained by increasing surface carboxyl content. The samples were padded with different concentrations of ornidazole and ofloxacin as antibacterial agents. Carboxymethylated cotton gauze treated with antibacterial agents may be suitable for the manufacture of antibacterial wound dressings [41]. Soares et al. in an integrative review in 2020, reported that sterile gauze with Vaseline, reduced the amount of pain after the bandages. This bandage provided pain relief, increased mobility, and improved sleep patterns, offer the client more comfort and more willingness and energy for self-care [42]. Paraffin gauze dressing helps keep the skin graft moist, reduces adhesion and allows for non-traumatic removal, and creates a moist environment that facilitates migration of epithelial cells. In addition, paraffin gauze dressings have some disadvantages, such as: B. the need for a secondary dressing, they do not absorb exudate and require frequent dressing changes to ensure they do not dry out and damage good cells when the dressing is removed [43]. Fang et al. in 2021 developed a reusable ionic liquid-grafted antibacterial cotton gauze wound dressing using 3-aminopropyltriethoxysilane, glycidyl methacrylate, 1-vinyl-3-butylimidazolium bromide and butyl acrylate. They reported that the treated gauze pad is reusable and showed good antibacterial activity even after three repeated antibacterial tests [44]. Traditional wound dressings such as gauzes and felt is keeping the wounds dry and warm. One of the biggest problems with traditional dressings was their adhesion to the wound and the difficulty of removing them from the wound surface [45]. In recent times, by impregnating paraffin onto the gauze, coating viscose fiber with polypropylene or adding polyamide contact layer, the adherence of traditional dressings were fixed [24].

TEXTILE DRESSINGS FOR WOUND HEALING

Textile materials have numerous superior features and are used in various industries. Textile materials have different properties such as compatibility, good mechanical properties, non-allergenic, hydrophilic/hydrophobic properties, air and moisture permeability etc. and can be used in all types of dry and wet dressings. For human existence, healthcare is very essential, and in recent years developing textile materials for biomedical purpose have increased extensively. Wound healing is a complex process and the manufacture of wound dressings for complex unhealed wounds requires further investigation. For caring open wounds or broken skin areas such as cuts, grazes or areas of delicate skin in minor injuries, cloth dressings are used widely. Cloth dressings are available in different shapes and sizes, in addition to pre-cut dressings, in a roll choice that can be cut to suitable size. According to the cause, textile wound dressings can be used as protective layers, drug carriers, contact layers and reinforcements of wound healing composites. Textile wound dressing structures can be changed by using different raw materials and changing production parameters [4]. Porosity, strength, flexibility, capillarity, absorption, three-dimensional structures, moisture permeability, air permeability, drape ability, extensibility, different fiber types and lengths, cross-sectional shape and geometry, fineness, combinability with medicines, etc. are the major and significant properties to produce an effective textile wound dressings. Natural fibers such as cotton and silk and synthetic fibers such as polyester, polyamide, polypropylene, polyurethane, etc. can be used as the wound dressing. The key benefits of new dressings are exudate transport, wound closure and on-demand drug delivery to the wound environment. Recently, innovative fibers and gels have been made from natural polymers such as polysaccharides (alginates, chitin and chitosan), proteins, polyglycolic acid, regenerated cellulose, etc. [6].

Wound dressings play a critical role in wound care and wound healing. Chitosan-based wound dressings are biodegradable, biocompatible and antibacterial and have increased significant attention in recent years. Chitosan is a natural polymer derived from chitin, which is originate in crustacean shells and has been widely considered in diverse presentations [46-47].

Recently, many researchers have focused on using biological materials such as chitin and chitosan [48]. Chitosan acetate theoretically has extensive biologically valuable properties such as antimicrobial activity, homeostasis and stimulation of healing, drug delivery, and tissue engineering scaffolds. Chitosan is the soluble form of chitin, which is mainly in marine arthropod shells and is a biopolymer consisting of poly-N-acetylglucosamine and prevalent in nature. The antimicrobial properties of chitosan depend on the degree of chitosan polymerization, substrate chemical and/or nutrient composition; type (plain or derivative); environmental conditions like moisture and host natural nutrient constituency. The site of action of chitosan is on the microbial cell wall and the antimicrobial effect occurs immediately on fungi and algae and then on bacteria [32]. The use of chitosan accompanied by various antibacterial agents such as Ag, Zn, CuO, TiO2 and Fe has been studied by many researchers in recent years [48]. Antimicrobial and scar-preventive wound dressings were developed by coating a mixture of chitosan, polyethylene glycol and polyvinylpyrrolidone on the cotton fabric and subsequent freeze drying by Anjum et al. in 2016 [49].

Multilayered or composite dressings are frequently a mixture of the described dressings. Blend of a semi/non-adherent layer with an extremely absorbent fibrous layer such as cotton is typically useful for burns, lacerations, abrasions or surgical incisions [31]. The wound healing has different phases and different wound dressing can be used in each phase of healing procedure. As a primary or secondary dressing, combination dressings can be used. Composite dressings are combination of dressing types and are simply a combination of a gauze dressing and a moisture retentive dressing. Depends on the type of dressing, it is useable on different wound. Although it is easy for clinicians to use and is available extensively. The composite dressing may contain hydro-fiber inner layer and a viscoelastic hydrocolloid outer layer, which can be used for post-operative applications, such as following a total knee replacement procedure [50]. Zhang et al. in 2021 engineered a nontoxic, biocompatible, and antibacterial chitosan-collagen dressing with water retention property [51]. Effect of alginate/chitosan hydrogel with different amounts of hesperidin on wound healing was reviewed in 2020 by Bagher et al. examined. They concluded that the produced hydrogel has suitable properties for wound healing applications and shows promise overview for successful wound treatment [52]. Purwar et al. made a composite wound dressing by embedding hydrogel on cotton fabric for drug release in 2014. The prepared dressing showed drug release at different pH values with maximum drug release in acidic medium [53]. A therapeutic and cost-effective chitosan–Vaseline gauze dressing was industrialized by Fang et al. in 2020 through coating the Vaseline and chitosan on sterile gauze following drying. They reported that chitosan– Vaseline dressing is useful for wound healing [54]. The treatment of cotton gauze with a nanocomposite of Ag/chitosan/ZnO can also improve wound care ability, increased wicking, drying time and water absorption capacity on the way to modern wound dressings [48]. Pinho et al. reported in 2018 on composite wound dressings obtained by crosslinking between cotton fabric and cyclodextrin-cellulose-based hydrogels. They reported that it is possible to synthesize antimicrobial composite wound dressings with natural compounds and eco-friendly techniques using gallic acid [55].

As it was mentioned before, hydrogels are developing as one of the best dressings because of their biocompatibility, drug loading capability and extracellular matrix imitating structure. Though, current hydrogel dressings reveal unfortunate environmental compliance, limited breathability, probable drug resistance, and partial drug options, which particularly confine their working conditions and therapeutic result. Jiang et al. presented the first model of hydrogel textile dressings by innovative gelatin glycerin hydrogel (glyhydrogel) fibers invented by the Hofmeister effect through wet spinning method. Through the exceptional knitted structure, the textile dressing features admirable breathability and stretchability (535.51 ± 38.66%). Totally these properties can not be reachable via traditional hydrogel dressings and offer a novel tactic for the growth of hydrogel dressings [56].

An innovative bio-printed textiles based on fish skin decellularized extracellular matrix (dECM) for wound healing was presented in 2023. Due to the good biocompatibility of fish-derived dECM, bioprinted textiles show excellent functionality due to cell adhesion and proliferation. Considering that the dECM-based hydrogels are produced by the bio printing method, the bio printed textiles exhibit a suitable and tunable porous structure with good air permeability throughout the fabric. Furthermore, a variety of active molecules can be loaded onto the hydrogel skeleton according to the porous structure, and increasing the wound healing effect [57].

Alginate dressings which are easy removal, have extremely great absorbing effectiveness and can remove great amounts of exudate. Alginate dressings can be used also in clean or infected wounds [58].

For higher state pressure ulcers, packing wounds, burns, venous ulcers and wet wounds with high liquid drainage, alginate dressings are suggested as primary dressings. Alginate is an ionic polysaccharide which can be used in different wound dressings and can improve the wound healing procedure. Alginate cross-link with various organic or inorganic materials, which can aid in healing properties. Bioactive alginate has hydrogel properties such as biodegradability, optimal water vapor permeability, exudate absorption and intrinsic swelling properties. These properties are beneficial for a sterile dressing and wound healing

[59]. Alginate dressings can contain some medicines like sodium and seaweed fibers, that can absorb high amounts of fluid, and more they are biodegradable after use. Alginates are mixed water-soluble Na and/or K, Ca and Mg salts of alginic acid. Alginates are mostly gained from brown sea algae. Biocompatibility, biodegradability, gelation, high absorbency, non-irritating, non-toxic, easy application and blending and swelling are the superior properties of alginate fiber. The alginate can absorb 15 to 20 times its weight in liquid. Many researchers have worked on applications of alginate in wound dressings. Alginate can be mixed with other textile fibers like cotton and chitosan [60]. Commoto et al. in 2019 produced an alginate-based hydrogel with implanted biologically active materials that was breathable for at least 72 hours and had excellent mechanical properties. Curcumin and t-resveratrol as antioxidants were individually encapsulated in the alginate-based hydrogel. The prepared hydrogel was biocompatible and was not toxic for human keratinocytes. The hydrogel encapsulated with curcumin was more effective against bacterial growth. The hydrogel dressings produced are useful in many skin diseases and can modulate the immune response while controlling bacterial growth [61].

Hydro fiber Technology (HT) was founded on a new sodium CMC hydrocolloid fiber material. Definitely, it was industrialized for wound care to include the required features of more traditional dressings (cotton gauze, alginates and foams) and for increasing aspects of exudate controlling. Mike Walker and David Parsons in 2010 reported that the initial material is advanced form of cellulose. In wound care, usually cotton gauze used as natural form. Cotton is very useful but its absorbency or the ability to retain fluid is not enough because of the physical spaces in cotton fabrics tightly bounding in the cellulose. Changing the macroscopic fiber structure and introducing several pathways for moisture permeability and fiber gelation confirm that improvements in both absorption and retention properties are being achieved in hydrofiber dressings. Number of sodium carboxymethyl groups in the molecular structure should be controlled. Subsequently, HT dressings afford hydration properties which make them different from other wound dressing [62]. Hydro fiber based dressings are able to lock in wound exudate and have antibacterial properties and removed bacteria and proteolytic enzymes which may presence in the fluid from the wound area. Hydrofiber products have wonderful properties such as gel blocking, high fluid absorption capacity, fluid retention under pressure (e.g. >90%) and are easy to apply and allow for non-traumatic dressing removal as demonstrated by in vivo and in vitro studies [63]. After achievements of alginate wound dressings, a gel-forming CMC fiber was produced as wet healing dressing under the name of Hydro-Fiber. This hydrofiber made from the solvent-spun cellulose fiber (Tencel), by replacing the -OH group in cellulose by sodium carboxymethyl groups. Fiber is insoluble in water, yet the sodium carboxymethyl groups draw enough water into the fibers and cause the fibers to swell and form a gel. Hydrofiber nonwoven felts are strong, soft and conformable, unlike the alginate fibers which are brittle, weak and light brown. Hydro-fibers gel wound dressings are highly absorbable and can be easily removed after use [64]. Aquacel Ag® (ConvaTec, Princeton, NJ, USA) is a hydro-fiber wound dressing made from soft, non-woven fibers of sodium carboxymethylcellulose that incorporate ionic silver. It is antimicrobial and is a moisture retaining wound dressing and forms a gel on contact with wound fluid. In 2009, Barnea et al. reported on the use of hydro-fiber dressings with silver (Aquacel Ag®) in wound care. They concluded that Aquacel Ag® is an effective, antibacterial and safe dressing for acute and chronic wounds [65].

Collagens are the greatest abundant protein originate in the body. For wound healing, these collagens are created by fibroblasts and improved into different morphologies. Wound healing and tensile strength of healed skin depend on the amount, type and organization of collagen [66]. Collagen-based biomaterials have been used for wound dressings cause of easy to apply, low immunogenicity, biocompatibility and ability to reactivate wound healing responses. Typically, the normal sources of collagen are bovine, equine, avian, or porcine. The use of animal-based collagen products is associated with allergic problems, microbial contamination and the spread of prion diseases. In addition, other natural (marine) or genetically engineered (recombinant human collagen from bacterial or plant material) sources of collagen have been considered. Collagen has been used as matrices/scaffolds for tissue engineering, hemostats, soft tissue repair, and in recent years as a drug delivery system. Collagen can be combined with natural and synthetic polymers such as hyaluronic acid, poly(L-lactic acid), polyethylene oxide, elastin and silk fibroin, alginate, chitosan. Some additives such as insulin, antibiotics or nanoparticles have been added for wound healing. Biocompatible nanocollagen is a fairly new material produced by electrospinning processes and this nanosize offers a higher surface area to volume ratio that can be used for therapeutic drug delivery systems [67].

Chitosan and collagen are used as natural polymers along with textiles for wound dressing. In a research work, a collagen-containing wound dressing was prepared using non-woven fabric with a collagen layer.

For burns, chronic, surgical or stalled wounds, transplant sites, pressure sores, ulcers and injuries; collagen dressing can be offered. Collagen dressings may remove dead tissue, grow fresh blood vessels, and help to bring the wound edges together and act as a scaffold for new cells. Santhanam et al. in 2020 reported about the role of collagen for wound treatments [68]. Doillon and Silver in 1986 were determined the effect of hyaluronic acid and fibronectin in a collagen-based wound dressing [69]. Amirah et al. studied antibacterial collagen dressings for diabetic foot ulcers in 2020. Encouraging results have been reported using a collagen-based dressing with integrated antibacterial components such as polyhexamethylene biguanide and silver for diabetic foot ulcer wound healing [70].

In the other point of view, nanofibers are widely used in numerous biomedical uses for example cancer therapy, gene delivery, drug delivery, cell therapy, tissue engineering and regenerative medicine [71]. Nanofiber composites can be used efficiently for wound healing and conformal tissue regeneration. Currently electrospinning, phase separation, self-assembly, and template synthesis are main methods for nanofibers preparation [72]. Among others, electrospinning is a modern, cheap and efficient method for large scale production of continuous fine nanofibers with tunable diameter and can process both natural and synthetic polymers to solve specific wound problems.

These fibers can be used in filtration, composite materials, wound dressing and membrane industry. Nanofibers are favorable materials for assisting wound healing and skin regeneration. Electrospun meshes have high surface area and microporosity which can be loaded by biomolecules or drugs and can be used as scaffolds for tissue engineering. Subsequently, different materials such as chitosan, gelatin, collagen, fibrinogen, poly lactic acid, polyurethane, poly caprolactone and polyvinyl alcohol can be electrospun and used as appropriate wound dressing [73-74]. The electrospun nanofibers have specific properties such as large surface areas, changeable morphologies, high porosities, and manageable mechanical properties and can be used for drug delivery applications [75]. Various antibiotics and anticancer drugs can be combined into electrospun polymeric nanofibers for making desirable wound dressings. Usually, these active ingredients are incorporated into nanofibers by mixing them into the polymer and then electrospinning the mixture or core-shell electrospinning. Iacob et al. described in 2020 a summary of widely used polysaccharides of animal, plant, fungal and bacterial origin for the production of nano-wound dressings. Drugs and biological molecules can be encapsulated in electrospun nanofibers and wound healing processes can be improved and accelerated. They concluded that electrospun polysaccharide nanofiber dressings had more desirable and appropriate properties such as cost-effectiveness, ease of preparation, efficient drug delivery, and better wound healing time compared to traditional dressings [75]. Recently, many researchers are investigating electrospun polymeric wound dressings with fiber diameters in the nanometer and micrometer range. These wound dressings have different properties that can accelerate the wound healing process. In a 2021 review, Akhmetova and Heinz gave an overview of cytocompatible and biodegradable fibrous wound dressings produced by electrospinning proteins and peptides of animal and plant origin [76]. Campa-Siqueiros et al. in 2020 described electrospun nanofibers from gelatin, chitosan and chitosan-polyvinyl alcohol that made through electrospinning method. The produced nanofibers provide good antimicrobial efficiency and can be used as wound healing dressings [77]. Multifunctional nanofiber dressings are effective for wound healing process due to their great biocompatibility, biodegradability and bioactivity, and can be produced by mixing various natural or synthetic polymers and combining drugs, nanoparticles and bioactive agents through the electrospinning process. Electrospinning of natural and synthetic biopolymers has larger structures for making wound dressings and tissue engineering scaffolds, and hence is valued for modern wound care and medical industry and other specific structures [78]. Wound dressings based on hydrophilic polyurethane with peppermint extract as a natural and herbal anti-inflammatory and antimicrobial agent were prepared through electrospinning method. Prepared nanofibers have potential wound healing property for diabetic ulcers [79].

Natural polymers such as glucan and galactan-based carbohydrate are inexpensiveness, natural, biocompatibile, biodegradable and are good candidate for using in wound healing dressings process. In addition, nanofibrous mesh have great surface area and are similar to the ECM (extracellular matrix) and supports fine proliferation and migration of fibroblasts. Therefore, nanostructured dressings derivative from glucans and galactans like chitosan, pullulan, carrageenan, agar or agarose and curdlan do not have the problems of traditional wound dressings` [80].

In the other research work nanofibrous wound dressings with synergistic antibacterial activity were developed. The process involves the layerwise co-assembly of benzalkonium chloride (BC) and metal–organic framework nanoparticles (MOFs, PCN-224) onto poly(ε-caprolactone) (PCL) electrospun nanofibrous membranes (ENMs) using a tannic acid (TA)-assisted adhesion strategy. The prepared nano composite presents a novel method for enhancing wound disinfection in clinical settings [81].

The inappropriate managing of wound exudate around the diabetic wound bed is one of the key parameters leading to delay diabetic wound healing. Zhuo et al., introduced a new diabetic wound dressing for achieving fast wound healing by electrospinning hydrophobic nanofibers on a hydrophilic modified non-woven fabric. The double-layer structure of the self-pumping dressing divert excessive exudate away from diabetic wounds, ultimately promoting wound healing [82].

ANTIMICROBIAL WOUND DRESSING

With a global market of US$20.4 billion by 2021, skin wound dressings are a core part of the wound care industry. Natural polymeric nanofibers loaded with antibacterial and biofunctional agents are intelligent classes of bioactive wound dressings and can be replaced by classic wound dressings [83]. In order to manufacture antimicrobial dressings, several performance criteria are important, such as wound surface protection, absorption of wound exudate, and ease of application and removal. Usually, textile wound dressings can combine with antimicrobial agents through different methods such as 1) antimicrobial creams and ointment (betadine solution and betadine cream or silver antimicrobial wound gel), 2) textile fabric impregnated with antimicrobial active ingredients, 3) antimicrobial coated textile substrate, 4) textile fibers containing antimicrobial active ingredients, 5) textile composite containing antimicrobial fibers. Wound dressings come in direct contact with injured skin and should be safe, non-toxic and free from allergy problems. It must be effective on broad-spectrum of bacteria without bacteria resistance and antimicrobial effect should sustained during the shelf time.

Studying about functional wound dressings with rapid hemostasis and antimicrobial efficiency is necessary for the managing of severe bleeding wounds. In general, cotton dressings are used in clinical practice; but, few number of dressings may concurrently have antimicrobial properties and fast hemostasis. Zeng et al. in 2023 developed a versatile cotton dressing in name of (GCQCNF-5) by deposition catechol modified quaternary chitosan (CQCS) and gelatin onto a cotton nonwoven fabric surface. They reported, cause of presence of a gelatin sponge layer with suitable thickness and porosity on its surface, GCQCNF-5 exhibits a particular enhanced hemostatic effect compared to raw nonwoven fabric both in vitro and in vivo, which is even somewhat superior to a commercial gelatin hemostatic sponge. They reported by exerting a rapid hemostasis effect, GCQCNF-5 can exploit catechol modified quaternary chitosan to apply excellent immediate antimicrobial and long-lasting bacteriostatic properties. By in vivo wound healing experiments they indicated that GCQCNF-5 could significantly promote rapid healing of infected wounds by effectively sterilizing, absorbing exudates, and providing moist healing environments [84].

Generally fibrous biomaterials are used for manufacturing of antibacterial wound dressings. Antibacterial and probiotic therapies can be used for preparing anti-infective dressings may have side-effects and biotoxicity. Zhang et al. in 2023 reported a method for fabricating wound dressings to combat infection. They claimed that Poly(4-methyl-1-pentene) (PMP) fabric can remove bacteria from infectious wounds through dressing changes based on its efficient bacterial adhesion. Also, they reported PMP fabric could inhibit the twitching motility of bacteria, which is beneficial for inhibiting infection. In a rat wound model, ability of the Poly(4-methyl-1-pentene) fabric was demonstrated in vivo for wound healing acceleration. They reported, by treating with the PMP fabric dressing, pathogenic bacteria in the wound were removed through dressing change; therefore, the wound exhibited better healing speed than when the commercial dressing was used. The low bacterial concentration effectively stimulated the expression of growth factors and inhibited wound inflammation and accelerating wound healing. They claimed that PMP fabric has been approved for use in clinical treatment by the Food and Drug Administration, no antibacterial agent or probiotics were used for preparation and the fabric could be manufactured through an industrial production process [85].

Clove (Syzygium aromaticum) is one of the useful herbal medicines to prevent the bacteria infection. The extract of Clove has phenolic compounds such as eugenol and this plant have great antioxidant, antimicrobial and anti-inflammation properties. Parham et al. endeavored to develop the flexible cellulosic textile nanocomposite by dipping the cellulosic textile in a nano emulsion containing clove herbal medicine (32%wt). This clove treated textile improve the in vitro cellular compatibility and in vivo wound healing and approximately 85% of the procedure of wound was mended in14 days [86].

In the other research in 2019, a wound dressing able to release chlorhexidine (CHX) as antiseptic agent, ensuring long-lasting antibacterial efficacy during the healing was designed by Aubert-Viard et al [87]. In similar research, the sandwich-like composite hydrogel wound dressings were settled by adding nonwoven fabrics for interior layer and chitosan and gelatin hydrogel treated with Centella asiatica as a base material. After treating with Centella asiatica, the treated wound dressing revealed brilliant antibacterial activity and drug release properties. This work indicates that the nonwoven composite hydrogels have wide application in the field of medical care in the future [88].

APPLICATIONS OF SMART MATERIALS IN WOUND CARE

Topical improvements on dressings like hydrogel dressings using combined treatment functions and monitoring, using intelligent materials or sensors to sense modifications in the wound situation and wound healing are ongoing. These dressings support reactive treatment for wound healing and are able to carry out dynamic treatment soon enough to successfully help wound healing. Some dressings can monitor and observe wound status and afford tailored treatment, for example temperature, pressure, pH and glucose sensitive dressings [25]. Developing smart dressing integration can help prevent amputations and ulcers and speed up the healing process. Recently, for smart wound dressings, researchers suggested bio-sensing technique for chronic wound environment condition. Some biomarkers recognized as probable indicators for treatment of non-healing chronic wounds. Biochemical and physical biomarkers are the two main categories. Biochemical marker classified as cytokine, enzyme, metabolic byproduct and pH and some physical markers classified as temperature, pressure, moisture content that can be converted into calculable electrical signals. Ginanini et al. reported that the chronic wound environment can be sensed in real time and the creation of a feedback system can measure the healing process [89]. Magnetization of cellulose fiber using $CoFe_2O_4$ as smart wound dressing was studied by Williams et al. in 2019 for healing monitoring ability. They concluded that prepared magnetic dressing can be used as a smart wound dressing concerning wireless magnetic announcement for tele-monitoring wound healing procedures [90]. Ghaderi and Afshar in 2004 [91] reported about honey application for skin wound treatment. Honey can accelerate the wound healing process and improve the formation of granulation tissue, keratinization of the wound surface, and the thickness of the basement membrane and epidermis. Honey can decrease inflammation, infection, edema, and improved resilience, ultimate tensile strength and toughness of wound. Nazeri et al. in 2015 reported about a honey-based alginate hydrogel for wound dressing [92]. Silver and silver derivatives have been used as an antimicrobial agent for many years, and the medicinal use of silver is not a new tactic. Metallic silver or silver nitrate was used for skin infection treatments and chronic wounds. Silver in ionized form and nanosilver shows excellent antimicrobial and antifungal properties and can be used to coat medical devices. Silver can be used in wound dressing's compound for healing the contaminated wounds [93].

Elsaboni et al. in 2022 focused on the design and fabrication of flexible textile-based protein sensors to be embedded in wound dressings. Chronic wounds need continuous monitoring for preventing additional difficulties and determining the best treatment in the case of infection. For the progression of wound healing, proteins are necessary and can be used as an indicator of wound status. By measuring protein concentrations, the sensor can monitor the wound condition continuously as a function of time. The protein sensor has electrodes printed on polyester fabric by silver and carbon composite inks. Currently, this is a collective backing fabric used for wound dressings. They concluded that, the best sensor design is comprised of silver conductive tracks but a carbon layer as the working and counter electrodes at the interface zone [94]. At least, much more research is needed for wound dressing and effective materials for wound healing.

CONCLUSION

Newer wound dressings create an ideal atmosphere in which cells can move freely. Because oxygen circulates efficiently throughout the wound in a moist atmosphere, bacterial growth is low and tissue renewal is faster. Large series of wound dressings have been developed because no single dressing is suitable for the treatment of different wounds. Wound healing procedures have different phases that require different dressings for each phase. In moist wound controlling, textile dressings can be used as advanced fibers like chitosan or alginate fibers, or the textile dressing can be coated and modified with several ingredients such as hydrogels or honey for achieving distinctive properties such as drug release or better hydrophilicity. Generally, different types of textiles such as nanofibers, filaments, yarns, woven, nonwoven and composite textiles can be used in wound-dressing products. In summary, textile materials and composite structures will continue to be one of the physical solutions for the care of people with wounds.

Acknowledgement: *The authors gratefully acknowledge the help and support of Department of Textile, Arak Branch, Islamic Azad University, Arak, Iran for performing the study and development work. Authors gratefully acknowledge the help of Rajamangala University of Technology Phra Nakhon (RMUTP), Thailand, for supporting this research.*

REFERENCES

1. Kubera S.K.S., Prakash C., Subramanian S.: Study on performance of different wound dressings on surgical non infected wounds, Journal of Natural Fibers 18(2), 2021, pp. 161-174. http://doi.org/10.1080/15440478.2019.1612812
2. Tavakoli S., Klar A.S.: Advanced hydrogels as wound dressings, Biomolecules 10(8), 2020, pp. 1-20. http://doi:10.3390/biom10081169
3. Andrews K.L., Derby K.M., Jacobson T.M., et al.: Prevention and management of chronic wounds. In: Cifu D.X., editor. Braddom's physical medicine and rehabilitation, Pennsylvania: Elsevier, 2021, pp. 469-484. http://doi:10.1016/B978-0-323-62539-5.00024-2
4. Ramazan E.: Advances in fabric structures for wound care. In: Rajendran S., editor. Advanced textiles for wound care, Cambridge: Woodhead Publishing, 2019, pp. 509 – 540. http://doi:10.1016/B978-0-08-102192-7.00018-7
5. Vachhrajani V., Khakhkhar P.: Science of wound healing and dressing materials, Springer Nature Singapore, Gateway East, 2020. http://doi:10.1007/978-981-32-9236-9_7
6. Voncina B., Fras L.Z., Ristic T.: Active textile dressings for wound healing. In: Langenhove L.V., editor. Advances in smart medical textiles: Treatments and health monitoring, Cambridge: Woodhead Publishing, 2016, pp. 73-92. http://doi:10.1016/B978-1-78242-379-9.00004-9
7. Cutting K.F., White R.J., Legerstee R.: Evidence and practical wound care–an all-inclusive approach, Wound Medicine 16, 2017, pp. 40-45. http://doi:10.1016/j.wndm.2017.01.005
8. Milne K.E., Penn-Barwell J.G.: Classification and management of acute wounds and open fractures, Surgery (Oxford) 38(3), 2020, pp.143- 149.

http://doi:10.1016/j.mpsur.2020.01.010
9. Sen C.K.: Human wounds and its burden: an updated compendium of estimates, Advances in wound care 8, 2019, pp. 39-48.
http://doi:10.1089/wound.2019.0946
10. Guest J.F., Fuller G.W., Vowden P.: Cohort study evaluating the burden of wounds to the UK's National Health Service in 2017/2018, update from 2012/2013, BMJ Open 10(12), 2020, pp. 1-15.
http://doi:10.1136/bmjopen-2020-045253
11. Tottoli E.M., Dorati R., Genta I., et al.: Skin wound healing process and new emerging technologies for skin wound care and regeneration, Pharmaceutics 12(8), 2020, pp. 1-30.
http://doi:10.3390/pharmaceutics12080735
12. Rizani N.: Modern wound dressing for wound infection: An overview, Indonesian Journal of Tropical and Infectious Disease 3(1), 2012, pp. 39-59.
http://doi:10.20473/ijtid.v3i1.201
13. Kuo F.C., Hsu C.W., Tan T.L., et al.: Effectiveness of different wound dressings in the reduction of blisters and periprosthetic joint infection following total joint arthroplasty: A systematic review and network meta-analysis, The Journal of Arthroplasty 36(7), 2021, pp. 2612- 2629.
https://doi:10.1016/j.arth.2021.02.047
14. Kumar K.S., Prakash C., Ramesh P., et al.: Study of wound dressing material coated with natural extracts of Calotropis Gigantean, Eucalyptus Globulus and buds of Syzygium Aromaticum solution enhanced with rhEGF (REGEN-DTM 60), Journal of Natural Fibers 18(12), 2021, pp. 2270-2283.
http://doi.org/10.1080/15440478.2020.1726239
15. Prakash C., Sukumar N., Ramesh P., et al.: Development and characterization of wound dressing material coated with natural extracts of curcumin, aloe vera and chitosan solution enhanced with rhEGF (REGEN-DTM), Journal of Natural Fibers 18(12), 2021, pp. 2019-2032.
http://doi.org/10.1080/15440478.2019.1710738
16. Shi C., Wang C., Liu H., et al.: Selection of appropriate wound dressing for various wounds, Frontiers in Bioengineering and Biotechnology 8, 2020, pp. 1-17.
http://doi:10.3389/fbioe.2020.00182
17. Vivcharenko V., Przekora A.: Modifications of wound dressings with bioactive agents to achieve improved pro-healing properties, Applied Sciences 11(9), 2021, pp.1-16.
http://doi:10.3390/app11094114
18. Thomas S.: Hydrocolloid dressings in the management of acute wounds: a review of the literature, International Wound Journal 5(5), 2008, pp. 602-613.
http://doi:10.1111/j.1742-481X.2008.00541.x
19. CLH Healthcare, 7 Types of Wound Dressings & When to Use Each.
https://clhgroup.co.uk/learning-centre/guides/7-types-of-wound-dressings-when-to-use-each
20. Thomas S.: Hydrocolloid dressings in the management of acute wounds: a review of the literature, International wound journal 5(5), 2008, pp. 602-613.
https://doi.org/10.1111/j.1742-481X.2008.00541.x
21. Kamińska M.S., Cybulska A.M., Skonieczna-Żydecka K., Augustyniuk K., Grochans E., Karakiewicz B.: Effectiveness of hydrocolloid dressings for treating pressure ulcers in adult patients: A systematic review and meta-analysis, International Journal of Environmental Research and Public Health 17(21), 2020, pp. 1-19.
http://doi:10.3390/ijerph17217881
22. Nguyen H.M., Le T.T.N., Nguyen A.T., et al.: Biomedical materials for wound dressing: Recent advances and applications, RSC advances 13(8), 2023, pp. 5509-5528.
https://doi.org/10.1039/D2RA07673J
23. Ahmad N.: In vitro and in vivo characterization methods for evaluation of modern wound dressings, Pharmaceutics 15(1), 2022, pp. 1-47.
https://doi.org/10.3390/pharmaceutics15010042
24. Long C., Qing Y., Li S., et al.: Asymmetric composite wound nanodressing with superhydrophilic/ superhydrophobic alternate pattern for reducing blood loss and adhesion, Composites Part B: Engineering 223, 2021, pp. 1-10.
http://doi:10.1016/j.compositesb.2021.109134
25. Jin S., Newton M.A.A., Cheng H., et al.: Progress of hydrogel dressings with wound monitoring and treatment functions, Gels 9(9), 2023, pp. 1-26.
https://doi.org/10.3390/gels9090694
26. Asdasd Weller C., Team V.: Interactive dressings and their role in moist wound management. In Rajendran R., editor. Advanced textiles for wound care Cambridge: Woodhead Publishing, 2019, pp. 105-134.
https://doi.org/10.1016/B978-0-08-102192-7.09001-9
27. Lu H., Yuan L., Yu X.,et al.: Recent advances of on-demand dissolution of hydrogel dressings, Burns & Trauma 6, 2018, pp.1-13.
http://doi:10.11846/s1038-018-0138-8
28. El-Sherbiny I.M., Yacoub M.H.: Hydrogel scaffolds for tissue engineering: Progress and challenges, Global Cardiology Science and Practice 2013(3), pp. 1-27.
https://doi.org/10.5339/gcsp.2013.38
29. Guo B., Qu J., Zhao X., et al.: Degradable conductive self-healing hydrogels based on dextran-graft-tetraaniline and N-carboxyethyl chitosan as injectable carriers for myoblast cell therapy and muscle regeneration, Acta Biomaterialia 84, 2019, pp. 180-193.
http://doi:10.1016/j.actbio.2018.12.008
30. Nielsen J., Fogh K.: Clinical utility of foam dressings in wound management: A review, Chronic Wound Care Management and Research 2, 2015, pp. 31-38.
31. Bullough L., Johnson S., Forder R.: Evaluation of a foam dressing for acute and chronic wound exudate management, British Journal of Community Nursing 20 (Sup9), 2015, pp. S17-S24.
http://doi:10.12968/bjcn.2015.20.Sup9.S17
32. Kowalczuk D., Miazga-Karska M., Gładysz A., et al.: Characterization of ciprofloxacin-bismuth-loaded antibacterial wound dressing, Molecules, 25(21), 2020, pp. 1-13.
http://doi:10.3390/molecules25215096
33. Wang Y.C., Lee H.C., Chen C.L., et al.: The effects of silver-releasing foam dressings on diabetic foot ulcer healing, Journal of Clinical Medicine 10(7), 2021, pp. 1-9.
http://doi:10.3390/jcm10071495
34. Pramod S.: A soft silicone foam dressing that aids healing and comfort in oncology care, British Journal of Nursing 30(1), 2021, pp. 40-46.
http://doi:10.12968/bjon.2021.30.1.40
35. Wille J.C., Alblas A.B.V.O., Thewessen E.A.P.M.: A comparison of two transparent film-type dressings in central venous therapy, Journal of Hospital Infection 23(2), 1993, pp.113-121.
http://doi:10.1016/0195-6701(93)90015-R
36. Silveira R.C.D.C.P., Braga F.T.M.M., Garbin L.M., et al.: The use of polyurethane transparent film in indwelling central venous catheter, Revista Latino-Americana de Enfermagem 18, 2010, pp.1212-1220.
37. Gallieni M.: Transparen film dressings for intravascular catheter exit-site, The Journal of Vascular Access 5(2), 2004, pp. 69-75.
http://doi:10.1177/112972980400500205
38. Atay S., Kurt F.Y.: Effectiveness of transparent film dressing for peripheral intravenous catheter, The Journal of Vascular Access 22(1), 2021, pp.135-140.
http://doi:10.1177/1129729820927238
39. Sharma S.K., Thakur K., Mudgal S.K., et al.: Efficacy of transparent vs. pressure pressing in prevention of post-cardiac catheterization pain, discomfort and hematoma: A systematic review and meta-analysis of RCTs, Journal of Caring Sciences 10(2), 2021, pp. 103-110.
http://doi:10.34172/jcs.2021.019
40. Edwards J.V., Yager D.R., Cohen I.K., Diegelmann R.F., Montante S., Bertoniere N., Bopp A.F.: Modified cotton gauze dressings that selectively absorb neutrophil elastase activity in solution, Wound Repair and Regeneration 9(1), 2001, pp. 50-58.
http://doi:10.1046/j.1524-475x.2001.00050.x
41. Balasubramanian E., Balasubramanian V., Babu G., et al.: Moist wound dressing fabrications: Carboxymethylation of

antibacterial cotton gauze, Journal of Engineered Fibers and Fabrics 8(4), 2013, 78-87.
http://doi:10.1177/155892501300800402
42. Soares H.P.L., Brandão E.D.S., Tonole R.: Primary bandages for people with pemphigus vulgaris lesions: An integrative literature review, Revista Gaúcha de Enfermagem 41, 2020, pp. 1-8.
http://doi:10.1590/1983-1447.2020.20190259
43. Edwards H., Finlayson K., Parker C., et al.: Wound dressing guide. Brisbane: Queensland University of Technology. 2019.
44. Fang H., Li D., Xu L., et al.: A reusable ionic liquid-grafted antibacterial cotton gauze wound dressing, Journal of Materials Science, 56, 2021, pp.7598-7612.
http://doi:10.1007/s10853-020-05751-8
45. Qin Y.: Antimicrobial textile dressings in managing wound infection. Rajendran S., editor. Advanced textiles for wound care, Oxford: Woodhead Publishing, 2009, pp. 179-197.
http://doi:10.1533/9781845696306.1.179
46. Atay H.Y.: Antibacterial activity of chitosan-based systems, Functional chitosan: drug delivery and biomedical applications 2019, pp. 457-489.
https://doi.org/10.1007/978-981-15-0263-7_15
47. Yang M., Wang H., Li K., et al.: A new soft tissue constructed with chitosan for wound dressings-incorporating nanoparticles for medical and nursing therapeutic efficacy, Regenerative Therapy 24, 2023, pp. 103-111.
https://doi.org/10.1016/j.reth.2023.06.005
48. Abbasipour M., Mirjalili M., Khajavi R., et al.: Coated cotton gauze with Ag/ZnO/chitosan nanocomposite as a modern wound dressing, Journal of Engineered Fibers and Fabrics 9(1), 2014, pp. 124-130.
http://doi:10.1177/155892501400900114
49. Anjum S., Arora A., Alam M.S., et al.: Development of antimicrobial and scar preventive chitosan hydrogel wound dressings, International Journal of Pharmaceutics 508(1-2), 2016, pp. 92-101.
http://doi:10.1016/j.ijpharm.2016.05.013
50. Ghomi E.R., Khalili S., Khorasani S.N., et al.: Wound dressings: Current advances and future directions, Journal of Applied Polymer Science 2019, 136(27), pp. 1-12.
http://doi:10.1002/app.47738
51. Zhang M.X., Zhao W.Y., Fang Q.Q., et al.: Effects of chitosan-collagen dressing on wound healing in vitro and in vivo assays, Journal of Applied Biomaterials & Functional Materials 19, 2021, pp.1-10.
http://doi:10.1177/2280800021989698
52. Bagher Z., Ehterami A., Safdel M.H., et al.: Wound healing with alginate/chitosan hydrogel containing hesperidin in rat model, Journal of Drug Delivery Science and Technology 55, 2020, pp.1-34.
http://doi:10.1016/j.jddst.2019.101379
53. Purwar R., Rajput P., Srivastava C.M.: Composite wound dressing for drug release. Fibers and Polymers 15, 2014, pp.1422-1428.
http://doi:10.1007/s12221-014-1422-2
54. Fang Q.Q., Wang X.F., Zhao W.Y., et al.: Development of a chitosan–vaseline gauze dressing with wound-healing properties in murine models, The American Journal of Tropical Medicine and Hygiene 102(2), 2020, pp. 468-475.
http://doi:10.4269/ajtmh.19-0387
55. Pinho E., Calhelha R.C., Ferreira I.C.F.R., et al.: Cotton - hydrogel composite for improved wound healing: Antimicrobial activity and anti - inflammatory evaluation—Part 2, Polymers for Advanced Technologies 30(4), 2019, pp. 863-871.
http://doi:10.1002/pat.4519
56. Jiang S., Deng J., Jin Y., et al.: Breathable, antifreezing, mechanically skin-like hydrogel textile wound dressings with dual antibacterial mechanisms, Bioactive Materials 2, 2023, pp. 313-323.
https://doi.org/10.1016/j.bioactmat.2022.08.014
57. Lin X., Zhang H., Zhang H., et al.: Bio-printed hydrogel textiles based on fish skin decellularized extracellular matrix for wound healing, Engineering 25, 2023, pp. 120-127.
https://doi.org/10.1016/j.eng.2022.05.022
58. Froelich A., Jakubowska E., Wojtyłko M., et al.: Alginate-based materials loaded with nanoparticles in wound healing, Pharmaceutics 15(4), 2023, pp. 1142-1181.
https://doi.org/10.3390/pharmaceutics15041142
59. Stoica A.E., Chircov C., Grumezescu A.M.: Nanomaterials for wound dressings: an up-to-date overview, Molecules 25(11), 2020, pp. 1-25.
http://doi:10.3390/molecules25112699
60. Ip, M.: Antimicrobial dressings. In: Farrar, D., editor. Advanced wound repair Therapies. Cambridge: Woodhead Publishing; 2011, pp. 416-449.
http://doi:10.1533/9780857093301.3.416
61. Comotto M., Saghazadeh S., Bagherifard S., et al.: Breathable hydrogel dressings containing natural antioxidants for management of skin disorders, Journal of Biomaterials Applications 33(9), 2019, pp. 1265 – 1276.
http://doi:10.1177/0885328218816526
62. Walker M., Parsons D.: Hydrofiber® technology: Its role in exudate management, Wounds UK. 6(2), 2010, pp. 31- 88.
63. Walker M., Lam S., Pritchard D., et al.: Biophysical properties of a Hydrofiber® cover dressing, Wounds UK. 6(9) 2010, pp. 16-29.
64. Qin Y.: Advanced wound dressings, The Journal of The Textile Institute 92(2), 2001, pp. 127-138.
http://doi:10.1080/00405000108659563
65. Barnea Y., Weiss J., Gur E.: A review of the applications of the Hydrofiber dressing with silver (Aquacel Ag®) in wound care, Therapeutics and Clinical Risk Management 6, 2010, pp. 21- 27.
66. Rangaraj A., Harding K., Leaper D.: Role of collagen in wound management, Wounds UK. 7(2), 2011, pp. 54-63.
67. Mathew-Steiner S.S., Roy S., Sen C.K.: Collagen in wound healing, Bioengineering. 8(5), 2021, pp. 1-15.
http://doi:10.3390/bioengineering8050063
68. Santhanam R., Rameli M.A.P., Effri A.A., et al.: Bovine based collagen dressings in wound care management, Journal of Pharmaceutical Research International 32(33), 2020, pp. 48-63.
http://doi:10.9734/jpri/2020/v32i3330949
69. Doillon C.J., Silver F.H.: Collagen-based wound dressing: Effects of hyaluronic acid and firponectin on wound healing, Biomaterials 7(1), 1986, pp. 3-8.
http://doi:10.1016/0142-9612(86)90080-3
70. Amirrah I.N., Wee M.F.M.R., Tabata Y., et al.: Antibacterial-integrated collagen wound dressing for diabetes-related foot ulcers: an evidence-based review of clinical studies, Polymers 12(9) 2020, pp. 1-17.
http://doi:10.3390/polym12092168
71. Guo W., Yang Z., Qin X., et al.: Fabrication and Characterization of the Core-Shell Structure of Poly (3-Hydroxybutyrate-4-Hydroxybutyrate) Nanofiber Scaffolds, BioMed Research International 2021, 2021, pp. 1-11.
http://doi:10.1155/2021/8868431
72. Gao C., Zhang L., Wang J., et al.: Electrospun nanofibers promote wound healing: theories, techniques, and perspectives, Journal of Materials Chemistry B 9(14), 2021, pp. 3106-3130.
http://doi:10.1039/D1TB00067E
73. Abrigo M., McArthur S.L., Kingshott P.: Electrospun nanofibers as dressings for chronic wound care: advances, challenges, and future prospects, Macromolecular Bioscience 14(6), 2014, pp. 772-792.
http://doi:10.1002/mabi.201300561
74. Fatahian R., Mirjalili M., Khajavi R., et al.: Recent studies on nanofibers based wound-dressing materials: A review. Proceedigns of 7 th International Conference on Engineering & Applied Science, 2018, pp.1-12
75. Iacob A.T., Drăgan M., Ionescu O.M., et al.: An overview of biopolymeric electrospun nanofibers based on polysaccharides for wound healing management, Pharmaceutics 12(10), 2020, pp. 1-49.
http://doi:10.3390/pharmaceutics12100983

76. Akhmetova A, Heinz A.: Electrospinning proteins for wound healing purposes: opportunities and challenges. Pharmaceutics 13(1), 2021, pp. 1-22. http://doi:10.3390/pharmaceutics13010004
77. Campa-Siqueiros P., Madera-Santana T.J., Ayala-Zavala J.F., et al.: Nanofibers of gelatin and polivinyl-alcohol-chitosan for wound dressing application: fabrication and characterization, Polímeros 30, 2020, pp.1-11. http://doi:10.1590/0104-1428.07919
78. Azimi B., Maleki H., Zavagna L., et al.: Bio-based electrospun fibers for wound healing, Journal of Functional Biomaterials 11(3), 2020, pp. 1-36. http://doi:10.3390/jfb11030067
79. Almasian A., Najafi F., Eftekhari M., et al.: Preparation of polyurethane/pluronic F127 nanofibers containing peppermint extract loaded gelatin nanoparticles for diabetic wounds healing: Characterization, in vitro, and in vivo studies, Evidence-Based Complementary and Alternative Medicine 2021, pp. 1-16. http://doi:10.1155/2021/6646702
80. Latiyan S., Kumar T.S., Doble M., et al.: Perspectives of nanofibrous wound dressings based on glucans and galactans-A review, International Journal of Biological Macromolecules 244, 2023, pp. 1-20. https://doi.org/10.1016/j.ijbiomac.2023.125358
81. Li Y., Xu Z., Tang L., et al.: Nanofibers fortified with synergistic defense route: A potent wound dressing against drug-resistant bacterial infections, Chemical Engineering Journal 475 (1), 2023, pp. 146492. https://doi.org/10.1016/j.cej.2023.146492
82. Zhou L., Xu P., Dong P., et al.: A self-pumping dressing with in situ modification of non-woven fabric for promoting diabetic wound healing, Chemical Engineering Journal 457, 2023, pp.141108. https://doi.org/10.1016/j.cej.2022.141108
83. Homaeigohar S., Boccaccini A.R.: Antibacterial biohybrid nanofibers for wound dressings, Acta Biomaterialia 107, 2020, pp. 25-49. http://doi:10.1016/j.actbio.2020.02.022
84. Li L., Chen D., Chen J., et al.: Gelatin and catechol-modified quaternary chitosan cotton dressings with rapid hemostasis and high-efficiency antimicrobial capacity to manage severe bleeding wounds, Materials & Design 229, 2023, pp. 1-18. https://doi.org/10.1016/j.matdes.2023.111927
85. Zhang H., Wan H., Hu X., et al.: Antimicrobial-free knitted fabric as wound dressing and the mechanism of promoting infected wound healing, Science China Technological Sciences 66, 2023, pp. 2147–2154. https://doi.org/10.1007/s11431-022-2260-x
86. Parham S., Kharazi A.Z.: Cellulosic textile/clove nanocomposite as an antimicrobial wound dressing: In vitro and in vivo study, Colloids and Surfaces B: Biointerfaces 217, 2022, pp. 1-9. https://doi.org/10.1016/j.colsurfb.2022.112659
87. Aubert-Viard F., Mogrovejo-Valdivia A., Tabary N., et al.: Evaluation of antibacterial textile covered by layer-by-layer coating and loaded with chlorhexidine for wound dressing application, Materials Science and Engineering: C 100, 2019, pp. 554-563. https://doi.org/10.1016/j.msec.2019.03.044
88. Wang L., Li D., Shen Y., et al.: Preparation of Centella asiatica loaded gelatin/chitosan/nonwoven fabric composite hydrogel wound dressing with antibacterial property, International Journal of Biological Macromolecules 192, 2021, pp. 350-359. https://doi.org/10.1016/j.ijbiomac.2021.09.145
89. Gianino E., Miller C., Gilmore J.: Smart wound dressings for diabetic chronic wounds, Bioengineering 5(3), 2018, pp. 1-26. http://doi:10.3390/bioengineering5030051
90. Williams S., Okolie C.L., Deshmukh J., et al.: Magnetizing cellulose fibers with CoFe2O4 nanoparticles for smart wound dressing for healing monitoring capability, ACS Applied Bio Materials 2(12), 2019, pp. 5653-5662. http://doi:10.1021/acsabm.9b00731
91. Ghaderi R., Afshar M.: Topical application of honey for treatment of skin wound in mice, Iranian Journal of Medical Sciences 29(4), 2015, pp. 185-188.
92. Nazeri S., Ardakani E.M., Babavalian H., et al.: Evaluation of effectiveness of honey-based alginate hydrogel on wound healing in rat model, Journal of Applied Biotechnology Reports 2(3), 2015, pp. 293-297.
93. Konop M., Damps T., Misicka A., et al.: Certain aspects of silver and silver nanoparticles in wound care: a minireview, Journal of Nanomaterials 2016, pp.1-10. http://doi:10.1155/2016/7614753
94. ElSaboni Y., Hunt J.A., Stanley J., et al.: Development of a textile based protein sensor for monitoring the healing progress of a wound, Scientific Reports 12, 2022, pp. 1-12. https://doi.org/10.1038/s41598-022-11982-3