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A Review

Progressive exploration on the influence of natural polymers and emerging biomaterials in advanced wound care strategies

Marwan Salem Bahaj[1], Marwan Abdelmahmoud Abdelkarim Maki[1]*, KRS Sambasiva Rao[2] & Palanirajan Vijayaraj Kumar[1]

[1]Faculty of Pharmaceutical Sciences, UCSI University, Kuala Lumpur-56000, Malaysia

[2]Department of Pharmacy, Mangalayatan University-Jabalpur, Jabalpur - 483 001, Madhya Pradesh, India

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The field of wound care has continuously improved by using techniques and materials to promote healing and minimize complications. A key factor, in this progress is the utilization of polymers and cutting-edge biomaterials. In this examination, we explore the role and impact of these substances on wound management practices. We delve into the characteristics of polymers like chitosan, alginate, and collagen which are derived from living organisms and offer advantages in terms of compatibility with the body's ability to break down naturally and suitability for various wound applications. Additionally, we investigate emerging biomaterials such as nanofibers, hydrogels, and bioactive glass highlighting their potential for delivering drugs in a controlled manner and influencing the healing environment within wounds. The incorporation of these materials into wound care has shown results including healing processes, reduced formation of scar tissue, and improved infection control. Despite these advancements, our review acknowledges existing challenges such as expanding production capacity standardizing products across the industry and overcoming obstacles in implementation. The aim of this paper is to provide an overview of the state of the art in wound care strategies while also offering insights into potential solutions and future directions, for research and application.

Keywords: Advanced wound care, Emerging biomaterials, Natural polymers, Synthetic polymers

Introduction

Wound management plays a role in the field of medicine, as it greatly impacts both individuals and healthcare systems. Dealing with wounds such as foot ulcers, venous leg sores, and pressure sores is particularly challenging and has an impact on patients' quality of life[1]. Several variables can impede the recovery of wounds, such as malnutrition, insufficient oxygen supply, smoking, underlying conditions such as diabetes and cancer, microbial infections, and various social determinants of health[2]. Therefore, wound care strategies that promote healing and enhance patient outcomes are needed. In recent years, interest in using polymers and novel biomaterials in wound care has increased. These substances possess characteristics that render them apt for wound coverings and tissue engineering uses[2]. Natural polymers such as gelatine, chitosan, and silk fibroin mimic the matrix. Create an environment that supports wound healing[2,3]. Innovative materials derived from substances, such as cellulose and self-assembling peptides, possess qualities such as porosity, mechanical strength, and the ability to promote cell growth and movement[4]. These materials can be combined with growth agents, cytokines, and various bioactive compounds to enhance their effects and support the regeneration of tissues[5]. A new approach in wound care involves the development of dressings that can adjust to the particular circumstances of a wound and deliver therapeutic agents in a controlled manner, thereby accelerating the healing process[6]. These dressings may even incorporate sensors to monitor real-time parameters such as pH levels, temperature, and moisture content. Based on these measurements, they can intelligently release growth factors, antimicrobial agents, or antioxidants tailored to the needs of the wound[6]. This personalized approach holds the potential for improving treatment outcomes and reducing complications. This comprehensive review article will explore how natural polymers and emerging biomaterials are being utilized in the field of wound care. It will examine the properties of the manufacturing techniques involved in their production as well as their extensive applications in developing advanced wound dressings and tissue engineering solutions. Furthermore, this review will also address

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*Correspondence:
E-mail: marwanaamaki@gmail.com

challenges faced within this domain while outlining directions for research. The main purpose of this assessment is to offer a synopsis of the research findings highlighting the significant advantages these materials offer for enhancing wound care and achieving better patient outcomes.

Stages of wound recovery

Crucial and intricate, the process of wound healing consists of phases with distinct characteristics. These stages include haemostasis, inflammation, proliferation, and maturation, (Fig. 1). After an injury occurs, the first step known as haemostasis is triggered. During this phase, platelets gather as a result of collagen and tissue factors being exposed. This leads to the release of growth agents and chemotactic proteins that eventually come together to form a blood clot. Typically, this phase overlaps with the inflammation stage, where neutrophils play a role in clearing debris and bacteria along with the help of oxygen species. This collective effort creates an environment for healing, which often results in redness and swelling at the wound site due to an influx of blood cells.

Following this stage is the proliferation stage characterized by an increase in cell types and the formation of a strong connective tissue framework. The wound site becomes populated by cells, keratinocytes, and fibroblasts. Components of the matrix, such as collagen, hyaluronic acid, proteoglycans, and elastin, come together to form granulation tissue that effectively replaces the blood clot. A variety of proteins and substances, including types of cytokines and growth factors, such as TGF β and interleukins, along with angiogenesis factors, such as VEGFs, contribute to the creation of tissue. This formed tissue usually appears pink or red over the area where the wounds are located. The last stage, called maturation, involves a balance between cell death (apoptosis) and the emergence of cells. Over time, there is a shift from type III collagen to mature type I collagen. Fibroblasts play a role in closing the wound, resulting in the development of a new layer of skin and eventually leading to scar formation. This concluding stage can persist for months or possibly years. Any disruptions during these stages can lead to complications, such as keloids or wounds that do not heal properly. The exploration of polymers and innovative biomaterials has had an impact on advancing the healing of wounds. Wound recovery is a procedure that seeks to repair injured tissue and restore normal physiological function. However, traditional wound dressings have limitations in terms of effectiveness and specificity. Fortunately, recent advancements in polymers and novel biomaterials offer potential for improving wound healing conditions. One area of focus in wound healing research revolves regarding the creation of on-site formulated wound coverings. These coverings present benefits such as the capability to conform to the wound bed's microstructure and design, simplicity of use, and enhanced patient adherence[7] Additionally, silk fibroin derived from silk has attracted attention due to its ability to enhance wound healing while exhibiting properties when combined with agents[2]. Another approach to enhance wound healing involves biomaterials. Biomaterials that can address wounds caused by conditions, such as diabetes, malignancies, infections and vasculopathies, have the potential to ease the social burdens associated with these ailments[8]. Metal-organic frameworks (MOFs) have been examined for their characteristics and their capability to deliver agents in wound healing contexts. Hydrogels, which are biocompatible and structurally similar to the matrix, have also been used in wound healing[9]. These biological materials serve as vessels for growth agents and cytokines that contribute to tissue renewal[10]. Scientists have explored the idea of controlled release of these molecules as a strategy to improve the recovery of skin wounds. Recent advancements in this field have focused on delivering combined growth agents and chemotactic proteins to foster wound recovery[10]. Apart from polymers and functional biomaterials, scaffolds have become an area of interest in research related to wound healing. Scaffolds provide a three-

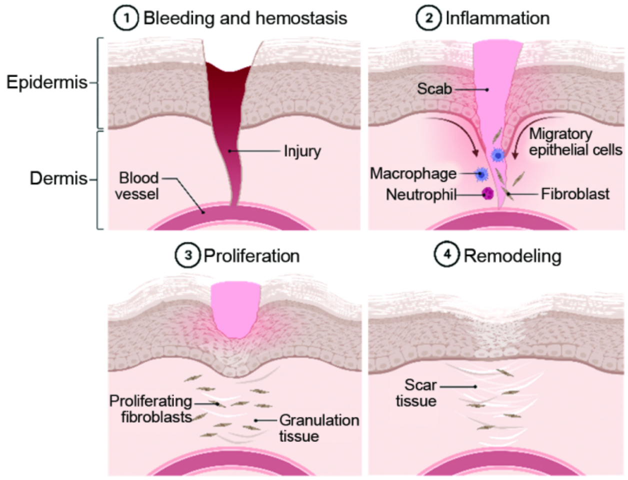

Fig. 1 — Schematic illustration of the recovery of a cutaneous wound

component framework that supports the growth of cells and facilitates tissue regeneration[7]. Various types of scaffolds, including materials, have been thoroughly researched for their uses in wound recovery[8]. For example, researchers have closely examined the effectiveness of scaffolds made from collagen and silk fibroin in promoting wound healing[8]. Additionally, synthetic polymers such as alginate have been found to be useful in dressings due to their biocompatibility and ease of forming a gel structure. The use of polymers and innovative biomaterials in improving conditions for wound healing is an area of research that is rapidly advancing. These materials offer advantages, such as adaptability, bioactivity, and the ability to control release. By utilizing these materials, scientists aim to develop customized wound dressings that facilitate tissue regeneration and improve patient outcomes.

Devices for wound healing management

Wound dressing

Wound dressings play a crucial role in the recovery of diverse wound types. Over the years, significant advancements have been made in wound dressing technologies, resulting in a range of options for healthcare professionals. Choosing the appropriate wound dressing requires evaluating elements such as the wound's type and intensity, underlying health conditions, and intended therapeutic results. An important aspect of choosing a wound dressing is its ability to create an environment for wound healing. Comprehensive studies have investigated the advantages and disadvantages of wound coverings for various wound classifications, including diabetic foot sores, pressure ulcers, burns, thermal injuries, and persistent leg ulcers[11]. This research underscores the significance of selecting a dressing that promotes moisture retention, angiogenesis, and effective management of wound exudate. Studies indicate that hydrofiber dressings outperform dressings in managing wounds based on a methodical review and meta-evaluation conducted by researchers[12]. Their findings demonstrate that wounds treated with hydrofiber dressings have risks of complications and better fluid handling capabilities. In addition, to create a moist environment, effective wound coverings should also have properties to prevent infections. Various research teams have pioneered the development of polymer-based dressings infused with curcumin, which has shown effectiveness against bacteria[13]. These dressings do not provide a barrier but also actively encourage the regeneration of skin, accelerating the healing process. A crucial aspect of wound coverings is their ability to encourage the movement and growth of cells, which are processes in the healing journey. Electrospun nanofibers have gained attention as a material for wound dressings because they can mimic the structure outside cells, allowing cells to adhere and grow[14]. By adding biomolecules such as growth factors to these nanofibers, their ability to heal wounds is further enhanced[15]. Moreover, smart wound coverings have emerged as a development in recent years. These innovative dressings can continuously monitor the wound environment in time. Deliver therapeutic substances as needed[16]. This personalized approach ensures treatment. Ultimately, it improves outcomes in wound healing. It is important to emphasize that selecting wound coverings should consider the requirements of different types of wounds. Chronic wounds, such as diabetic foot ulcers, necessitate dressings that efficiently handle exudate and stimulate angiogenesis. On the other hand, acute injuries, such as cuts, can benefit from dressings that create a protective barrier and reduce the risk of infection[12]. In summary, choosing the appropriate wound dressing is vital for enhancing the wound healing process. Considerations include the nature and severity of the wound, intended treatment results, and technological advancements. Modern wound dressings, including hydrofiber dressings, curcumin-loaded polymer-based dressings electrospun nanofiber dressings, and smart dressings, offer a range of benefits, such as retaining moisture-promoting cell growth fighting infections and delivering therapeutic substances when needed. Equipped with this knowledge and keeping up with advancements in wound dressing technology, healthcare professionals can make informed decisions to enhance wound healing outcomes.

Traditional dressings

Traditional wound coverings, such as gauze and plaster, have long been used in wound management and recovery. These coverings serve purposes, including stopping blood flow, absorbing wound discharge, protecting and cushioning the wound, and maintaining an environment[17]. However, there are limitations to these methods. One common issue is the discomfort experienced during removal, which can worsen the wound and lead to increased inflammation[6]. Additionally, traditional coverings made from materials such as cotton and wool may not possess the technology to effectively maintain an optimal wound atmosphere or deliver agents for the healing process. To address these challenges, researchers are exploring the development of wound coverings that offer improved healing properties and overcome existing deficiencies that hinder the healing of wounds[18]. An exciting approach involves the use of dressings that can adapt to changing wound conditions and administer substances as needed[6]. For example, self-healing hydrogels are being investigated as wound coverings that can create an environment for optimal healing while also providing protection against infections and promoting tissue regeneration[17].

Biological dressings

Biobased wound coverings have a part in the recovery procedure. It has gained significant attention in medical research. These dressings are designed to promote tissue growth and prevent infections. They can be made from sources including ingredients such as plant extracts and honey as well as synthetic materials such as polymers and compounds[19]. An emerging area of focus in bio based wound dressings is the incorporation of substances that conduct electricity. Many tissues in our bodies, including the skin layer, respond to important signals for various biological processes, including wound healing. Conductive polymers and compounds possess the capability to boost tissue development and wound healing by offering impulses to the wound area, which may help increase cell movement, blood vessel formation, and collagen production[20].

Artificial dressings

Synthetic wound coverings contribute to wound care and recovery. Their main purpose is to provide a layer to promote the healing process and prevent infections. There is a variety of wound dressings, each with unique characteristics and uses. A new trend in wound dressing research involves using 3D-printed hydrogels with properties[21]. The research presented provides an overview of the creation and refinement of hydrogels for therapeutic use in wounds. These hydrogels are known for being biocompatible. A protective layer can be created over injuries while preserving a humid setting conducive to recovery. The research underscores the importance of a standardized alginate gel wound dressing suitable for specific wound types. Addressing wound infections is an aspect of wound dressing strategies[22]. Research has examined the effects of oxynitrate-based dressings on preventing biofilm formation and enhancing healing. This study investigates the effectiveness of silver-infused dressings in reducing bacteria in laboratory-cultured biofilms. The results show that specific silver-infused coverings, such as Ag Oxysalts and Ag^{1+}/EDTA/BC coverings, notably reduce presence and promote wound healing. The choice of dressing also influences the recovery procedure for pressure injuries[23]. A comprehensive study was conducted by evaluating the effectiveness of dressing types on pressure injuries through network meta-analysis. The research concludes that polymeric membrane coverings demonstrate healing rates compared to gauze coverings, highlighting the importance of careful dressing selection for managing pressure injuries. Recent advancements in wound dressings include films, foams, hydrogels, alginates, and hydrocolloids, as listed in (Table 1). Table 2 provides an overview of polymeric dressings with details on their trade names, primary applications, and usage proportions within the field of wound and burn care[23].

Hydrogels

Recent research has highlighted the biocompatibility and biodegradability of hydrogels used for wound healing. Hydrogels, 80% to 90% of hydrogels derived from polyvinylpyrrolidone (PVP) and methacrylate, are composed of water molecules, creating a moist wound environment[24]. These three-dimensional networks are composed of hydrophilic, water-soluble polymers with various physicochemical properties[25]. Hydrogels provide a nontoxic and nonadhering dressing option by absorbing a significant quantity of water while maintaining a gelatinous structure. Their gelatinous consistency makes them ideal for irregularly shaped and edged incisions. In a study conducted by Chen *et al.,* they introduced a hydrogel system that combined benzaldehyde-ended PEG with dodecyl-altered chitosan for controlled delivery of VEGF (endothelial growth factor). When examined on a complete-depth skin model, this composite hydrogel notably enhanced the recovery procedure of injuries. It achieved this by promoting mechanisms such as angiogenesis (formation of blood vessels), collagen accumulation, macrophage orientation, and the development of granulation tissue. These findings highlight the enhanced healing capabilities of this composite hydrogel system for wound recovery[26]. Another investigation led by Wang *et al.* focused on developing a hydrogel driven by polypeptides and

Table 1 — Advantages and disadvantages of polymeric dressings for wounds

Category of polymeric dressings	Characteristics	Benefits	Drawbacks
Films	Slim, transparent polyurethane sheets that adhere to the skin are ideal, for treating injuries that are uncontaminated caused by lasers or located on the surface.	Gas transmission is excellent. It also shows resistance to bacteria and liquids. It allows for the observation of wounds due to its film. Moreover, it reduces maceration. It can be applied without causing any pain.	It can be difficult to manage as it does not adhere well to the wound surface and is ineffective at absorbing wound secretions. Additionally, it is prone to penetration and contamination. Does not offer much resistance, against proteins and drugs.
Foams	Layers of polyurethane, PEG, and silicone combined. Effective, for treating burns, chronic wounds, wound depressions, and deep sores.	It has absorbency maintains a moist environment prevents bacteria from entering is very easy to use and does not require any payment.	It has a quality forming a nonclear layer that makes it difficult to observe wounds. The material allows some air to pass through but may not be suitable, for wounds due to its stability.
Hydrogels	Certain polymers, both natural and synthetic possess absorbing properties that make them ideal, for providing comfort and cooling effects to skin injuries. They are suitable, for a range of injury types, including burns.	It possesses absorptive qualities, does not adhere to the injury, can be effortlessly removed without inflicting pain, accelerates the recovery procedure, and diminishes both pain and inflammation. The best part is that it is cost-effective and easy to prepare and use.	It is somewhat see-through allows some air and moisture to pass through provides some protection, against bacteria, and may have structural strength at times.
Alginate	Alginate polymer is arranged in a structure of intertwined strands. When calcium alginate encounters sodium in blood plasma an ion exchange takes place. This material is well-suited for treating injuries and full-thickness burns.	The material has absorption does not stick easily is strong and long-lasting can be removed with saline solution and offers protection, against bacteria.	Due, to their scarcity these items can be quite expensive emit an odour, present handling difficulties, and frequently run out of stock.
Hydrocolloids	Biphasic systems derived from iodine-stabilized starch, dextran PEG, or synthetic interlaced polymers. Ideal, for treating lasting wounds and burns.	The coverings are designed to absorb and can be easily removed using saline or purified water they do not stick they have a structure are resistant to water and cause no pain.	Depending on their composition these substances can have effects. They have toxicity to cells. Their size may not be consistent. They can also produce secretions in wounds. The dextran hydrocolloid used in them can slow down the healing process. They are not breathable, to gases. Moreover, they may emit an odour. Change colour over time.

infused with exosomes derived from mesenchymal stem cells sourced from tissue. The objective was to improve wound healing and promote skin tissue renewal. This hydrogel formulation demonstrated advancements in aspects of wound repair, as depicted in (Fig. 2). It significantly enhanced the growth and movement of HUVECs under laboratory conditions. When tested in animal models, the hydrogel formulation promoted the formation of granulation tissue and reorganization of collagen, ultimately facilitating the healing of wounds and complete restoration of the epidermis. This research highlights the potential of using a hydrogel for accelerating the recovery process of wounds and repairing damaged layers of skin. The acidity levels of pH-sensitive hydrogels in wounds are noticeably different from those in skin. Healthy skin typically has a pH range of 4.5 to 6.5, while the pH level in wounds tends to become more basic, reaching approximately 7.4 due to the presence of alkaline byproducts from growth[27]. Researchers have successfully developed a pH hydrogel by combining red cabbage extract with methacrylated chitosan. This hydrogel does not detect changes in wound pH. It also accelerates the healing process. This breakthrough opens possibilities for creating materials that can both diagnose and aid in healing wounds. PH adaptive hydrogels have shown potential in controlling drug delivery to combat infections[28]. In a study conducted by Ren *et al*., they introduced a hydrogel that combines tannic acid and

Table 2 — List of polymeric wound dressings presently accessible in global markets

Type of Dressing	Trade Name	Description	Employed for	Worldwide Usage Percentage (%)
Synthetic Dressing Substances				
Polymer-based films	Tegaderm™ Opsite™ Bioclusive™ Mepore™ Film Suprasorb™ F Hydrofilm™	Coverings were made using polyurethane or other types of polymer materials.	Superficial injuries. Wounds caused by laser treatment. Locations of incisions. Cuts, on the skin.	8
Polymer-based foams	Mepilex™ Allevyn™ TIELLE™ Biatain™ Lyofoam™ Polymem™	Dressing sponges were made using foams that absorb water and backers or semibreathable materials that repel water. These materials include polyurethane or silicone/polyester, with absorbent layers, like polyoxyethylene glycol enclosed within them.	Long-standing injuries. Scalds. Mohs surgical sites and injuries. Laser rejuvenation wounds.	5
Polymer-based Hydrogels	Intrasite™ Nu-Gel™ Solosite™ DuoDERM™ Hydrogel Purilon™ Gel Aquasorb™	Water absorbing polymers such, as alcohol, polyvinyl pyrrolidone or polyethylene oxide were used to create hydrogels.	Exfoliations caused by chemotherapy. Ulcers. Laser treatment, for rejuvenation. Injuries of medium depth. Areas where transplants are taken from and injuries to organs.	43
Polymer-based Alginates	Kaltostat™ Algisite™ M Sorbsan™ Curasorb™ Melgisorb™ SeaSorb™	When sodium alginate from seaweed is mixed, with solutions containing salts, like calcium, magnesium, or zinc it undergoes a chemical bonding process that leads to the creation of alginate hydrogels.	Severe burns. Injuries, from operations. Injuries, with secretions. wounds.	20
Polymer-based Hydrocolloids	DuoDERM™ CGF Comfeel™ Plus Tegasorb™ Aquacel™ Hydrofiber Hydrocoll™ KerraLite Cool™	Hydrocolloids were developed by attaching iodine to modified starch derived from cadexomeriodine particles that dissolve in water. This process creates a gel when the iodine reacts with wound secretions and the polymeric substance. Another type of hydrocolloid is dextranomer, which combines linked dextran with polyethylene glycol.	lasting wounds. Burns. Injuries of severity. Regions where tissue has been donated for grafting.	24

keratin crosslinked with graphene oxide quantum dots. This hydrogel has the ability to expand by more than 80% in alkaline environments, which can greatly aid in wound healing. Its impressive swelling property ensures that drugs are evenly distributed for long-term infection management. This hydrogel does not accelerate the healing process. It also exhibits strong antimicrobial properties against bacteria such as *E. coli* and *S. aureus*. As a result, there is growing interest in exploring pH hydrogels as solutions for anti-infection wound care[29].

Polymeric Film

Polymeric sheets have become popular for covering wounds due to their flexibility and ability to support stages of the healing process. These sheets aim to provide a shield to create an environment for healing and allow the controlled release of healing

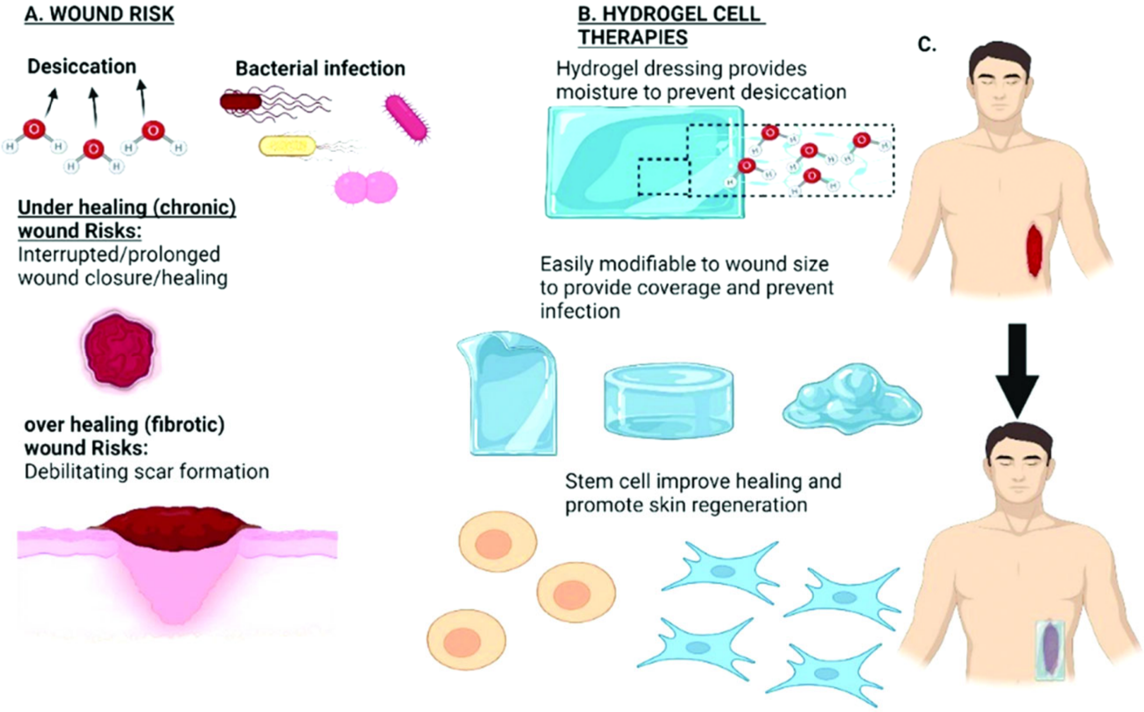

Fig. 2 — Benefits of using hydrogel dressings for the delivery of cell therapies

substances. A recent study explored using a polymer sheet made from sodium alginate and sodium carboxymethyl cellulose to heal surgical wounds in diabetic animals. The research team adjusted the composition of the polymer films. Its chemical properties were examined. The results showed that the refined composition of the polymer sheet had improved characteristics, such as increased moisture absorption and decreased water vapour permeation rate, indicating its suitability for skin tissue regeneration and wound care applications. Polymeric film offers advantages regarding covering wounds. They offer a shield against elements, ensure a humid setting conducive to wound recovery, and dispense compounds in a regulated fashion. Additionally, these sheets can be customized by incorporating agents, growth stimulators or other active components to enhance wound healing outcomes[30].

Foam

Foams constructed from polymer-derived substances have gained interest in the domain of wound dressing owing to their properties and prospective advantages for wound recovery. These foams are designed to create a moist environment that promotes wound recovery and regulates the amount of fluid released by the wound. A study focused on developing hydrogel foams based on high porosity PEG for treating wounds. These foams demonstrated the ability to adapt to moisture levels, effectively managing wound fluid. The results highlighted the effectiveness of these foams in facilitating wound healing and their suitability for long-term wound care. However, foam dressings may not be suitable for all types of wounds. According to a study, foam dressings with retention properties are better suited for injuries with medium to elevated levels of fluid discharge. They may not be ideal for necrotic areas of wounds[31].

Hydrocolloids

Hydrocolloids are a type of polymer-based wound covering that are frequently employed in wound treatment. These dressings contain polymers that attract water and form a gel substance when they come into contact, with wound fluid creating an environment that promotes moisture for wound healing. The properties of dressings, including their haemostatic and wound healing abilities, have been extensively studied. In an investigation, researchers focused on developing a chitosan-based wound patch that aims to enhance haemostatic and wound healing functions. To create this patch, the team combined poly (vinyl alcohol) (PVA). Chitosan combined with

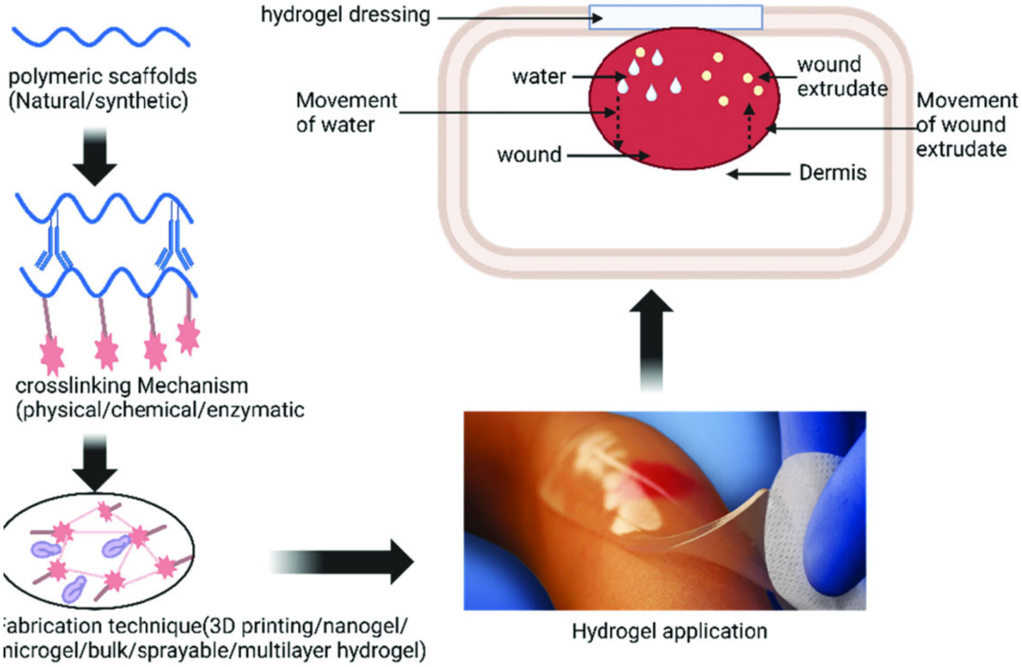

Fig. 3 — The nanofiber fabrication method for fabricating wound dressings

a photocatalytic graphene nanocomposite (GO/TiO_2 (V-N)). The research showed the efficacy of chitosan-based coatings in enhancing wound recovery and warding off infections[30].

Scaffold mode of nanofibers

A scaffold is a support structure that aids in preserving the structure of tissues. While the body naturally produces these scaffolds in response to injury, man-made scaffolds can significantly enhance the healing process. To function best, these artificial scaffolds need to emulate the biological features of the natural extracellular matrix (ECM), providing mechanical assistance and regulating cell activity. 3D scaffolds are particularly useful, as they can hold various cells and growth stimulants that foster tissue restoration. They help facilitate cell growth, migration, transformation, and the formation of scars in skin wound recovery. Both synthetic and natural polymers, known for their biocompatibility and biodegradability, have been employed in creating these scaffolds for the purpose of skin tissue regeneration. Furthermore, recent studies have consolidated knowledge on the manufacturing of nanofibers for wound recovery. In a clinical setting, skin injuries frequently present complex obstacles. Typically, traditional procedures such as autografts and allografts do not yield optimal results. Electrospun nanofibers have garnered significant interest as a potential new approach to skin tissue regeneration during the past decade. The production method for these is depicted in (Fig. 3). The porous, hydrophilic surfaces of electrospun nanofibers allow oxygen to diffuse, keep the surrounding area wet, and soak up wound exudates. Mechanical backing from nanofiber frameworks and an active 3D matrix for cellular colonization are provided by these fibres, which are structurally and physiochemically similar to the natural ECM.Cellular adhesion, proliferation, differentiation, and migration are all aided by signals sent between the nucleus and the ECM. In addition, it regulates processes including apoptosis, the discharge of growth agents, and the triggering of intracellular signals. To create biodegradable electrospun nanofibers, several different types of natural and synthetic polymers have been tested. For instance, collagen scaffolds enhance cell proliferation and allow cells to enter the ECM, making them the most biomimetic alternatives for genuine skin. Nanofibrous mats injected with zinc oxide nanoparticles and generated from electrospinning PLGA/silk fibroin showed weak antioxidant properties and action against gram-positive and gram-negative bacteria. A chronic wound therapy with promising *in vivo* results.

Infectious wounds might be treated using a coaxial PLA-derived electrospun nanofiber. According to the suggestions of Hajikhani *et al.*, core solutions of PLA/PEO were encased in shell solutions of cefazolin/PVP/collagen. The drug release from this scaffold was manageable, and its antibacterial characteristics were sufficient. Additional *in vivo* studies confirmed its effectiveness in accelerating wound healing. Separate research used curcumin as a model ingredient to encapsulate, including PEG of varying molecular weights into PLA and spinning the resulting nanofibers. Drug release was shown to be enhanced by both a decrease in molecular weight and an increase in PEG content. Furthermore, curcumin-infused scaffolds were shown to be clinically appropriate for usage as wound dressings[32].

Polymeric Materials

Natural polymers

Occasionally, natural polymers have risen in prominence in wound care approaches because of their inherent compatibility with human physiology and their proficiency in facilitating the healing journey. Chitosan, a biopolymer derived from chitin, stands out for its properties and ability to break down naturally. This makes it particularly valuable in situations where clotting is needed, such as for sealing wounds with biofilms and hydrogels. It has also shown effectiveness in treating wounds. Hydrogels made from polymers such as alginate, hyaluronic acid, collagen, gelatine, chitosan, and cellulose are recognized as viable materials in wound therapy. These hydrogels provide a three-dimensional structure that resembles the ECM. This structure promotes cell attachment, movement, and reproduction. Additionally, these hydrogels can be tailored to release substances such as growth factors that enhance the healing process[33] (Table 3).

Biopolymers made by combining synthetic polymers have found applications in both surgical wounds and burns. These biopolymers aid wound recovery by providing an environment that supports cell growth and division while also controlling inflammation and promoting blood vessel formation. Depending on the requirements of each wound case, the choice of biopolymer can be adjusted based on characteristics such as biodegradability and mechanical strength[34]. Among all biopolymers studied far, polysaccharides have received attention for their role in wound healing processes. They could create hydrogels that can adapt to stimuli such as pH, temperature, or enzymes. When exposed to these stimuli, the hydrogels release substances that have activity. These hydrogels create an environment with high moisture levels, which is beneficial for healing, preventing infections and promoting tissue regeneration. In wound healing, derived biopolymers are commonly used because they are compatible with systems and possess a structure akin to the extracellular matrix. These biopolymers promote cell attachment, movement, and multiplication. They also help regulate inflammation and stimulate angiogenesis. To enhance wound healing, these natural polymers can be incorporated into treatments and frameworks[35]. Biodegradable electrospun structures made from polymers such as chitosan, collagen, and gelatine have been recognized as a method for regenerating skin tissue. These structures mimic the matrix of natural skin tissue. Provide an environment that facilitates cell attachment, growth, and differentiation. They can also be enriched with substances to support the healing process. The importance of wound management in healthcare cannot be overstated. The use of polymers has gained popularity due to their characteristics and potential benefits in promoting wound healing. Chitosan, alginate, and collagen are commonly used polymers in wound care. Each of these polymers has properties and mechanisms that contribute to improving the healing process of wounds.

Chitosan, a compound extracted from chitin, has garnered interest because of its therapeutic potential in wound healing. Studies have shown that it can promote the growth of tissue, enhance the absorption of fibrinogen and platelet adherence and increase the production of collagen and hyaluronic acid. Additionally, chitosan possesses properties that can help prevent infections in wounds. Furthermore, dressings made from chitosan have been found to accelerate wound healing and reduce the formation of scars[36].

Alginate, a polysaccharide found in nature, is commonly used in wound care to create scaffolds. It could absorb fluid from wounds, creating a moist environment that promotes healing. Research indicates that alginate dressings can stimulate the production of cytokines in cells, enhancing the response and facilitating tissue regeneration. Moreover, these dressings act as a barrier against intrusion and can be effortlessly taken off without inflicting damage to the underlying injury area[36].

Collagen, a protein found abundantly in the matrix, plays a role in wound healing. It provides support. It

Table 3 — Properties of Polymers Used in Wound Care

Polymer	Properties	References
Gelatine	It is compatible with systems, encourages blood coagulation, exerts minimal adverse impacts on cells, provokes a minimal immune reaction, and fosters the adhesion and proliferation of cells.	8
Chitosan	Nontoxic, biodegradable, biocompatible, antimicrobial properties, good mechanical properties, promotes tissue regeneration	41
Cellulose	It is designed to work with living tissues decomposes naturally has mechanical properties and can effectively expand and maintain a moist environment.	42
Alginate	Biocompatible, biodegradable, good swelling properties, high mannuronic content stimulates cytokine production, haemostatic capability	11
Hyaluronic Acid	Biocompatible, biodegradable, major component of extracellular matrix, promotes tissue regeneration.	38
Silk Fibroin	Biocompatible, biodegradable, slow biodegradability, excellent biological and physicochemical properties, promotes tissue regeneration.	7
Polycaprolactone (PCL)	Biocompatible, biodegradable, good mechanical properties, stimulates quicker wound healing, decreases inflammatory infiltration.	32
Polyvinyl Alcohol (PVA)	Biocompatible, good mechanical properties, used in wound dressings for faster haemostasis and wound healing rate.	32
Poliglecaprone	Less hypertrophic scar formation compared to other sutures, improved healing rates in diabetic wound models.	41
Polylactic-co-glycolic Acid (PLGA)	Made to work well with living tissues able to break down over time used in stitches that release medication to improve the healing process of wounds.	32
Polysaccharides	It has the ability to work well with living tissues without causing harm. It naturally. Possesses properties, for fighting germs.	7
Proteins	Good biocompatibility, biodegradability, promote tissue regeneration.	43
Composite Materials	Combining types of polymers to enhance properties such, as strength, resistance, to germs and the ability to release medication.	7
Nanocomposites	Combining particles, with polymers to enhance qualities such, as the ability to fight germs and promote healing of wounds.	7

promotes cellular activities such as migration, proliferation, and differentiation. Studies have shown that dressings containing collagen can accelerate wound healing, enhance the closure of wounds and promote the growth of blood vessels. Moreover, collagen dressings have the ability to absorb fluid from wounds while maintaining a moist environment for effective recovery[37].

Hyaluronic acid: Connective tissue contains hyaluronic acid, a glycosaminoglycan. The skin's primary ECM integrant aids in tissue repair and regeneration. Hyaluronic acid retains structures that enhance organ function and has a great ability to hold water on the wound surface, relieving blankness and accelerating healing[38]. The extraordinarily high density of hyaluronic acid products at low concentration is one of the downsides of employing them in the electrospinning process. Despite these limitations, even with these problems, Tableware nanoparticles were used to create hyaluronic acid/polygalacturonic acid nanofibrous mats by El-Aassar *et al*. Evidence from *in vivo* research reveals that it aids in the rapid resolution of wound infections, with epithelization and collagen deposition occurring by day 14. The biocompatibility, biodegradability, and mechanical properties of silk containing colourful insects are exceptional[39].

Casein, which is a component of cows' milk, accounts for 80% of the milk's protein content. Its natural compatibility, with living organisms' ability to break down over time and tendency to self-assemble, has attracted attention. It is worth noting that 55% of casein is made up of amino acids, which promote the formation of hydrogen bonds[40]. However, when casein is electrospun alone, it does not dissolve easily. As a result, it has become practical to use polymers such as cut or PVA as aids during the electrospinning process involving casein[40]. Due to its hydrophilicity, casein lacks water stability and mechanical strength. Therefore, it is crucial to incorporate linking agents such as glutaraldehyde and silane when producing products based on casein. Electrospun mats that combine casein and PVA have proven effective in promoting blood clotting through thrombin generation. The addition of casein has also been found to enhance growth and expedite wound healing[40].

Natural polymers offer advantages in wound treatment. These materials are biocompatible, biodegradable, and safe for use. They can be shaped into forms such as hydrogels and filaments to meet wound care needs[41]. Additionally, they possess bioactive properties that can enhance wound healing by providing antibacterial and anti-inflammatory effects[42]. Moreover, these polymers mimic the matrix, creating an environment for cellular adhesion, growth, and tissue regeneration[41]. However, there are challenges associated with using polymers in wound care. Variations in characteristics such as dimensions or deacetylation levels in chitosan can affect their functionality and effectiveness. Obtaining and extracting these polymers can be difficult since they primarily come from sources such as crustacean exoskeletons or fungal structures. Furthermore, careful control of the decomposition rate of polymers is necessary to ensure wound-healing outcomes[42]. Natural-origin polymers such as chitosan, alginate, and collagen have shown promise in wound treatment due to their features and mechanisms of action. They play roles essential for promoting tissue development, enhancing cellular adhesion and growth, and creating an ideal environment for tissue regeneration. Despite the challenges involved in using them, natural polymers offer benefits in wound care. They possess qualities such as biocompatibility, biodegradability, and inherent bioactivity. It is crucial to make advancements and conduct research in this field to improve the utilization of polymers in wound treatment and achieve better therapeutic results[42].

Synthetic polymers

Pharmaceutical-grade PVA, has excellent biocompatibility. PVA, a macromolecular organic molecule without side effects, is utilized in prosthetic joints, contact lenses, cardiovascular devices, and wound treatment. Because of its linear structure, PVA may be crosslinked using methods including irradiation and chemical agents. To enhance the robustness and stability of PVA-based solutions, Venkataprasanna *et al.* crosslinked them with glutaraldehyde. Recent publications on wound healing have highlighted the effectiveness of a composition of PVA, chitosan, and glucose. Nanofibrous mats were generated in one study by electrospinning PVA/chitosan/starch, the cell viability was high, and the mats were effective against bacteria. Despite the absence of *in vivo* studies vouching its biological integrity, the *in vitro* scratch assay confirmed its effectiveness in accelerating wound recovery. Using electrospinning, PVA/chitosan nanofibers embedded with the silk protein sericin were produced.Cell proliferation was stronger in. PVA/chitosan nanofibers with reduced sericin concentration than in PVA/chitosan nanofibers alone. Furthermore, animal research has proven their capacity to heal wounds. Another study utilized. PVA/starch to produce hydrogel membranes. Incorporating three distinct essential oils, clove, oregano, or tea tree oil, was incorporated into hydrogel films. PVA/starch hydrogels crafted with 0.1 mL of clove oil in a 7% (w/v) starch mixture exhibited enhanced antibacterial performance relative to the other essential oils. As suggested by the researchers, this makes them a recommended choice for burn wound dressings[32].

PEG is an amphiphilic polymer that may be dissolved in water and used topically, orally, or intravenously without causing adverse effects. The less desirable properties of poly(lactic acid) (PLA), such as brittleness and poor hydrophilicity, are minimized by mixing PEG and PLA, resulting in polyurethane wound dressings composed of alternating and random blocks of PEG and PLA. These dressings had anti-inflammatory effects and were more successful in encouraging healing than gauze alone when evaluated on a live mouse skin model. Silver nanoparticle-containing PEG/chitosan hydrogels possess the capability to improve diabetic wound healing. Both lab-based and live diabetic rabbit models displayed antibacterial and antioxidant capabilities, as well as better wound healing, indicating the material's promise for treating diabetic rabbit chronic wounds[32].

Polycaprolactone (PCL) is highly biocompatible, biodegradable, and mechanically strong. It has shown widespread application in tissue engineering applications. Electrospinning. When PCL is used at low voltages, scaffolds with exceptional mechanical resistance can be produced. Electrospinning and electrospraying curcumin-loaded chitosan nanoparticles resulted in PCL/chitosan/curcumin nanofibers. The electrospun nanofiber strength and spinnability of chitosan were enhanced by the incorporation of PCL. The antibacterial, antioxidant, and cell proliferation capabilities of PCL/chitosan/curcumin nanofibers were verified in an *in vivo* investigation, showing that these nanofibers expedited the wound healing process. Insulin-delivering chitosan nanoparticles were electrospun onto PCL/collagen nanofibers and evaluated in a mouse model by Ehterami *et al.* When compared to sterile gauze, wounds treated with PCL/collagen-based dressings almost closed after 14 days, demonstrating their potential for use in clinical practice[32].

Polylactic acid, which falls under the category of polyester, can be produced either through condensation polymerization of the acid units or by ring-opening polymerization of lactide cyclic dimers. PLA possesses characteristics, including biocompatibility, biodegradability, and adaptability. It has uses in the realm of science, specifically in tissue engineering and suture manufacturing. Nevertheless, PLA possesses certain shortcomings, including its rate of degradation and restricted mechanical robustness. These challenges may be mitigated by incorporating additional polymers or additives with PLA. An innovative technique called double nozzle electrospinning was utilized to manufacture wound dressings using a combination of PLA, PCL (polycaprolactone) and extracts. The resulting structure demonstrated efficacy against both gram-negative microbes with an average fibre size of 638 ± 69 nm. While *in vitro* scratch testing or animal assessments were not conducted by the authors to investigate the impact of these nanofibers on wound healing, MTT proliferation analysis revealed improved cell viability with increasing doses of the plant extract derivative. Therefore, further investigations are needed to determine its effectiveness in promoting wound recovery. In a study, core shell nanofibers were generated using electrospinning techniques involving poly(glutamic acid) (PGA) as the core material and PLA as the shell material. By adjusting the electrospinning parameters, the authors verified that these nanofibers are biocompatible and nontoxic. In a rodent-based study, these unique nanofibers accelerated wound healing and fostered skin cell proliferation 2 weeks postinjury. This suggests that these nanofibers have the potential to be useful in efforts to repair wounds[32].

Poly(lactic-co-glycolic acid) (PLGA) is a copolymer derived from lactic acid and glycolic acid and is known for its biocompatibility and biodegradability. Its adaptability in various applications is attributed to these characteristics. The precise proportion of the two components dictates the physical and chemical characteristics, as well as the degradation behaviour of PLGA. In their quest to promote angiogenesis during wound healing, Porporato *et al.* utilized PLGA along with added lactate to accelerate the process. Notably, they observed a 60% increase in the healing area after 10 days with PLGA intervention compared to the control group. In another study, researchers created scaffolds by electrospinning a mixture of PLGA and gelatine in volume ratios of 9:1, 7:3 or 5:5. They evaluated these scaffolds for their chemical and biological characteristics. The volume ratio of 7:3 specifically encouraged cell growth without triggering any reactions, making this combination of PLGA/gelatine highly promising for the treatment of wounds. However, we believe that their investigation lacks evidence to fully endorse the effectiveness of PLGA/gelatine nanofiber scaffolds in wound healing scenarios. More comprehensive studies involving assessments and evaluations using animal models are indispensable. Gao *et al.* made strides by developing a dual-layered dressing using PLGA/PVA that incorporates nanoparticles into the electrospun layer of PLGA. Furthermore, stem cells were added to the gelatine-enriched portion of the PVA hydrogel. Interestingly, the PLGA layers infused with silver enhanced the durability and moisture retention of the PLGA/PVA dressings. Moreover, incorporating stem cells into the dressing effectively preserved growth factors that promote cell growth and facilitate wound healing. This type of wound dressing has the potential to bring about a transformation in tissue engineering[23].

Emerging Biomaterials in Wound Care

In the field of wound care, there are advancements being made in biomaterials and techniques that aim to improve the healing process. These innovative biomaterials go beyond methods. Provide customized treatment options. One area of focus is the use of scaffolds that contain growth stimulants, bioactive compounds, and modified cells. These frameworks create an environment that promotes cell growth and tissue rejuvenation, leading to better wound recovery[44]. There is growing interest in using mimetic materials such as silk fibroin for wound healing. These derived biopolymers offer possibilities for creating platforms that support tissue regrowth. Another interesting development in this field is the use of glasses. With their properties, these materials are well suited for applications, including wound healing. They release ions that promote tissue rejuvenation and enhance the healing process[44]. Furthermore, nanomaterials are emerging as a player in this area. Designed to mimic mechanisms involved in tissue restoration, they offer a sophisticated and effective approach to managing wounds[40]. In summary, the innovative biomaterials used in wound care include a range of cutting-edge materials and methods that aim to improve wound healing outcomes. This range includes scaffolds enriched with growth factors, bioactive compound cells enhanced through techniques, materials that mimic processes, such as silk fibroin, bioactive glasses, and nanomaterials. While these materials offer benefits, they also present challenges. The benefits of using biomaterials in wound management encompass their capacity to accelerate the healing timeline, foster an optimal setting for tissue regeneration, and amplify the efficacy of wound dressings[7]. Polymer-based biomaterials, including micro- and nanoparticles, fibres, and hydrogels, have shown potential in the field of wound healing. These substances, sourced from synthetic origins, exhibit characteristics that enhance the healing journey[7]. Specialized biomaterials have been developed to address the requirements of wounds. Dressings made from these biomaterials target stages of wound development and enhance healing outcomes by creating an environment conducive to tissue revival[8]. Additionally, bioactive glasses are being investigated for their potential to release ions to accelerate wound healing[44]. These materials release ions that stimulate tissue renewal and show promise in treating burn injuries and critical diabetic ulcers. Triboelectric nanogenerators (TENGs) offer another technology in wound therapy. Capable of generating impulses while exhibiting properties and facilitating drug delivery TENGs serve as versatile tools in wound care. These self-contained devices can provide stimulation to enhance wound healing, combat infections and deliver compounds directly to the affected area[41]. However, there are challenges associated with using biomaterials for wound management despite their benefits. One primary concern is selecting the biomaterial that suits the characteristics and stage of progression of a particular wound. Elements such as the dimensions, position, and intensity of the injury influence this choice procedure[7]. Another challenge lies in developing mechanisms for controlled drug release within these biomaterials. The dispersion of substances from these materials needs to be meticulously calibrated to satisfy therapeutic needs, encompassing both timing and dose[41]. Novel biomaterials present considerable advantages in wound care, such as accelerating wound recovery, establishing a prime setting for tissue development, and boosting the efficacy of wound coverings. However, challenges such as biomaterial selection, controlled drug delivery, and translation to clinical practice need to be addressed. Continued research and development in the field of biomaterials for wound care are essential to overcome these challenges and improve patient outcomes.

Advanced Strategies Incorporating Natural Polymers & Biomaterials

Composite bandages are versatile wound coverings made up of layers of materials. These bandages provide benefits, such as absorbing liquids regulating moisture and protecting against infections. They are commonly used for wounds such as pressure sores and diabetic foot ulcers as well as acute injuries. Typically, composite bandages consist of a layer that does not stick to the wound, a layer that absorbs moisture, and an outer layer that protects against microbes and contaminants. The nonadhesive layer ensures discomfort when changing the bandage, while the absorbent layer helps manage wound discharge and creates a moist environment to aid healing. The outermost protective layer shields the wound from pollutants. Invading microorganisms. Additionally, these composite bandages can be enhanced with other substances to enhance their healing properties[6]. Different methods are employed to deliver wound therapeutics, which involve using materials to release substances to the injured area. These techniques ensure that therapeutic substances are dispensed in a controlled manner, maximizing their effectiveness in promoting healing. Various delivery systems, such as hydrogels, nanoparticles, and electrospun threads, have been investigated for wound care purposes[30]. Active wound dressings contain substances such as growth factors or antibacterial agents that aid in the healing process. Designed to create an environment for healing, these dressings deliver these substances directly to the injured area. These dressings can be derived from sources, including hydrogels, nanoparticles and natural polymers[38]. NPs can transport and release their contents when incorporated into dressings. Natural polymers such as chitosan or collagen can form structures infused with these substances for application on wounds. These advanced wound dressings have the potential to enhance healing in slow-healing injuries[38]. Bioengineered skin replacements imitate the structure and functions of skin. These created replicas often combine a framework that provides support with cells capable of transforming into actual skin tissue. The foundational framework can be made from polymers or natural cellular components, while the cellular component can either come from the patient's body (autologous) or from a donor (allogeneic)[44]. These innovative skin replacements offer possibilities for a range of skin issues, including injuries, burns, and deformities, with the potential to enhance healing and reduce reliance on traditional skin grafts[44]. However, there are still challenges to overcome in optimizing and implementing these substitutes in settings to ensure their long-term stability and effectiveness (Table 4).

Bioactive Glasses and Ceramics

Bioactive glasses and ceramics have emerged as biomaterials in the field of wound care. These materials possess characteristics that can enhance the healing process. This overview aims to explore the dynamics, benefits, and challenges associated with using glasses and ceramics for wound healing. Bioactive glasses are compounds that release ions such as calcium, phosphate, and silica directly into the wound site. Studies have shown that these ions possess properties such as reducing inflammation, fighting against growth-promoting blood vessel formation (angiogenesis) and aiding in blood clotting, all of which are advantageous for wound healing. When introduced into a wound, these ions from glasses influence behaviours by supporting cell movement, multiplication, and differentiation and ultimately facilitating tissue regeneration[44]. The release of these ions occurs as the bioactive glass structure dissolves upon contact with fluids. This disintegration results in the creation of a surface layer that engages with adjacent tissues[44]. Additionally, bioactive glasses possess abilities, which is another advantage. Persistent wounds are often vulnerable to infections that can hinder the healing progress. Bioactive glasses can release ions, such as silver and copper, which have antimicrobial properties and can inhibit the growth of bacteria. This antibacterial activity of bioactive glasses can help prevent and treat wound infections, promoting a favourable environment for wound healing[44]. Bioactive ceramics, such as bioactive glass-ceramics, have also shown promise in wound care applications. These materials combine the advantages of bioactive glasses and ceramics, offering enhanced mechanical properties and controlled degradation rates. Bioactive glass ceramics can provide mechanical support to the wound site, protecting it from external forces and promoting tissue regeneration. They can also release therapeutic ions, similar to bioactive glasses, which can stimulate cellular responses and enhance wound healing[44]. Despite their potential advantages, there are

Table 4 — Comparative Analysis of Advanced Wound Dressing

Type of Dressing	Main Components	Mechanism of Action	Applications	Benefits	Challenges
Composite Bandages	Layers, in this context typically consist of a sticky layer, an absorbent layer and a protective layer.	Absorbs liquid, regulates moisture, protects against infection.	Pressure sores, diabetic foot ulcers, acute injuries.	Reduces discomfort helps manage moisture and protects, against pollutants.	Creating an environment of both comfort and efficiency regarding managing moisture levels.
Hydrogels	Polymer networks.	Gradual release of therapeutic agents.	Wound care, slow-healing injuries.	Enhanced healing, controlled release.	Long-term stability, effective integration with wound.
Nanoparticles	Nanometre-sized entities.	Encapsulate and transport medications or growth factors.	Targeted wound healing.	Precise delivery, enhanced effectiveness.	Optimizing release rates, ensuring biocompatibility.
Electrospun Threads	High surface-to-volume ratio fibres.	Hold and release drugs efficiently.	Drug delivery in wound care.	Efficient drug release, high surface area.	Manufacturing consistency, drug compatibility.
Bioengineered Skin Replacements	Polymers, natural cellular components, autologous or allogeneic cells.	Imitates skin structure and functions.	Injuries, burns, deformities.	Potential to enhance healing, reduce reliance on traditional grafts.	Long-term stability, effectiveness in diverse settings.

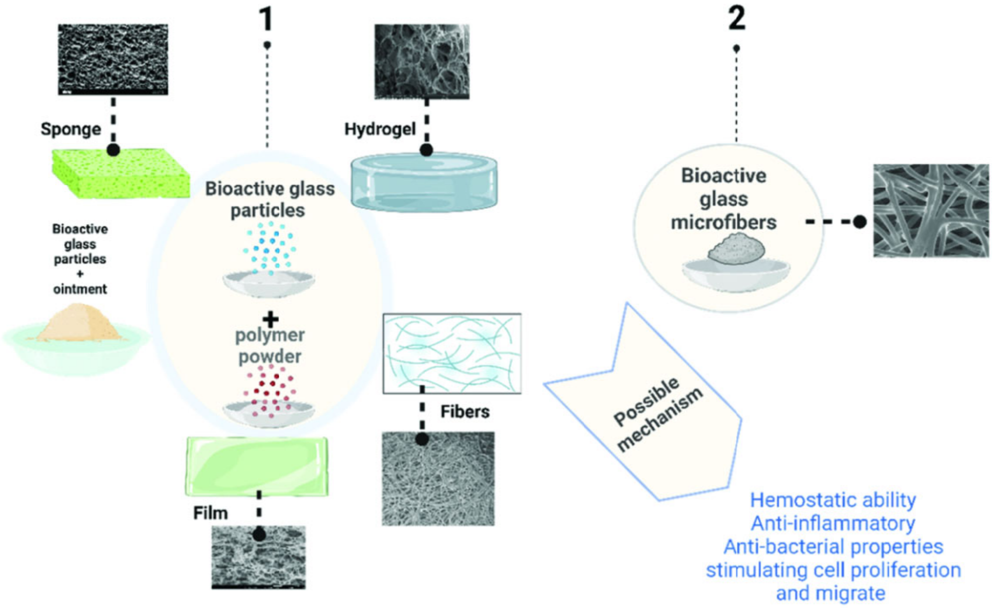

Fig. 4 — There are ways to use glasses in wound care and how they can potentially affect the healing process. These include 1) incorporating glass fragments into ointments or polymer-based structures, such as sponges, films, hydrogels, or threads, and 2) creating glasses in the form of bandages made from microfibers

challenges associated with the use of bioactive glasses and ceramics in wound care. One challenge is the optimization of the composition and structure of these materials to achieve the desired biological response. The discharge rates of medicinal ions must be meticulously regulated to ensure their effectiveness without causing adverse effects[44]. Additionally, the mechanical properties of bioactive glasses and ceramics must be adjusted to align with the particular demands of wound recovery, such as suppleness and resilience[44]. Achieving the right balance between bioactivity and mechanical properties is crucial for the successful application of these materials in wound care. The integration of glasses into structures presents a promising strategy for treating various aids for wound healing. These aids can include bandages and skin substitutes or frameworks made of both organic materials. They can be designed in the form of hydrogels, sponges, or filamentous barriers. This combination takes advantage of the benefits offered by both glasses and/or artificial polymers. Bioactive glasses do not enhance the effectiveness of the polymer structure. It also strengthens the overall assembly's mechanical durability[30]. Moreover, ointments containing glass have the potential to be used as treatments for skin injuries. Figure 4 illustrates the techniques employed for creating glass/polymer composites, bioactive glass ointments, and microstrand glass fibres[44].

Novel Technologies in Wound Care: Nanotechnology, Hydrogels, 3D Printing

The field of wound care has experienced advancements with the emergence of nanotechnology, hydrogel 3D printing, and other innovative techniques. These cutting-edge methods bring functionalities and potential applications that hold promise in transforming wound treatment approaches and improving patient recovery outcomes. Nanotechnology plays a role in wound care by leveraging its ability to manipulate materials at the small nanoscale. Silver and gold nanoparticles have become well known for their properties and ability to improve the healing of wounds[23]. Conversely, AuNPs demonstrate potential in wound repair owing to their anti-inflammatory and antioxidant properties. These nanoparticles can influence activities that stimulate angiogenesis (the formation of blood vessels) and enhance tissue revitalization[23]. Hydrogels, which are composed of polymer networks, excel in retaining water, making them ideal for supporting wound healing processes. They are highly regarded for their biocompatibility, customizable properties, and potential use as carriers for compounds. By embedding growth factors or cytokines within hydrogels, one can amplify the wound-healing response and boost tissue rejuvenation mechanisms. The wide range of benefits they offer, from providing support to promoting growth, is truly impressive. Recent advancements in self-healing hydrogels also suggest that wound dressings could last longer by releasing substances[43]. Additive manufacturing, commonly referred to as 3D printing, has transformed wound care by allowing the creation of intricate designs with meticulous oversight of their structure and makeup. This technology allows for the creation of patient-specific wound dressings, scaffolds, and implants that can closely mimic the native tissue environment. 3D-printed scaffolds can provide mechanical support, guide cell growth, and promote tissue regeneration. They can be designed with porous structures to facilitate nutrient and oxygen exchange, as well as the infiltration of cells and blood vessels. In addition, 3D printing allows for the integration of biologically active compounds, such as growth factors and antimicrobial substances, into the structures, amplifying their healing capabilities[12]. Other novel technologies in wound care include the use of biobased electrospun fibres, interactive wound dressings, and the exploration of natural materials such as honey and pearl powder. Electrospinning is a technique that produces ultrafine fibres with diameters in the nanometre to micrometre range. Electrospun fibres can mimic the structure of the extracellular matrix and provide a suitable environment for cell attachment, migration, and proliferation[41]. Interactive wound bandages, however, incorporate advanced functionalities such as moisture management, antimicrobial properties, and controlled drug release. These dressings can create an optimal wound-healing environment and promote faster healing[12]. Novel technologies such as nanotechnology, hydrogels, 3D printing, and other advanced approaches have the potential to revolutionize wound care. These technologies offer unique mechanisms and applications that can enhance wound healing processes, including antimicrobial properties, controlled release of bioactive molecules, patient-specific designs, and the ability to mimic the native tissue environment. However, further research and development are needed to optimize these technologies, address challenges related to scalability and cost-effectiveness, and translate them into clinical practice.

Challenges and limitations

Using polymers and innovative biomaterials in wound care shows promise. It also presents challenges and limitations. These include issues with the properties of polymers, complexities of wound healing, regulatory considerations, and commercial feasibility. Natural polymers such as collagen, chitosan, and hyaluronic acid, due to their origins, can exhibit variations in composition, structure, and characteristics. These inconsistencies from one batch to another make it difficult to ensure performance and reproducibility. Such differences may affect factors such as strength, decomposition rate and biological activity, potentially impacting their effectiveness for wound treatments. Another limitation is that natural polymers tend to have strength compared to synthetic polymers[41]. This can restrict their use in applications where high mechanical strength is needed, such as scaffolds or treatments, for lasting wounds. To overcome this, techniques such as cross-linking blending with polymers or incorporating strengthening agents can be employed to enhance the properties of natural polymers. Additionally, the complex nature of wound healing poses challenges. It involves a series of interconnected phases, such as inflammation, cell growth, and tissue restructuring. Designing biomaterials that can effectively guide these stages and promote wound healing is a task. The interplay between biomaterials and recipient tissue, coupled with the regulated discharge of bioactive substances, holds pivotal importance in achieving the desired therapeutic outcomes. The market potential of polymers and emerging biomaterials for wound care is significantly influenced by factors. In regard to developing and introducing solutions based on biomaterials, it is important to comply with norms and obtain approval from governing bodies such as the U.S. Food and Drug Administration or the European Medicines Agency. However, this regulatory process can be time-consuming and expensive, which can pose challenges for companies or academic institutions looking to bring their innovations to market[44]. The commercial viability of these materials is shaped by factors such as production scalability, cost-effectiveness, and market demand. Increasing the production of these materials can present difficulties related to accessing material extraction methods and fabrication techniques. Additionally, the costs associated with materials, processing, and quality assurance can also impact their feasibility in the market. Moreover, the demand for these materials in wound care is heavily influenced by healthcare professionals' and patients' endorsement, which plays a role in determining their success. Simply put, the field of wound treatment holds potential, with polymers and cutting-edge biomaterials. However, there are hurdles and obstacles that need to be overcome. These range from the limitations and variability of polymers in the wound recovery procedure and regulatory requirements and commercial feasibility. To tackle these challenges ahead, it is crucial that we invest in research and foster collaboration between institutions, industries, and regulatory bodies. Then, we can successfully translate these materials into clinical applications.

Conclusion

The global market for wound care dressings is expected to experience growth in the coming years. Estimates indicate that by 2027, the advanced wound care sector could reach a market value of approximately $19 billion. The employment of polymers such as collagen, chitosan, and alginate along with the introduction of biomaterials such as synthetic polymers and bioactive ceramics represents a significant advancement in advanced wound care. These materials are known for their compatibility with the body and their potential to drive innovation, offering opportunities to enhance the wound healing process. However, it is essential to address challenges related to scalability and potential immune reactions to ensure adoption in clinical settings. Looking ahead, the combination of nanotechnology and 3D printing suggests a future where personalized and adaptable wound care treatments could become commonplace. This overview underscores the role of science in revolutionizing wound care while emphasizing a commitment to improving patient outcomes through creative and effective strategies. The journey continues towards a future where expertise in biomaterials guides advancements in the science of wound healing.

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Conflict of interest

All authors declare no conflict of interest.

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