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Intelligent Wound Dressing Textile Fabric Using Various SMART Materials

Ahmed G. Hassabo [1,*], Fedaa Saad [2], Bouthaina M. Hegazy [2], Hala M. Elmorsy [2], Nanees Gamal [2], Aya Sedik [2], Hanan A. Othman [2]

[1] National Research Centre (Scopus affiliation ID 60014618), Textile Research and Technology Institute, Pretreatment and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza,
[2] Textile Printing, Dyeing, and Finishing Department, Faculty of Applied Arts, Benha University, Benha, Egypt
* Correspondence: aga.hassabo@hotmail.com (A.G.H.);

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Abstract: One area that gives textile materials more value is smart textiles. New technology, fibers, and textile materials have allowed this sector to develop. Developing smart or intelligent textiles involves collaboration with other branches, such as nanotechnology, materials science, design, electronics, and computer engineering. SMART textiles are intelligent textile structures or fabrics that have the capability to sense and interact with environmental conditions or stimuli, such as those from chemical, thermodynamic, mechanical, electric, magnetic, or other sources. In addition to its multi-functional scope, low energy, small size, and weight, the flexibility of forming and low cost provide various end uses in the medical, sports and fitness, military, fashion, automotive, aerospace, built environment, and energy industries. During the past decade, smart wound dressings have sprouted, and various smart wound dressings, including hydrogels, hydrocolloids, chitosan biopolymers, alginate, and biomaterials.

Keywords: smart textiles; intelligent textile; medical industry; smart wound dressing.

1. Introduction

Textiles, with the basic qualities of clothing, protection, and aesthetics, are an essential part of our lives; however, with technological advancement and the variation of requirements, the need for smart materials and intelligent textiles has grown significantly all over the world in recent years. Intelligent or smart materials are the source of the term “smart textiles. In 1989, the term “smart material” was known for the first time in Japan [1].

The first textile material to be classified as a smart textile’ was silk fiber with a shape memory effect (by identification with the more well-known shape memory alloys’) [2]. However, the discovery of shape memory materials in the 1960s and intelligent polymeric gels in the 1970s were widely considered the birth of true smart materials [3]. Intelligent textile materials were not introduced until the late 1990s. It is a new type of product that offers the same possibility and benefits as technical textiles.

Smart textiles are fabrics designed and manufactured to contain technologies that supply the wearer with raised practicality [4]. In other words, technology has also gained control of the textile sector. Smart textiles provide improved performance and functionality for applications ranging from simple to complex, such as military, healthcare, sportswear, and so on. Next-generation textiles are another name for smart or intelligent textiles [5].

2. Definition of Smart Textiles

Smart textiles are defined as those textile items that can behave differently from typical fabrics and can typically implement a specific function. Smart textiles are those that incorporate functions into the fabric's structure to enable them to sensation environmental stimuli, interact with them, and adjust to them. Both the stimulation and the restraint may have chemical, magnetic, electrical, or other origins. Other examples of smart textiles include materials that can control body temperature, fabrics that can release moisturizer or medication into the skin, and textiles that can reduce muscle vibration during physical activity. Smart fabrics can also be used in simple, aesthetically pleasing ways, such as by changing color, lighting up in patterns, or even displaying images and videos [6,7].

2.1. Classification of smart textiles.

Smart textiles are classified into three groups according to their performance characteristics: passive smart textiles, active smart textiles, and ultra-smart textiles [8,9].

2.1.1. Passive smart textiles.

The earliest generations of technical textiles offer additional functions passively or without considering environmental conditions. Because they act as essential sensors, passive smart textiles can only sense their surroundings. Passive smart textiles include UV-protective clothing, electrical fibers, plasma-treated clothes, and waterproof fabrics. Other examples of a wide range of qualities include items that are bulletproof, antimicrobial, anti-odor, and anti-static [10,11].

2.1.2. Active smart textiles.

Active smart textiles can recognize and react to environmental stimuli; in addition to the sensor function, they feature an activator mission. Actuators and sensors are both present in the second generation. Active smart textiles automatically adjust their performance to different environmental conditions. Shape-memory, chameleonic, water- and moisture (hydrophilic/nonporous), heat-storage, thermo-regulated, vapor-absorbing, and heat-evolving fabric are examples of active smart textiles. Phase change materials, shape-memory materials, and heat-sensitive dyes are active smart textile applications [1,12].

2.1.3. Ultra-smart textiles.

The third generation of smart textiles, known as ultra-smart textiles, can perceive, respond to, and adapt to external stimuli. A unit that functions like the brain and has cognition, reasoning, and activation capabilities makes up the majority of an extremely smart or intelligent textile. [13] capacities. The production of very smart textiles is now a reality after a successful marriage of traditional textiles and clothing technology with other branches of science like material science, structural mechanics, sensor and actuator technology, advanced processing technology, communication, artificial intelligence, biology, etc. New fiber and textile materials and miniaturized electronic components prepare smart textiles possible to create truly usable smart clothes. These intelligent clothes are worn like ordinary clothing, providing help in various situations according to the designed applications (see Table 1) [14,15].

Table 1: intelligent clothes according to the designed applications

Smart textile	Sensing external conditions	Reacting	Responding and adopting
passive	✓		
Active	✓	✓	
Ultra	✓	✓	✓

2.2. Smart materials and fibers in smart textiles.

‘Smart’ or ’‘Functional' materials are typically part of a ‘Smart System’ that can sense its environment and the impacts of that environment and, if properly smart, respond to that external stimulus through an active control mechanism. Smart materials and systems exist in a ‘Technology space,’ which also contains sensors and actuators [16,17].

2.3. Materials.

Smart’ or ’‘Functional' materials are typically part of a ‘Smart System’ that can sense its environment and the impacts of that environment and, if properly smart, respond to that external stimulus through an active control mechanism. Smart materials and systems exist in a ‘Technology space,’ which also contains sensors and actuators [18].

Mixing pure metallic or natural fibers with conductive compounds results in conductive yarns and fibers. Pure metallic yarns can be made of composite stainless steel, or fine continuous conductive metal-alloy combinations of fibers with conductive materials can be completed by the following methods: fibers filled with conductive material (e.g., carbon or metallic particles); fibers coated with conductive polymers or metal; and fibers spun with thin metallic or plastic conductive threads. Fabric sensors have been made using metallic silk, organza, stainless steel filament, metal-wrapped aramid fiber, conductive polymer fiber, conductive polymer coating, and specific carbon fiber [17,19].

Metallic, optical fibers, and conductive polymers, for example, can be inserted into the textile construction to provide electrical conductivity, sensor systems, and transmit data. Organic polymers may provide a solution to overcome the stiffness of inorganic crystals such as silicon. These materials are light, elastic, resilient, mechanically flexible, inexpensive, and easy to process [20,21].

2.3.1. Conductive inks.

To impart conductivity to certain regions of a garment, a layout can be screen-printed with conductive inks. To make traditional printing inks conductive, carbon, copper, silver, nickel, and gold can be added [22]. Therefore, functional conductive inks can be developed from metals, metal oxides, conductive polymers, organometallic inks, graphene, carbon nanotubes, and a mixture of the different inks. The development of functional printable inks with various nanoscale sizes and architectures has contributed to the success of inkjet printing for printed electronics [23].

Conductive inks can be classified as three-dimensional nanostructured materials such as nanoparticles, nanowires, nanotubes, or plate-like structures based on their contents [24]. Conductive inks can be made from conductive metal nano- and micro-particles. An example of the conductive inks employed to develop conductive textiles is reactive silver. Printed areas can be subsequently used as switches or pressure pads to activate circuits. For instance, a silver

nanoparticle-based was used as conductive ink configured with poly (styrene-block-ethylene-ran-butylene-block styrene) to develop a skin-inspired ultra-sensitive pressure sensor [25,26].

2.3.2. Metal fibers.

Metal threads are formed of incredibly tiny metal strands. Fibers are created by either a bundle-drawing method or by shaving the edge of thin metal sheeting. Metallic threads and yarns can be knitted or woven into a fabric and utilized to link components. They can also be used to monitor electrical physiological activity, such as electrocardiogram (ECG) signals, as electrodes [27,28].

2.3.3. Coating with nanoparticles.

Nanotechnology has been essential in the development of smart fabrics. Coating a fabric with nanoparticles is frequently used in the textile industry to increase textile performance and functionality. Nanotechnology can create long-lasting effects and provide high-durability fabrics [29,30]. Coating with Nanoparticles can enhance the textiles with properties such as antibacterial, water-repellence, UV-protection, and self-cleaning while still maintaining breathability and tactile properties of the textile. Nano-tex has a range of products using such coatings to resist spills, repel and release stains, and resist static. Smart devices based on nanomaterials are increasingly being combined with textiles to provide a variety of purposes, including energy harvesting and storage, sensing, medication release, and optics [31-33].

2.3.4. Optical fibers.

Optical fibers are thin strands that can transmit information by transporting optical signals. Optical fibers contain two basic parts: core and cladding. Optical fibers can be produced using different materials, including silica glass (SiO_2), fluoro aluminate, fluorozirconate, crystalline materials, chalcogenide glasses, and polymers. Plastic optical fibers are simple to incorporate into textiles. They benefit from not producing heat and being insensitive to electromagnetic radiation. In a smart garment, optical fibers can transport data signals, transmit light for optical sensing, detect fabric deformations due to stress and strain, and perform chemical sensing [34-36].

2.3.5. Shape memory materials.

When a certain stimulus is applied, shape memory materials (SMMs) restore their original shape after a large and seemingly plastic deformation. This is known as the shape memory effect (SME). Super elasticity (in alloys) or visco-elasticity (in polymers) are also commonly observed under certain conditions [37,38].

Shape memory alloys, such as nickel-titanium, have been created to provide greater resistance to heat sources. A shape memory alloy has distinct characteristics below and above the activation temperature. The alloy exerts a force to return to a previously established shape at the activation temperature and becomes substantially stiffer. The activation temperature can be adjusted by adjusting the nickel-to-titanium ratio in the alloy. Cuprous-zinc alloys can produce the reversible variation needed for protection from changeable weather conditions [38,39].

Shape Memory Polymers have the same effect as Ni-Ti alloys, but because they are polymers, they may be more compatible with fabrics. Electroactive polymers (EAPs) are typically composed of highly functionalized polymers. The "Gel robots," which are made of poly 2-acrylamido-2-methylpropane sulfonic acid and are fully explored for applications in the replacement of muscles and tendons, are one of the most well-known EAPs [40,41].

2.3.6. Chromic materials.

Chromic materials can change color depending on the environment. These materials have primarily been employed in the fashion industry to make amusing color-changing designs. Chromic materials can be classified based on the sort of stimuli they receive.

Electrochromic: External stimulus is electricity.
Mechanochromic chromic: External stimulus is pressure.
Solvate chromic: External stimulus is liquid or gas.
Photochromic: External stimulus is light.
Thermochromic: External stimulus is heating.
Halochromic: External stimulus is PH
Tribochromic: External stimulus is friction

At various phases, chromic compounds can be applied to textile fabrics using various ways. A chronic dyestuff, for example, can be used to dye fibers using traditional dyeing methods; the fibers can be added to the fiber structure during the polymer stage; color-changing fibers can be obtained through melt spinning or wet spinning; they can be mixed with resin and coated onto the fabric surface, allowing them to be used for fabric printing or dyeing [41-44].

2.3.7. Phase change materials.

Nowadays, phase change materials are highly applied in the field of textiles for different kinds of products such as apparel, underwear, socks, shoes, bedding accessories, and sleeping bags. For multi-functional products also are applicable in the specialty items like anti-ballistic vests, automotive, medical, or other industrial applications [45-47].

For a Suitable application of PCMs in textiles, the temperature must be within a temperature range of human skin. This exciting property of PCMs would be useful for the application of producing protective garments in all kinds of weather, from the strongest winter to the hottest summer. Textile materials treated with PCMs can store the heat if it is excess and released. The PCMs can be applied in the fiber spinning or during chemical finishing processes like Coating, lamination, and others [48-50].

3. How do Smart Fabrics function?

Conduit polymers, encapsulated phase change materials, shape-memory materials, smart materials, and other electrical sensors and communication tools can all be used to create smart textiles. These materials react to stimuli in their environment following their designed feature. All smart materials include an energy transport from the stimuli to restrain given out by the substance. They are incorporated and compound materials [51,52].

They are capable of processing, analyzing, and responding in some way. Even they can adjust to the surrounding conditions. They obtained the full capacity to modify themselves in response to internal energy, pressure, density, or temperature changes. The material's properties determine the amount of transported energy [53,54].

All materials, including intelligent ones, behave in a method that is defined by the relationship between the quantum of energy required and the fixed grade of change. If they get energy or any stimuli from the surrounding environment, they do not modify it [55,56].

4. Wound Dressings Based on Smart Textile

A dressing is an object applied to a wound to help it heal and/or prevent further damage. It is intended to be in direct contact with the wound, as opposed to a bandage, which is primarily used to hold a dressing in place. In the past, a dressing was a piece of fabric, though descriptions of cobwebs, excrement, leaves, and honey have also been made. Modern dressings include gauzes (which may be infused with a substance to promote sterility or speed up healing), films, gels, foams, hydrocolloids, alginates, hydrogels, pastes, granules, and beads made of polysaccharides [57,58].

4.1. Characteristics of the multi-functional wound dressing.

Depending on the type of wound, an intelligent, multi-functional dressing material must be used. The ability to (1) provide a moist environment; (2) allow the epidermis to move more easily; (3) promote the development of new blood vessels and tissue regeneration; (4) provide adequate permeability for vaporized water and oxygen; (5) ensure suitable heat in the area of the wound to promote blood flow; (6) defend against bacterial and viral infections; (7) be non-adhesive to the wounded area and easily removed; (8) be sterile, harmless, and free of a (10) Medication administration that is both biocompatible and effective; (11) When choosing the best dressing, high wound exudate absorption potential should be considered [59,60].

4.1.1. pH-responsive wound dressings.

pH is one of the elements that have a master effect on the recovery process in all four stages. The pH range of a healthy epidermis is 4.5 to 6.5, but acute and chronic wounds have different pH ranges. As a result of microbial infection and the formation of alkaline byproducts, the pH of the wound may rise to 7-9. During the healing process, the pH of a wound is monitored using a variety of techniques, including colorimetry, electrochemical, and electromechanical methods. These methods are time-consuming, costly, and consume more utility. As a result, sensor-based dressings would be affordable and easy to monitor. Flex circuit transducers, optical sensor-based dyes, pH-sensitive color dyes, pH-sensitive electrodes, and carbon dots are examples of pH-sensitive wound dressing manufacturing methods [61-63].

4.1.2. Pressure-responsive wound dressings

Patients with pressure ulcers and diabetic foot ulcers frequently receive pressure-relieving treatments. Friction, jerky motions, shear, and the pressure of the environment all contribute to this pressure on the damaged area. This pressure restricts blood flow, killing nearby cells and tissues and slowing healing. Furthermore, immobile people, particularly those who are bedridden, are more vulnerable to these diseases. Pressure sensor dressings have simplified the monitoring of injured areas. Sensors are classified as piezoresistive, capacitive, triboelectric, or flexible pressure sensors. Numerous flexible pressure sensors are currently being developed to monitor wounds [64,65].

4.1.3. Moisture-responsive wound dressing.

The amount of moisture in the wound region is critical at all stages. Less moisture inhibits healing by desiccating the wound surfaces, whereas too much moisture can cause macerated tissues. Exudates from the wound, excessive perspiration, urinary incontinence, and transepidermal water loss are all potential causes of the wound's high moisture content. Excessive wound moisture necessitates numerous dressing changes and may harm the skin around the wound, leading to maceration. As a result, dressings with real-time sensors would be preferable to standard dressings. The first commercially available moisture-sensitive wound dressing, dubbed "Wound Sense," was introduced in 2016. Breathable dressings with sensor integration are made from various composite materials (polyvinyl alcohol, carbon nanotubes, graphene oxide, and graphene nanosheets made of palladium and cerium oxide) 66-68].

4.1.4. Sustained drug-releasing wound dressings.

Externally managed stimuli-responsive dressings allow for the monitoring and managing medication release to damaged areas. Hydrogels have been extensively researched and used to incorporate pharmaceuticals into dressing layers for long-term drug release. These drug delivery dressings are made from polymers such as polylactide-co-glycolide, polyvinyl pyrrolidone, polyvinyl alcohol, polyhydroxy alkyl methacrylates, polyurethane-foam, hydrocolloid, alginate, hyaluronic acid, collagen, and chitosan [69].

Additionally, wound dressings have self-healing properties. Some dressings are available in spray form, while others are injectable. Several dressing forms were developed to treat various ranges and stages of healing by incorporating multi-functional elements. In this review, we attempted to compile the most recent research data on multi-functional wound dressing materials and studies on their benefits in wound healing [70,71].

4.2. Wound dressing based on hydrocolloid.

A group of hydrocolloid dressings aids wound healing by providing occlusion. It is usually a multilayered structure with a protective outer layer and a supporting material such as film, foam, or fiber. The composite, which consists of an adhesive that disperses hydrophilic particles, is laminated onto this supporting material [72,73].

Nonwoven polyester fibers and semipermeable polyurethane films are the most common supporting materials used in hydrocolloid dressings, whereas the hydrophilic component of the adhesive may also include synthetic polymers like polyurethane gels, proteins (such as gelatin), and polysaccharides (cellulose derivatives) [74].

These hydrocolloid dressings physically interact with wound exudates to form a hydrated gel on the wound surface. When the dressing is removed, this gel separates and protects the newly formed skin. Brand-name hydrocolloid dressings include Tegasorb, DuoDerm CGF control gel formula dressing, and Coloplast's Comfeel ulcer care dressing (from 3M Health Care). In addition to helping to debride the wound, hydrocolloids absorb exudate [75].

Patients should be informed that the wound may begin to smell and appear larger at first. When the gel leaks out, the dressing must be replaced. To avoid frequent changes, the dressing should be at least 2 cm larger in diameter than the wound. Hydrocolloids can be used

in the presence of necrotic material, but they frequently cause exudate buildup in large wounds and those with anaerobic colonization [76].

In a comparison trial comparing a hydrocolloid dressing (Comfeel Ulcer DressingTM) combined with compression stocking and a rigid bandage (Unna boot) for treating venous ulcers, the hydrocolloid dressing and compression stocking combination was found to be superior to the rigid bandage [77]. In that study, the two groups of dressings were compared by tracking time to complete healing, wound surface reduction, pain during the application, and total duration of dressing change. A randomized trial comparing paraffin gauze and a hydrocolloid dressing applied to skin draught donor sites revealed that the hydrocolloid achieves faster healing and is a less painful dressing [78,79].

On patients with lacerations, abrasions, and minor surgery incisions, another study compared a hydrocolloid dressing to a nonadherent dressing. While the two groups' healing times were comparable, patients who used the hydrocolloid reported less discomfort, required fewer analgesics, and could go about their daily lives normally, including taking showers or baths without damaging the dressing or the wound [80,81].

AquacelTM hydrocolloid dressing outperformed tulle gauze dressing regarding acute inflammatory responses observed during the early stages of wound healing in rats with partial thickness wounds. The outer cover of hydrocolloid dressings is usually occlusive, preventing water vapor exchange between the wound and its surroundings. This can be harmful to infected wounds that need a certain amount of oxygen to heal quickly. Another disadvantage is that fiber-containing dressings deposit in the wound and must frequently be removed during dressing changes [82,83].

Microscopic studies comparing the ability of CMC hydrocolloid and alginate dressings to adsorb harmful bacteria revealed that the CMC dressings were superior. The CMC-containing wound dressing produced a gel upon hydration that effectively encapsulated large numbers of *P. aeruginosa* and *S. aureus* in that study. The authors also demonstrated CMC's ability to immobilize these bacteria within the swollen fibers, as opposed to alginate gel, which immobilized fewer bacteria [84,85].

4.3. Wound dressings based on hydrogels.

Hydrogels are insoluble hydrophilic materials made from synthetic polymers such as poly(methacrylates) and polyvinyl pyrrolidine. These systems can swell in water to an equilibrium state while retaining their original shape, creating the moist environment required for an ideal dressing [86,87].

Hydrogels can be chemically stable or degrade, eventually dissolving and disintegrating. When secondary forces such as ionic and H bonds or molecular entanglements hold the networks together, they are referred to as "reversible" or "physical" gels. When networks are covalently crosslinked, they become "permanent" or "chemical" gels (Fig. 4)[88,89].

Some of the known methods of making hydrogel dressings using hydrophilic polymers include

(i) physical method by repeated freezing and thawing;

(ii) chemical method using chemicals like borax, boric acid, formaldehyde, and glutaraldehyde; and

(iii) irradiation. The main disadvantage of hydrogels is their poor mechanical strength.

Hydrogels are commonly used for the following purposes as scaffolds in tissue engineering, environmentally sensitive hydrogels (pH-sensitive, temperature sensitive), sustained release delivery systems, biosensors, disposable diapers, sanitary towels, contact lenses (silicone hydrogels, polyacrylamides) and medical electrodes using the hydrogels composed of crosslinked polymers such as chitosan, poly(ethylene oxide) (PEO), poly(vinyl alcohol) (PVA), poly(2-acrylamido- (PVP) [90,91]. Figure 5 depicts common polymers used as hydrogels. Hydrogels' high water content (70-90%) benefits granulation tissues and epithelium in a moist environment. The soft, elastic nature of hydrogels allows for easy application and removal after the wound has healed without causing any damage [92,93].

Hydrogels reduce the temperature of cutaneous wounds by providing a soothing and cooling effect. Dry chronic wounds, necrotic wounds, pressure ulcers, and burn wounds are all treated with hydrogels. Hydrogel dressings can be used at all four stages of wound healing. Hydrogel dressings are non-irritating, non-reactive to biological tissue, and metabolite permeable [94,95].

Hydrogel dressings have been reported to be used to treat chronic leg ulcers by many researchers. Hydrogel dressing difficulties include exudate accumulation, which causes maceration and bacterial proliferation, resulting in a foul odor in wounds. Furthermore, the low mechanical strength of hydrogels makes them difficult to handle. Hydrogels include IntrasiteTM, Nu-gelTM, AquaformTM polymers, sheet dressings, impregnated gauze, and water-based gels [96,97].

Natural as well as synthetic polymers have been used as hydrogel wound dressings. Natural polymers like dextran-dialdehyde, bovine-serum albumin, glycosaminoglycan, chitosan (CS), and collagen have been investigated for their potential as hydrogel wound dressings. Chitosan and collagen are the most commonly used natural polymers, along with textile materials such as wound dressings. In one of the research works, a dressing was generally produced in the form of a pad containing a supporting layer (nonwoven fabric) and a collagen layer [98].

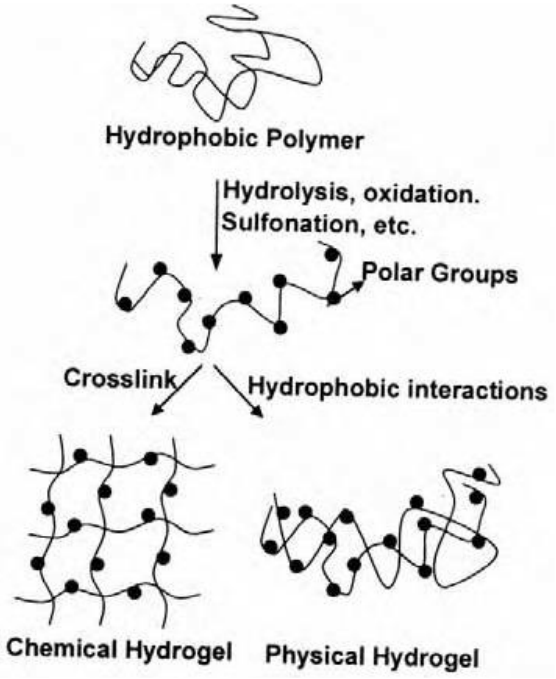

Figure 4. Formation of physical and chemical hydrogels.

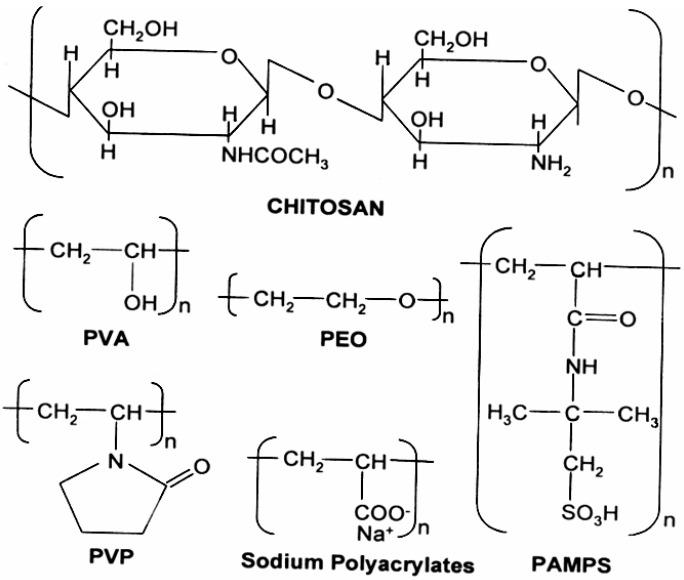

Figure 5. Chemical structure of polymers used as a hydrogel.

The chitosan-modified cotton fabric absorbs antibiotic molecules from aqueous solutions. The amount of absorption is determined by the degree of modification of the samples. The amount of antibiotic bonded to the textile increases with the degree of modification. Such cotton textile finishing enables the development of therapeutic new-generation dressings to prevent infection in surgical wounds [99,100].

In addition, chitosan was impregnated on acrylic acids (AA) or isopropyl acrylamide (NIPAAm) bi-grafted polypropylene (PP) nonwoven fabrics for wound dressing to provide higher water vapor transmission rates as well as good antibacterial activities and cell adhesiveness. Recently, some wound healing products derived from chitosan and collagen hydrogels have been approved [101,102].

4.4. Wound dressings based on biopolymers.

4.4.1. Wound dressings based on chitosan.

Chitin is a valuable natural polymer with excellent bioactive properties. Chitin is non-toxic, non-allergic, antibacterial, antiviral, and antifungal. Three-dimensional chitin fiber materials with a soft handle, breathability, absorbency, smoothness, and non-chemical additives are determined to be the best dressings for wound healing. Chitin is a 1, 4-linked N-acetyl-d-glucosamine linear homopolymer, whereas chitosan (CS) is partially N-deacetylated chitin [103,104].

Both chitin and CS have several advantageous biological properties that make them equally suitable for use as a wound dressing, including biocompatibility, biodegradability, hemostatic activity, anti-infective activity, and the ability to accelerate the healing process. Scar prevention is the most aesthetically pleasing standard in the field of wound dressing technology today [105]. Chitosan, a bioactive component, provides a dressing that prevents scarring and meets other requirements. A unique asymmetric CS membrane was created using the immersion precipitation phase-inversion approach (Fig. 1) [106,107].

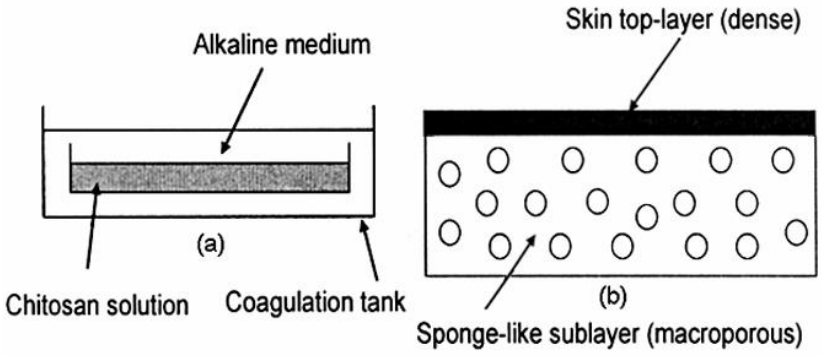

Figure 1. Preparation (a) and structure (b) of the asymmetric membrane.

This innovative dressing's upper skin surface is supported by a sublayer that resembles a microporous sponge. This asymmetric membrane has excellent oxygen permeability, controlled evaporative water loss, and better fluid drainage due to its thick skin layer and the inherent antibacterial properties of CS. It may, however, be able to repel the invasion of foreign germs [108,109].

Polyethylene glycol (PEG) and CS were applied to the cotton fabric before it was freeze-dried in one of the studies. Scanning electron microscopy revealed a porous structure in the coated fabric (SEM). The pore size was 75-120 m, and the material's porosity was 54-70%. The increased PEG concentration in the blend composition resulted in improved pore instability, which increased pore size with an elongated morphology. Phase separation between the two components appears to be an important feature in the observed behavior of the porous structure [110,111].

A layer of cotton fabric has been used to support the CS-PEG layer, resulting in extremely thin and light constructions. The dressing's structure has been designed in such a way that it has a high porosity. The thickness of the CS coating also has a significant impact on the degree to which it develops porosity on the surface. Adding PEG to CS changes the surface shape of this freeze-dried CS-PEG/cotton membrane, also known as the CPC membrane. Membranes have a clear tendency to lose their naturally occurring, extended porous structure, and the addition of PEG results in partially collapsed porosity. This demonstrates that the observed surface shape results from a very weak interaction between CS and PEG. Pore instability has been observed to increase with PEG concentration, resulting in larger pores. This is evident from the shape of the CPC membrane at 50% PEG-20 concentration. (Fig 2) [110].

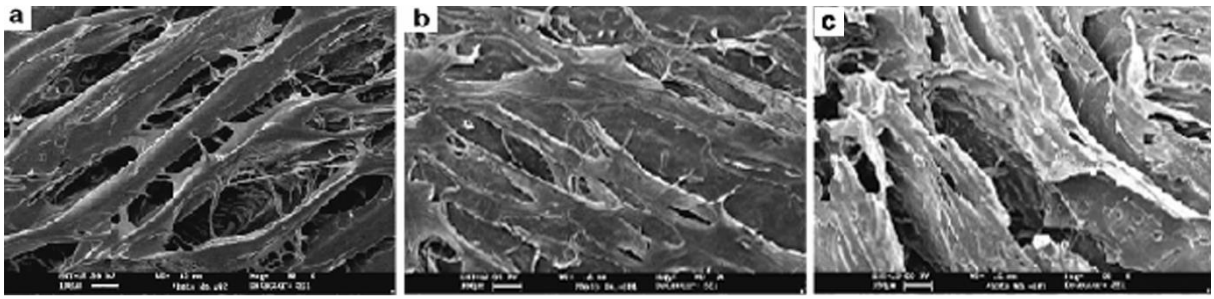

Figure 2. -SEM of freeze-dried CPC membranes with (a) 10% PEG-20, (b) 30% PEG-20, and (c) 50% PEG-20 [magnification × 80].

According to one of the articles, chitosan oligomer and an antibiotic agent are present in polyvinyl alcohol, poly (N-vinyl pyrrolidone), and chitosan hydrogels. Both are observed,

to begin with, as a quick release before becoming progressively slower over time. These dressings are excellent materials for wound care treatment because they have a high gel content, a moderate ESR, an appropriate tensile strength, and an adequate elongation at break [112].

In another study, the linear polymer PEG serves as the domain, and the CS crosslinking network serves as the matrix in a semi-interpenetrating polymer network (IPN) system. The dispersion phase PEG is extracted successfully in water, and pores form throughout the extraction process, resulting in the formation of the porous structure. The chemical, thermal, and antibacterial properties of CS were evaluated as coated gauze. The antibacterial activity of the CS-coated gauze was tested against *E. coli* and Lactobacillus. Because it was effective against these microorganisms, CS-coated gauze was identified as a viable wound dressing [113].

Graft copolymerization has also received much attention as a method of modifying polymeric materials because it can give materials the desired qualities by carefully selecting the molecular features of the side chain to be grafted. Chitosan contains two types of reactive groups that can be changed by grafting: hydroxyl groups in C-3 and C-6 that can be acetylated or deacetylated units, and free amino groups in C-2 that can be acetylated or deacetylated units. The primary goal of this study was to develop membranes for wound treatment with dual effects, namely, to accelerate wound healing due to chitosan's inherent bioactivities and, at the same time, to function as a delivery system for numerous medications to prevent or treat bacterial infections. To create a new material, vinyl monomers, AA, and HEMA were grafted onto CS. (Fig. 3) [114].

4.4.2. Wound dressing based on alginate.

Alginate dressings are produced from alginic acid's calcium and sodium salts, a polysaccharide comprising mannuronic and guluronic acid units [115]. Alginate dressings occur either as freeze-dried porous sheets (foams) or as flexible fibers; the latter is indicated for packing cavity wounds. The use of alginates as dressings stems primarily from their ability to form gels upon contact with wound exudates (high absorbency). The high absorption occurs via strong hydrophilic gel formation, which limits wound secretions and minimizes bacterial contamination [116,117].

When hydrated, mannuronate-rich alginates like SorbsanTM (Maersk, Suffolk, UK) form soft, flexible gels, whereas guluronic acid-rich alginates like KaltostatTM (Conva Tec) form firmer gels after absorbing wound exudate. Some, such as SorbsanTM and TegagenTM, contain calcium alginate fiber (3M Healthcare). Comfeel PlusTM is a dressing that combines hydrocolloid and alginate. When applied to wounds, the ions in the alginate fiber exchange with those in the exudate and blood to form a protective gel film. This helps to keep the lesion moist and at a healing temperature. The presence of calcium ions contributes to the gelling property of alginates, which aids in forming a crosslinked polymeric gel that degrades slowly. Calcium alginate dressings are ideal materials for tissue engineering scaffolds due to their ability to form crosslinks with the alginic acid polymer [118,119].

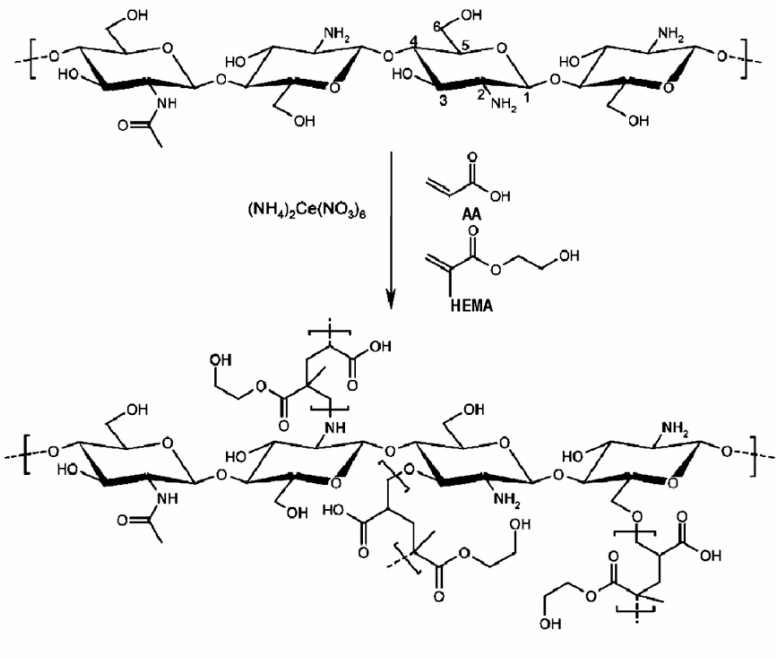

Figure 3. Graft copolymerization of HEMA and AA onto chitosan.

A comparison of hydrocolloid dressings and alginates revealed that alginate gels stayed on the wound longer than hydrocolloids. Alginate dressings have a pharmacological function in addition to forming gels due to the action of the calcium ions present in the dressing. The role of calcium alginate in wound healing was researched. This process was further modeled *in vitro*, revealing that calcium alginate increased fibroblast proliferation but not motility [120]. This implies that the dressing's effects were mediated by calcium ions released from the alginate and that calcium alginate may improve some cellular aspects of wound healing but not others. Some alginate dressings have been shown to stimulate human macrophages to produce tumor necrosis factor-a (TNFa), which initiates inflammatory signals as part of the wound-healing process. The potential role of calcium released from alginates in wound healing has been discussed [121].

Alginate dressings can be used at any stage of wound healing, as described above. When calcium ions in alginate dressings are released into the wound, they play a physiological role in assisting the clotting mechanism (hemostat) during the first stage of wound healing [122]. The early use of alginates as hemostats and wound dressings and their apparent lack of toxicity are discussed, and clinical studies demonstrate their successful use in neurosurgery. Alginate dressings are useful for moderate to heavily exuding wounds [123,124].

When trapped in a wound, alginate dressings in the form of fibers are easily biodegradable and can be rinsed away with saline irrigation. As a result, subsequent removal does not destroy granulation tissue, making dressing changes virtually painless. Alginate sutures used in surgical wound closures take advantage of the ease of biodegradation [125]. A comparison of different brands of alginate dressings revealed significant differences in fluid retention, adherence, and dressing residues. Alginate dressings cannot be used on dry wounds or those covered with hard necrotic tissue because they require moisture to function properly. This is because it can potentially dehydrate the wound, thereby delaying healing, which is their primary disadvantage [126].

4.4.3. Wound dressings based on collagen.

Collagen is the most abundant extracellular matrix macromolecule and the primary integrant responsible for structural integrity in human skin. During wound healing, the production of collagen molecules by fibroblasts stimulates the development of new tissue and wound debridement. Collagen can also bind excess proteases, free radicals, and inflammatory cytokines found in the wound bed [127].

Because animal derivatives may cause allergies and pathogen transmission, collagen derived from heterologous expression in insect and yeast cells provides an alternative. Collagen-based wound dressings have recently been shown to modulate macrophage inflammatory response [128]. Improved wound macrophage function and epithelialization provide a valuable archetype addressing the importance of collagen-based dressings. Collagen-based hydrogels have received a lot of attention in wound healing applications. However, conventional collagen hydrogels are hampered by the presence of irreversible bonds. Self-healing collagen-based hydrogels based on dynamic covalent chemistry can repair wounds and regenerate tissue [129].

Polymer-nanoparticle composites have been widely used due to the unique properties endowed by the particle's high surface-to-volume ratio and the versatility and tenability of the materials' physicochemical properties. Rifampicin and gentamicin encapsulated in silica-collagen demonstrated medicated dressing to prevent bacterial infections in chronic wounds [130]. Aloe vera and ZnO nanoparticles with Zein/PCL/Collagen nano fiber demonstrated enhanced mechanical and antibacterial activity, indicating promising scaffolds for wound healing issues [131].

Collagen dressings are available in a variety of forms that use a variety of carriers/combining agents such as gels, pastes, polymers, oxidized regenerated cellulose (ORC), and ethylene diamine tetra acetic acid (EDTA). The collagen in these products is typically derived from bovine, porcine, equine, or avian sources and is purified to make it nonantigenic. The concentration and type of collagen in a given collagen dressing can vary. Certain collagen dressings contain only Type I (native) collagen, whereas others contain denatured collagen as well. A collagen dressing may contain ingredients such as alginates and cellulose derivatives that can improve absorbency, flexibility, and comfort while also assisting in maintaining a moist wound environment [132,133].

Collagen dressings have a wide range of pore sizes and surface areas. All of these characteristics are intended to improve the wound management aspects of the dressings. To control pathogens within the wound, many collagen dressings contain an antimicrobial agent. A secondary dressing is usually required with collagen dressings (see Appendix I for a summary of currently available collagen-based wound dressings)—mode of action (MoA). Research has shown that some collagen-based dressings produce a significant increase in fibroblast production, have a hydrophilic property that may be important in encouraging fibroblast permeation, enhance the deposition of oriented, organized collagen fibers by attracting fibroblasts and causing a directed migration of cells, aid in the uptake and bioavailability of fibronectin; help preserve leukocytes, macrophages, fibroblasts, and epithelial cells; and assist in the maintenance of the chemical and thermostatic microenvironment of the wound [134,135].

The MoA of several collagen dressings includes the inhibition or deactivation of excess MMPs. Excess MMPs, as previously stated, are a significant contributor to wound chronicity.

Collagen dressings may contain different types of collagen in addition to the various collagen sources (bovine, porcine, etc.). Because of their different substrate specificity, these collagens may cause distinct activity in the wound bed. Type I (native) collagen, for instance, attracts MMP-1 [136].

Natural polymer derived from collagen is obtained through incomplete denaturalization of collagen obtained from skin, boiling bones, and connective tissue. At a physiological pH, type A gelatin obtained from acid-cured tissue is positively charged, whereas type B gelatin obtained from lime-cured tissue is negatively charged [137].

Gelatin has been used as a drug delivery system for growth factors due to its biodegradability, biocompatibility, and lower antigenicity when compared to collagen, and gelatin crosslinking has been investigated to modify the degradation and release rate of encapsulated cargos. Gelatin has a broad molecular weight and, under the right conditions of pH, temperature, or solvents, can adopt various conformations such as microparticles, microspheres, or hydrogels. Wound dressings made of gelatin have been engineered with other biomaterials to provide remarkable next-generation healing properties [138,139].

MMP-2 and MMP-9 are drawn to denatured collagen (gelatin). Strome lysin and matrilysin are also drawn to gelatin. These MMPs (among others) are found in abundance in chronic wounds and contribute to the chronicity of the wound. Types of collagen biochemistry. When a migrating cell (such as a keratinocyte) comes into contact with Type I collagen, the cell secretes MMPs to convert the Type I collagen to gelatin. One important reason for this is that when Type I collagen is converted into gelatin, many active sites (RGD sequences) become available to cells. RGD (Arg-Gly-Asp) sequences are attachment sites and chemotactic for various cells involved in granulation tissue formation [140,141].

Thus, a collagen dressing containing gelatin could improve signaling to the cells responsible for granulation tissue formation. A collagen dressing containing only Type I collagen requires MMP-1 to convert collagen to gelatin at the start, so cells in the wound must first release MMP-1 to convert the Type I collagen to gelatin to receive this benefit. The size and surface area of the ore. The pore size of collagen dressings is important for allowing cells to enter and concentrate within the dressing. Furthermore, the surface area is important in exudate management. The greater the surface area, the more exudate is absorbed [142,143].

4.4.4. Wound dressings based on hyaluronic acid.

The non-immunogenic polysaccharide is made up of N-acetyl-D-glucosamine and glucuronic acid. The hygroscopic nature of hyaluronic acid has been used to create hydrogel-like constructs that aid keratinocyte migration and angiogenesis and promote scar-free wound healing. It interacts with CD and RHAMM cell receptors to modulate inflammation, stimulate cell migration, and promote the formation of new vasculature in injuries [144,145].

However, the wound repair mechanism is dependent on the polysaccharide molecular size. High molecular weight hyaluronic acids inhibit extracellular proliferation, resulting in anti-inflammatory and immunosuppressive responses and a reduction in the formation of new blood vessels. Short-chain, low molecular weight hyaluronic acid with disaccharide units, on the other hand, is a potent anti-inflammatory molecule that can stimulate extracellular proliferation, migration, and angiogenesis in injured tissue [146].

Wound healing tools based on hyaluronic acid, either pure or impregnated with other materials, have been proposed for the treatment of both acute and chronic wounds. Hyaluronic acid-modified liposomes have been studied and reported on as bioadhesive carriers for delivering growth factors to wound sites. A recent open-ended study of hyaluronic acid-based dressings discovered that they are effective for managing acute wounds, especially regarding safety and efficacy. However, no standard wound dressing was chosen for comparison in this study, and the dressing was applied to various wound types [147].

Various HA-based wound dressings, such as the HylaSponge® System, Hyalomatrix®, and Hyalosafe®, are now available in the clinic. The HylaSponge® System is created using a free-radical polymerization process, which results in the formation of a complex HA network capable of protecting and hydrating the wound site [148]. Hyalomatrix® is a bi-layered dermal substitute that is flexible, conformable, and designed to promote wound closure and dermal regeneration. The bottom layer (the layer that comes into contact with the wound) is a 3D fibrous matrix made of HYAFF® 11, while the top layer is a thin sheet of transparent silicone. HYAFF® 11 is an HA-derived product obtained by esterifying the free carboxylic group of HA with benzyl alcohol [149].

This esterification step limits water entry into the macromolecule, hence increasing HA's hydrophobicity. Furthermore, such a method lengthens the polymer's breakdown time: 75% of esterified HA dissolves in 7-14 days, whereas 95% of esterified HA may take up to 2 months to decompose. Furthermore, the transparency of the top layer is critical for performing continual monitoring of the healing process. The therapeutic effectiveness of Hyalomatrix® was examined in clinical tests, and the results indicated that after 29 days of therapy, 85.7% of the patients (28/57) had a full wound closure, while 14.3% had only partial re-epithelization. Hyalosafe®, on the other hand, is a translucent film used to treat second-degree superficial burns. The breakdown of this film results in the release of HA, which promotes the proliferation of epithelial cells [150,151].

5. Summary

Smart textiles were portrayed as fictitious items with restricted applications. Nowadays, smart textiles have implanted client attention and are projected as the future of the textile industry as a result of scientific efforts and development stages. With the growing need for smart textiles throughout all stages of life, many scientists are inventing new solutions, concepts, and tangible items. The promotion of smart textiles should also be prioritized. Biomaterials have sparked substantial interest in biomedical sectors such as wound dressings, sutures, and tissue engineering during the last few decades. Biopolymers such as chitin, chitosan, alginates, and hydrocolloids, as well as textile materials, are diverse possibilities for wound dressings. These standards include everything needed for a good wound dressing. For the previous two decades, these smart dressings have sparked a lot of curiosity in the biomedical profession.

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Conflicts of Interest

The authors declare no conflict of interest.

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