Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 5s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Electrospun Nanofibers: An Impressive Regimen to Manage Burn Wounds

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Cite this paper as: Rajesh Kumar, Dr. Deepti Saxena, Somendra Kumar, Vinita Kumari, Sheela Kushwaha, Mamta Kumari, Shashi Kiran Misra, (2025) Electrospun Nanofibers: An Impressive Regimen to Manage Burn Wounds. *Journal of Neonatal Surgery*, 14 (5s), 481-498.

ABSTRACT

Burns are a worldwide public health issue that poses significant obstacles to both the economy and public health. Shock, multiple organ failure, systemic infection, and even death are common outcomes of severe burns. Because standard dressings only serve one purpose and have several negative consequences, they have not been able to satisfy the growing need for burn wound therapy. In this regard, electrospinning presents a promising avenue for developing cutting-edge wound dressings that encourage wound healing and guard against infection. With its large specific surface area, high porosity, and similar to natural extracellular matrix (ECM), electrospun nanofibers can load drugs and accelerate wound healing. It offers a potentially effective way to control and treat burn injuries. This review article introduces the concept of burn and the types of electrospun nanofibers, and then summarizes the polymers used in electrospun nanofiber dressings. The medications filled with electrospun burn dressings (plant extracts, small molecule medications, and nanoparticles) are finally compiled. Promising elements are suggested for the development of commercial electrospun burn treatments.

Keywords: *Nanofibers, Burns, Shock, Organ failure, Systemic infection, Electrospun.*

1. INTRODUCTION

Skin makes up almost 10% of a person's total weight and covers the whole body, making it the biggest organ in the human body.[1] Severe thermal (flame or scald), electrical, chemical, frictional, or radioactive skin injuries are known as burns.[2] Just like any other kind of wound, burns go through a complicated healing process. Typically, there are four steps to a wound's healing process: clotting, inflammation, cell proliferation, and tissue remodeling.[3] with the help of some drugs, minor burns can heal rapidly. However, shock, organ failure, and bacterial infections are common sequelae of severe burns. Burns weaken the skin's immunomodulatory function, leaving the wound open to bacterial infection. An increase in wound exudate, brought on by a bacterial infection, presents significant obstacles to wound healing and poses formidable hurdles to wound management. When the skin damage is too severe and the autologous healing ability is not enough to restore the original structure and function, the conventional approach of skin transplantation is often performed. The use of different skin grafts has greatly increased the survival rate of burn victims in the last several decades. Even though they are used a lot, there are still problems with allogeneic transplants and the lack of donors for autologous skin grafts.[4] with the progress of biotechnology, multifunctional wound dressings and nanofiber scaffold materials have become more common[4]. These materials have made skin transplantation a little easier. To prevent further infection from germs in the environment, a wound dressing can cover the wound temporarily. It has a big effect on how quickly wounds heal, and it may also work as a template to guide skin cells to recombine, invade, and become part of host tissues. Wounds treated with traditional dressings like bandages and gauze is commonplace in clinical practice. They offer mechanical protection and can soak up blood and wound exudate. Traditional dressings have their uses, but they aren't ideal for wound healing since they can't prevent infections and stick to the skin, which can lead to further harm for the patient. The perfect wound dressing would have the following qualities[5]

(1) It would soak up excess blood and exudate from the wound;

(2) It would keep the wound moist so it can heal;

(3) It would be easy to breathe in and out;

(4) It would prevent the wound from becoming infected by harmful substances and microbes outside the wound;

(5) It would be biocompatible and biodegradable; and

(6) Taking it off the patient's wound wouldn't inflict any further harm.

Common dressing materials include not just standard dressings but also films, foams, hydrogels, hydrocolloids, and nanofiber composites. There are many dressings for different wounds, each with pros and cons. A sponge dressing can facilitate wound healing by absorbing large amounts of water due to its very porous nature. However, due to their poor mechanical strength, sponge dressings may cause skin maceration. Because they are permeable, film dressings can alleviate discomfort for patients. The problem is that this dressing type doesn't soak up much water, so it sticks to wounds and causes exudate to build up. A type of hydrophilic macromolecular networks called hydrogels can soak up and hold on to wound fluids while also encouraging the movement of glial cells and the growth of fibroblasts. After swelling and water absorption, hydrogel's mechanical stability deteriorates. Nanofibers are finding more and more applications as wound dressings due to their status as a widely marketed nanoscale material. Nanofiber dressings are better than regular ones because they are made of tiny structures that mimic the properties of the natural extracellular matrix. This makes them perfect for putting on and spreading medicine and soaking up more wound fluid. From to the mechanical and biological characteristics of the electrospun nanofibers are excellent.[5,6]

Electrospinning, microphase separation, self-assembly, template synthesis, and drawing procedures are some of the ways that nanofibers are prepared. The low cost, great efficiency and simplicity of operation of electrospinning make it a popular choice for nanofiber preparation. An efficient way to create fibers with sizes between nanometers and micrometers is electrospinning. It is possible to tailor the structure of electrospun nanofibers to suit a wide range of uses. Electrospun nanofibers have several applications in biomedicine, including medication delivery, tissue engineering scaffolds, and wound dressings.[29–33] several notable benefits are associated with electrospun nanofiber wound dressings. The greater specific surface area of electrospun nanofibers allows for additional cell attachment and growth sites. Second, the great porosity of electrospun nanofibers allows for excellent airflow and moisture permeability while simultaneously preventing the entry of harmful microorganisms. To increase wound healing efficiency, electrospun nanofibers can be used as drug carriers to load different bioactive components and medications. Their structure is adjustable.[7] Furthermore, the rate and duration of medication release may be controlled using nanofiber wound dressings. That is why electrospun nanofibers are so promising for use in medicine.[8]

By using the search terms "wound dressing" and "electrospun wound dressing" in the "PubMed" and "Web of Science" databases, we may access the pertinent literature from the last decade. You can see the outcomes of the search in Figure 1. The search results show that both databases get thousands of literatures on wound dressings annually, with an upward tendency over time. There has been a meteoric rise in the volume of publications on wound dressing since 2018, indicating that this area of study is now quite popular among biomedical researchers. Similarly, there is a growing pattern in the literature on electrospun nanofiber dressings. Evidence that the wound dressing made from nanofiber has gained recognition with the introduction of electro-spun nanofiber technology. This study primarily aims to provide a comprehensive overview of electrospun nanofibers, polymers utilized in their production, and a range of therapeutic or antimicrobial medications that may be encased in these dressings.[8,9]

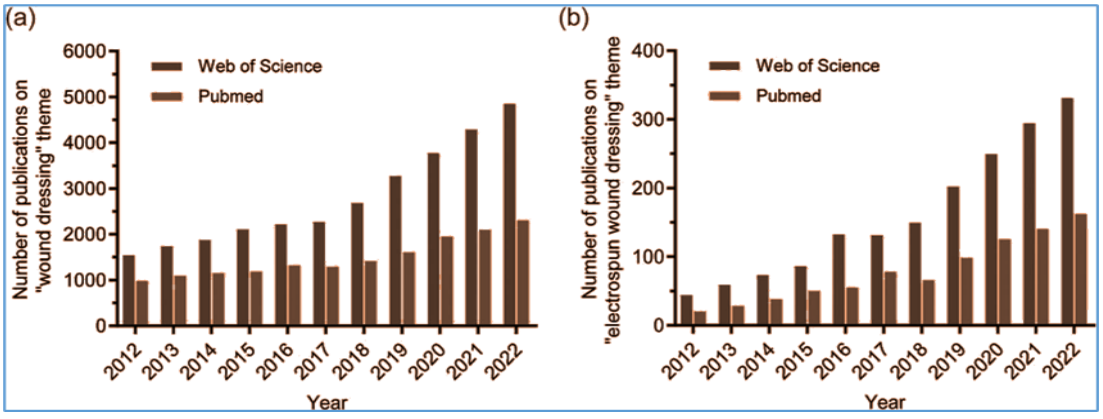

Figure.1 shows the results of a search of the "PubMed" and "Web of Science" databases for articles published in the last decade relevant to wound dressing and electrospun wound dressing, respectively.

2. BURN AND WOUND HEALING

2.1 Burn

Nobody is safe from burns, which may happen to anybody at any moment.A burn can be classified as first-degree, second-degree, third-degree, or fourth-degree depending on its severity. Minor redness and discomfort, which go away within 48 to 72 hours, are symptoms of first-degree burns, which only affect the skin. A burn of this severity does not need any specific care and will not result in scarring. When it comes to burns, there are two main types: superficial and profound. Painful, superficial second-degree burns affect the skin's outer layer and a small portion of the dermis.[10] Due to the gradual onset of pain and the destruction of certain pain receptors; profound second-degree burns affect both the epidermis and the dermis. Scarring and surgical therapy are necessary for burns of this severity. In the absence of infection, the wound should heal within three to four weeks. A third-degree burn can affect any part of the dermis.[9] They require special care to prevent infection and typically do not experience pain due to damaged nerve endings.[10] Skin grafting is typically necessary for the treatment of third-degree burns.[11] Also, a fourth-degree burn is what you get when the burn goes into deep tissue. Combining features of second- and third-degree burns, it damages muscles and bones by reaching the dermis and subcutaneous layers.[12] Figure 2 displays the depth of each burn stage. Typically, minimal intervention is required for the natural healing process of superficial burns, similar to that of typical mechanical injuries, surgical wounds, etc. On the other hand, serious burns can compromise the skin's structure and function, leaving it more susceptible to bacterial infections and triggering a cascade of systemic responses. People who have severe deep burns often have severe systemic inflammation, hypermetabolism, and catabolic reactions. If they don't get surgery right away, these people could die from organ failure. out of Hypertrophic scars, another consequence of burns, can impair normal bodily function in addition to affecting appearance. The primary goals of burn wound care should be infection prevention and the amelioration of scarring. This is why, instead of using regular wound dressings, it is best to add antimicrobial medications to burn dressings. Additionally, you can add pharmaceuticals with anti-inflammatory action to prevent scarring caused by excessive inflammation.[13]

2.2 Healing process of burn wounds

A wide variety of cells, cytokines, growth factors, and neuroendocrine systems work together to facilitate wound healing. Hemostasis, inflammation, proliferation, and remodeling are the four often overlapping stages of skin wound healing (Fig. 3).[14] Damage to cells and tissues triggers the bodies inflammatory and hemostasis responses, which are triggered by inflammatory mediators.[15] The accumulation of neutrophils in the wound and their subsequent removal of germs and damaged tissue are facilitated by the release of different cytokines. Over time, the number of neutrophils decreases while the number of macrophages increases. In this stage, macrophages and neutrophils start to engulf bacteria and dead host cells. Furthermore, macrophages promote capillary angiogenesis and fibroblast proliferation by secreting transforming growth factor-b, interleukin-1 (IL-1), tumor necrosis factor (TNF), platelet-derived growth factor (PDGF), fibroblast growth factor (FGF), and IL-1. An essential step in the angiogenesis process is the migration, remodeling, and proliferation of endothelial cells.[16] Granulation tissue, made up of newly formed capillaries and hyperplastic fibroblasts, undergoes remodeling and eventually develops into a scar. Wound epithelium regeneration by keratinized cells and extracellular matrix buildup by fibroblasts and endothelial cells are both processes that occur throughout the tissue remodeling phase.[15,16]

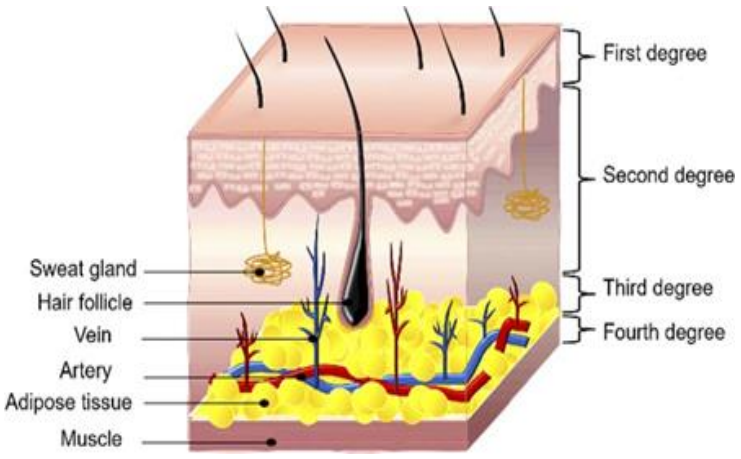

Fig. 2 Burns depth and level. Burns are classified into four grades based on the size and depth of skin damage: first-degree, second- degree, third-degree, and fourth-degree burns.

3. ELECTROSPUN NANOFIBER

3.1 Introduction to electrospinning technology

One easy and flexible way to make nanofibers with bioactive chemicals is by electrospinning. The number of in comparison to nanofibers produced by conventional dry or wet spinning techniques, electrospun nanofibers have dimensions that are two to three orders of magnitude smaller, ranging from nanometers to microns. Injection pump, syringe with spinneret, collecting device, and high voltage power source are the four primary components of the electrospinning apparatus (Fig. 4). The steps involved in electrospinning are as follows.[18] To regulate the flow rate of the prepared polymer solution to the spinneret, it is fed into a syringe that is attached to the syringe pump. At the tip of the spinneret, a polymer solution collects electrostatic charge from the high-voltage power source, which drives the droplet into a cone called the "Taylor cone" over time. There are if the electrostatic field is stronger than the solution's surface tension, the charged polymer solution will be ejected from the Taylor cone's tip. The collected polymer solution is propelled through a series of bending and whipping phases by means of an electric field force that acts upon the spinneret. Eventually, it settles on the collecting device. Nanofibers are created as the solvent evaporates, depositing the stretched and cured polymer solution onto the collecting device.[19]

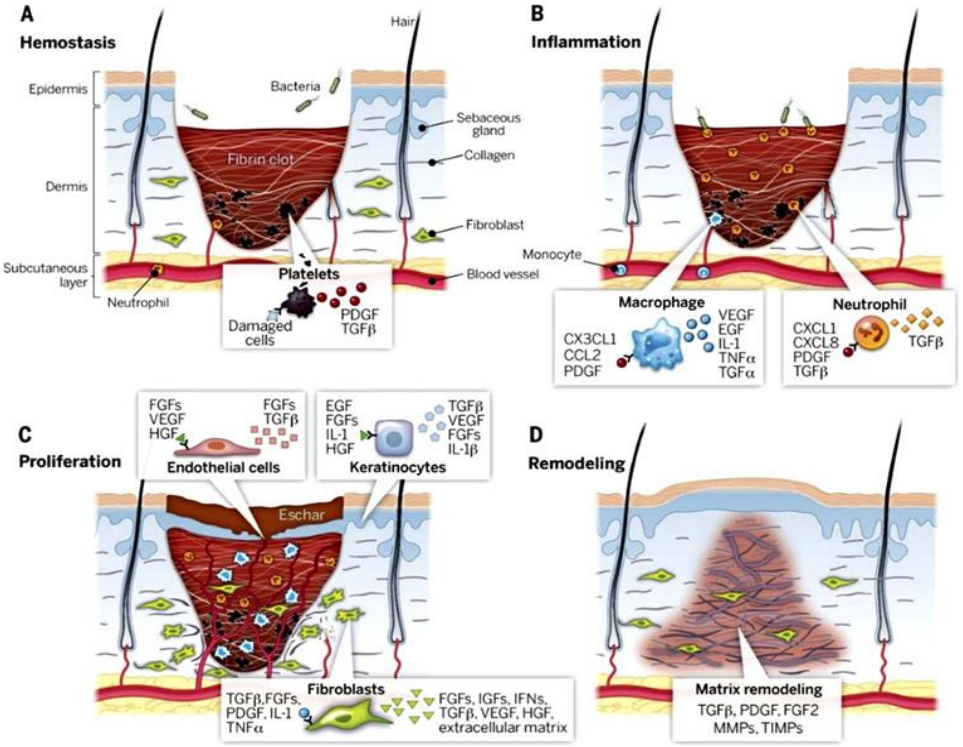

Fig. 3 Stages of wound healing: (A) hemostasis, (B) inflammation, (C) proliferation, (D) remodeling. Reproduced from ref. 50 with permission from science, copyright 2003.[13,14]

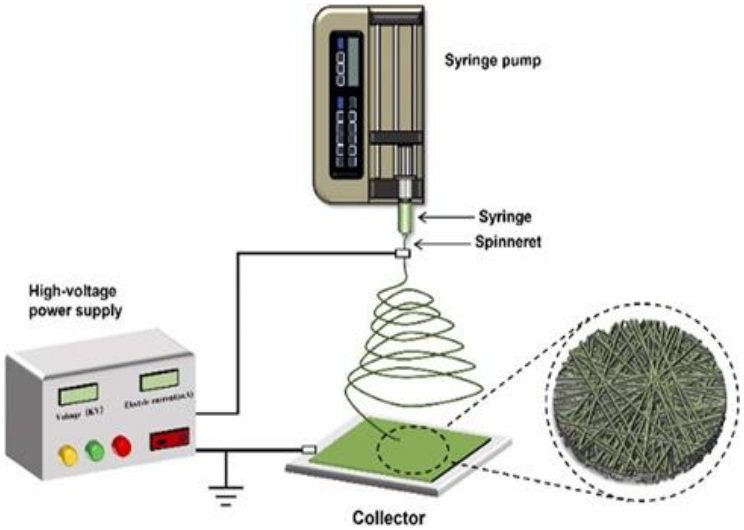

Fig. 4 Electrospinning apparatus. The essential components of an electrospinning apparatus are a collector, a high-voltage power source, a syringe coupled with a spinneret, and an injection pump.

By adjusting the electric field strength, electrostatic potential, acceptance distance, pore diameter, and environmental conditions (such as temperature, humidity, and local airflow), one can alter the size and shape of nanofibers during the electrospinning process. Solution parameters such as polymer type, concentration, conductivity, and surface tension are also affected.[15]

The loading and precisely controlled release of various drugs can be achieved using nanofibers with different morphological structures. By minimizing the need for dosing and increasing compliance, sustained drug release makes sure that the drug is evenly distributed throughout the wound. Percent Nanofibers that have been electrospun hold great promise for use in skin regeneration and wound healing, and they have already contributed to the advancement of drug delivery systems. The number of the electrospinning process has been the subject of several innovations in an effort to increase the variety of nanofiber shapes available.[17]

Several varieties of electrospun nanofibers are displayed in Figure 5: (1) mixing electrospinning and emulsion electrospinning are examples of single-fluid electrospinning. (2) coaxial and side-by-side electrospinning are examples of double-fluid electrospinning. (3) multi-fluid electrospinning is another option.[18]

3.2 Single-Fluid Electrospinning

3.2.1 Blending Electrospinning.

To create blended nanofibers with two or more distinct polymers, blending electrospinning is a typical technique. Dollars It is necessary to add various polymers to the solvent in a certain ratio and mix them well before electro-spinning. By adjusting the characteristics of the fluid, cell inhibitors, antibiotics, and medicinal medications can be delivered by electrospinning blends, according to the results of the tests. Figure-5 the three main categories of electrospinning based on the number of fluids used are single-fluid (emulsion and blended electrospinning), double-fluid (coaxial and side-by-side electrospinning), and multi-fluid Functions.[19]

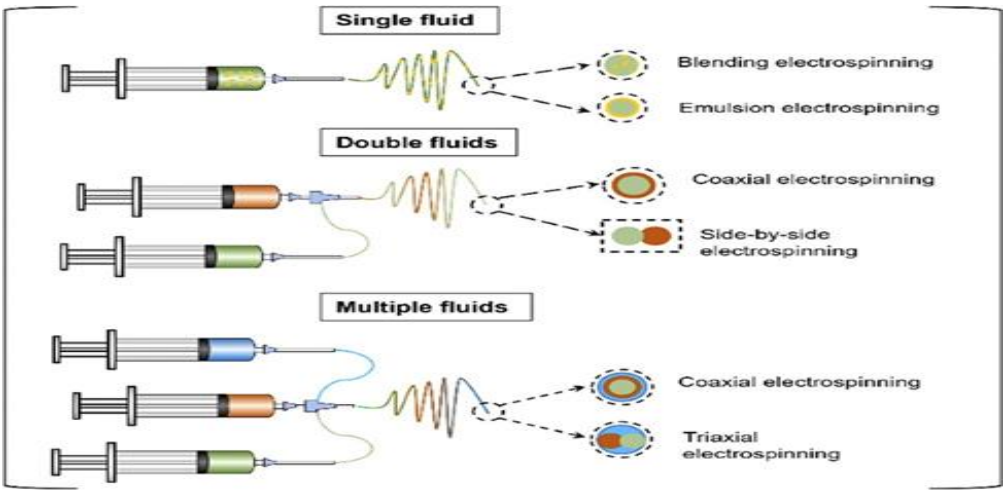

Fig. 5 According to the number of fluids, electrospinning can be divided into single-fluid electrospinning (blended electrospinning and emulsion electrospinning), double-fluid electrospinning (coaxial electrospinning and side-by-side electrospinning), and multi-fluid electrospinning.

The ability to completely dissolve polymers and pharmaceuticals is dependent on the solvent used. In cases where the medication is insoluble in the polymer-solvent mixture, it may be required to dissolve the drug in a separate, smaller volume of solvent before combining electrospinning with the polymer solution. Sixty-three ninety-two Blending electrospinning also has the apparent drawbacks. Sudden drug release can occur if the drug is not completely dissolved before it accumulates on the surface of the nanofibers. Experimental electrospinning of emulsions.[20] To address the issue of abrupt medication release that can occur with mixing electrospinning, emulsion electrospinning has emerged as a straightforward and efficient technique for producing core-shell nanofibers. Two different kinds of emulsions are often used in emulsion electrospinning.[21] Two phases, one lipophilic and one hydrophilic, combine to form a water-in-oil emulsion. Little hydrophilic molecules, such as pharmaceuticals or proteins, can be encased in this emulsion form. A balance between the emulsion's hydrophilicity and lipophilicity is maintained by surfactants/emulsifiers.[16] In contrast, a lipophilic droplet phase and a hydrophilic continuous phase combine to produce an oil-in-water emulsion. After dissolving in the oil phase solvent, the hydrophobic medication was gradually released into the hydrophilic continuous phase by diffusion. When it comes to creating nanofibers with medications that have a limited solubility, emulsion electrospinning offers greater benefits than mixing electrospinning. The drug distribution in nanofibers made using emulsion electrospinning is more consistent than in nanofibers loaded with drugs that were made using mixes electrospun.[20] Electrospinning a Pickering emulsion stabilized with ZnO/Ag nanocomposites

and loaded with tea tree oil (TTO), a natural antimicrobial ingredient, was described by Jiang et al. as an antimicrobial dressing.[22] Stabilizing ZnO and Ag nanoparticles allowed for the uniform and stable distribution of TTO in the Pickering emulsion. In addition to being biocompatible and compatible with blood, the produced nanofiber dressings exhibited outstanding long-term bacteriostatic effectiveness against Gram-positive and Gram-negative bacteria. Furthermore, at concentrations of 800 mg/ml or lower, it successfully stimulated cell proliferation and migration.[23]

3.3 Double-fluid electrospinning

3.3.1 Coaxial electrospinning:

It is handled in section nanofibers with core-shell configurations may be created via coaxial electrospinning by concurrently using two types of polymer solutions. This structure's main benefit is that the medication is placed in the core layer, which makes the drug release period longer and less prone to the phenomena of abrupt release. The core layer of a coaxial electrospinning setup can contain both spinnable and non-spinnable solutions. Coaxial electrospinning of core-shell nanofibers requires careful consideration of interlayer conductivity, viscosity, and miscibility. Sections Guo et al. used a novel method of coaxial electrospinning to create nanofiber burn dressings that loaded ciprofloxacin and Centella total glucoside, two drugs that are notoriously difficult to get together.[22,23] (In order to extend the drug's therapeutic effect and prevent abrupt release, they inserted Centella complete glucoside within the nuclear layer.[24] Both in vitro cellular and antibacterial studies demonstrated that the synthesized nanofibers could stimulate the growth of fibroblasts and had remarkable antimicrobial activity. Also, by encouraging the growth of endothelial cells and new blood vessels, the nanofiber dressing greatly sped up the healing process after rat burns. In a separate investigation, synthesized core-shell nanofibers by layering gelatin with Gymnema sylvestre extract and loading minocycline hydrochloride onto the shell of the nanofibers. Their core-shell nanofibers allow for more controlled and prolonged release of bioactive components than the blended nanofibers they made. The antibacterial activity and cell proliferation were obtained by a good synergistic effect between the antibiotics in the core layer and the plant extracts in the shell layer. Results showed that the dressing successfully promoted collagen deposition and re-epithelialization in experiments with second-degree burns in pig skin. One efficient way to encase bioactive substances in biomedical nanofibers is by coaxial electrospinning.[25]Electrospinning from side to side Janus nanofibers may be made utilizing parallel spinnerets based on single-fluid electrospinning. The Janus construction allows for complete outside exposure, in contrast to the core-shell design. Biphasic controlled release of drugs is possible with Janus nanofibers. The Janus nanofiber dressing was created by Yang et al. using side-by-side electrospinning. It was loaded with ciprofloxacin and silver nanoparticles on both sides. The constructed Janus exhibited a distinct Janus structure, as seen by transmission electron microscopy photographs. To maximize antibacterial activity during early wound healing, in vitro drug release studies shown that ciprofloxacin was nearly fully released during the first 30 minutes.[25] The synergistic action of ciprofloxacin and silver nanoparticles allowed Janus nanofibers to exhibit strong antibacterial efficacy against Staphylococcus aureus and Escherichia coli. In a related work, Shi et al. used polyvinyl alcohol and polylactic acid-glycolic acid to create amphiphilic Janus nanofiber membranes that were loaded with valsartan, mupirocin, and copper sulfide nanoparticles.[1]Their Janus nanofiber membranes could release the antibacterial mupirocin continuously in a hydrophilic environment and showed clear signs of being amphiphilic. The amphiphilic Janus nanofiber membrane's photothermal effect can also regulate valsartan's release, an anti-inflammatory drug. Their wound dressing offers a practical solution to the issues of infection and inflammation during wound healing, making it a promising option for clinical use. Energy, electronic clothing, medication administration, and environmental science are among the many current research hotspots concerning functionalization's of Janus nanofibers.[26]

3.3.2 Side-by-side electro-spinning.

Based on Single-Fluid electrospinning, Janus nanofibers can be prepared using parallel spinnerets. Unlike the core–shell structure, all parts of the Janus structure can be in direct contact with the external environment.[27] Janus nanofibers can achieve biphasic controlled release during drug release prepared Janus nanofiber dressing loaded with ciprofloxacin and silver nanoparticles on both sides by side-by-side electrospinning.[28]

Transmission electron microscopy images showed that the prepared Janus had a clear Janus structure. In vitro drug release experiments showed that the release of ciprofloxacin was

almost complete within the first 30 minutes, which ensured that the strongest antimicrobial activity was achieved in the early stage of wound healing. In addition, Janus nanofiber showed good antimicrobial activity against Staphylococcus aureus and Escherichia coli due to the synergistic effect of ciprofloxacin and silver nanoparticles. In a similar study, Shi et al. prepared amphiphilic Janus nanofiber membranes loaded with copper sulphide nanoparticles, mupirocin and valsartan using polyvinyl alcohol, polylactic acid-glycolic acid.[29] Their prepared Janus nano-fibre membranes possessed obvious amphiphilic characteristics and were capable of sustained release of the antimicrobial agent mupirocin in a hydrophilic environment. In addition, the photothermal effect of the amphiphilic Janus nanofibers membrane can also control the release of the anti-inflammatory agent valsartan. Therefore, the wound dressing they prepared can effectively solve the problems of infection and inflammation in wound healing, providing a feasible method for clinical application. Presently, side-by-side electrospinning and the functionalization's of Janus nanofibers are hot topics in some scientific fields such as energy,

electronic textiles, drug delivery, and environments.[30]

3.4 Multi-fluid electrospinning

Triaxial electrospinning has several potential applications, including the loading of pharmaceuticals with diverse characteristics, the extension of drug release periods, and the resolution of the difficulty in dissolving certain medications. in the range of Although it is difficult to dissolve in water, curcumin has several good antioxidant, anti-inflammatory, and antibacterial effects.[28,30] Using modified triaxial electrospinning, created nanofibers with a sheath layer thickness that could be regulated, allowing for the controlled release of curcumin. This would increase the usage of curcumin's active components.[31] Their produced nanofibers had a clear core-sheath structure and a consistent linear shape. Experiments demonstrated that core-sheath nanofibers effectively inhibited the growth of Staphylococcus aureus and Escherichia coli bacteria while also demonstrating fine control over the release of curcumin.[29] A novel approach to the manufacture of complicated nanomaterials, triaxial electrospinning technique demonstrates significant benefits in the development of drug delivery systems including intricate nanostructures.[30,31]

4. POLYMER USED FOR MAKING ELECTROSPUN NANOFIBER BURN DRESSINGS

Because it impacts the dressings' mechanical qualities and therapeutic action, the choice of polymers for electrospun nanofibers is critical for burn wound treatment. Viscosity, nanofiber shape, biocompatibility, and other factors vary. Polymers used to make electrospun nanofibers, including their partibility and mechanical strength, are listed in Table 1. Possible options include both synthetic and natural polymers. While synthetic polymers offer superior mechanical qualities, natural polymers are more biocompatible. The list of synthetic and natural polymers utilized to make electrospun nanofiber burn dressings is summarized in Table 1. Chitosan, gelatin, silk, and other naturally occurring polymers are mostly comprised of this category.[31,32]

Table-1 Polymers for preparation of electrospun nanofibers

Polymer type	Polymer
Natural polymer	Chitosan
	Gelatin Silk fibroin
	Sodium alginate
Synthetic polymer	Poly(3-caprolactone)
	Poly vinyl alcohol
	Poly ethylene oxide
	Poly vinyl pyrrolidone
	Polyurethane
	Polylactic acid

fibroin, sodium alginate, and synthetic polymers such as poly(3-caprolactone), poly (vinyl alcohol), poly (ethylene oxide), poly (vinyl pyrrolidone), poly- urethane and polylactic acid.[32]

4.1 Natural polymers

4.1.1 Chitosan:

It is a natural polymer made from chitin, chitosan goes by the acronym CS. It is highly effective against germs, has antioxidant properties, is biodegradable, and is biocompatible. Many medical applications make use of CS as a wound dressing, a scaffold for tissue engineering, or a vehicle for drug administration because of its unusual biological activity. Producing nanofibers utilizing electrospinning technology from a single CS solution is a challenging process. Found that increasing the concentration of chitin nanofibril in the CS solution greatly accelerated the nanofiber production rate. Polyamide nanofibers make up the wound dressing's outer layer, which is responsible for providing mechanical strength and warding off external bacterial invasion. The dressing is constructed of two layers. Wound exudate is mostly sterilized and absorbed by the inner layer, which is made of CS mixed with chitin nanofibril. To enhance the physical qualities of chitosan, lended it with polycaprolactone (PCL), which has good mechanical properties. With the bioactivity of CS and the mechanical stability of PCL, you get the PCL/CS graft copolymer. Clinical trials demonstrated that compared to conventional dressings, PCL/CS

nanofiber dressings outperformed the former in terms of mechanical characteristics and antibacterial activity. As a naturally occurring cationic polymer, CS allows for the incorporation of other synthetic or naturally occurring negatively charged polymers, setting it apart from the majority of polysaccharides. Because of its positive charge and the negative charge on bacterial surfaces, chitosan is able to disrupt bacterial biofilms and exert its antibacterial effect.[33] The bilayer wound dressing created by Mirhaj et al. mimics the structure of skin tissue; the top layer consists of chitosan electrospun nanofibers loaded with L-arginine, while the bottom layer is composed of chitosan/polyethylene glycol with advanced platelet-rich fibrin (A-PRF). According to the findings, the produced bilayer dressing might potentially encourage the creation of blood vessels and had outstanding antibacterial action. This occurred because the positively charged Larginine and the similarly positively charged chitosan worked together to provide a synergistic antibacterial action. Research has demonstrated that arginine can promote vascular regeneration and increase collagen production. So, this wounds dressings L-arginine and A-PRF work together to speed up the healing process by increasing blood vessel formation.[34]

4.1.2 Gelatin:

Gelatin which is mainly collagen in animal tissues (skin, muscle, and bone) is the primary source of gelatin, a complex combination of several peptides with a strong affinity for water. There are Many biological stents, vaccines, anticancer medications, and wound dressings rely on gelatin. To improve its mechanical qualities, gelatin must be mixed with other polymers seed coaxial electrospinning to create hydrophilic and biocompatible nanofibrous membranes filled with Epigallocatechin-3-O-gallate (EGCG). Gelatin was also added to make the membranes more flexible. The wound dressing was found to be biocompatible, antibacterial, antioxidant, and capable of promoting wound closure, according to the results.[35] Developed composite dressings with chondroitin sulphate and coaxial nanofibers by combining gelatin and poly-caprolactone. They set up a pig skin burn model to see how two different nano-fibres affected the healing process.[35] Nanofibers with a core-shell design were more effective in stimulating cell growth and achieving regulated drug release than those with a polycaprolactone/gelatin blend. A great deal of exudate is generated as burn wounds heal, and this might impede the healing process. In response to this issue, used electrospinning to create an asymmetric wettable fibre membrane.[36] Hydrophilic gelatin and ginsenoside Rg1 made up the inner layer, whereas poly(lactic-glycolic) acid and black phosphorus grafted chitosan made up the outside layer (Fig. 6). The inner hydrophilic layer, which is similar to the dermis of human skin, may both eliminate excess wound exudate and provide a moist environment for the wound.[37]

4.1.3 Fibrin from silk

The silkworm cocoon is the source of the natural macromolecular fibrin known as silk fibroin (SF).[38] When it comes to biocompatibility, non-toxicity, biodegradability, resistance, and thermal stability, SF is head and shoulders above other synthetic and natural polymers. Times Furthermore, SF is commonly combined with other polymers to enhance the mechanical characteristics of nanofibers, and it exhibits outstanding toughness on its own. Wound dressings incorporating cationic antimicrobial peptides were developed by Khosravimelal using CS/SF electrospun nanofibers.[39] The antibacterial action of nanofiber dressings can be enhanced when cationic antimicrobial peptide and chitosan are combined. Evidence from the stress-strain curve clearly shows that SF can strengthen chitosan's lacking mechanical characteristics. Nanofiber wound dressings were prepared by Mollaghadimi using SF and PCL; allicin was added to enhance the antibacterial characteristics total Electrospun nanofibers were created by. by the combination of antibiotics, polyvinyl alcohol, and silk fibroin. The efficacy of nanofiber dressing as a wound treatment was evaluated using a rat burn model. The findings demonstrated that the dressing not only enhanced fibroblast cell adhesion and vitality, but also exhibited remarkable antibacterial properties. SF eliminates infections by coming into touch with the wound and releasing antibiotics. The biodegradability of silk fibroin and the rate of drug release are the primary indicators of the activity of silk fibroin/polyvinyl alcohol nanofiber dressings.[4]

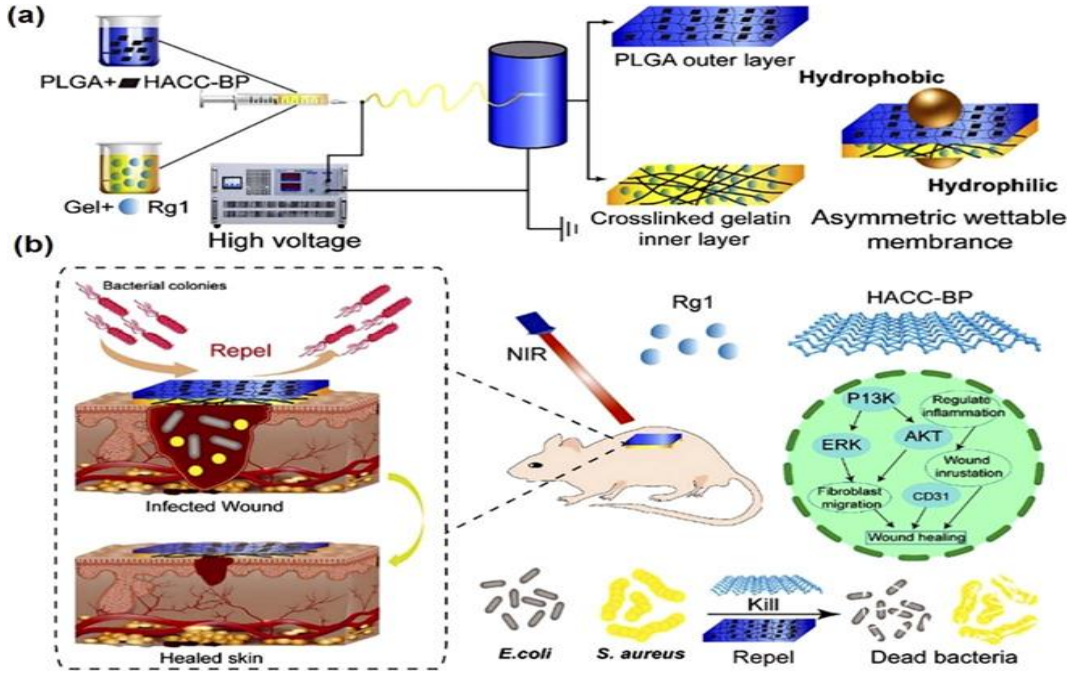

Fig. 6 (a) Preparation process of the asymmetric wettable membrane. (b) The antibacterial and wound healing properties of asymmetric wettable film. with permission from Wiley, copyright 2022.

4.1.4 Sodium alginate:

Brown algae are a natural source of sodium alginate, a poly- saccharide polymer. Biomedical applications have shown a lot of interest in it due to its non-toxicity, antioxidation, biocompatibility, and biodegradability.[41] Because of its poor mechanical characteristics, the sodium alginate polymer requires the addition of additional polymers in order to retain its structural integrity. Guo et al. developed a number of nanofibers burn dressings using PU, HACC, and SA as its framework.[42] While interacting with the cationic HACC to lessen its cytotoxicity, the naturally occurring anionic polysaccharide SA collects wound exudate and keeps the area wet. Nanofibers containing SA greatly enhanced keratinocyte and fibroblast migration and proliferation, according to cellular studies. In their study, detailed a multilayer nanofiber film consisting of tetracycline hydrochloride-loaded nanofibers in the middle layer and electrospun nanofiber films made of poly (ethylene oxide) and sodium alginate on the top and bottom, respectively. Cell attachment and proliferation are facilitated by the multilayer nanofiber membrane's regular organization structure and many vacancies. The antimicrobial and drug-controlled release properties of the fibre membrane were particularly noteworthy. The release time exceeded 10 days. The release of bioactive compounds and reduction of proinflammatory factor expression by sodium alginate offers promising results for the treatment of burns.[42-43]

4.2 Synthetic Polymers

Poly(3-caprolactone).

FDA-approved for use in biomedicine, poly(3-caprolactone) (PCL) is a hydrophobic synthetic polymer that is safe, non-toxic, and biodegradable.[44] It has been widely employed as a raw material for the production of electrospun nanofibers because of its superior mechanical qualities and biocompatibility. However, the PCL-derived electrospun nanofibers lack hydrophilia, which might not be ideal for cell attachment and proliferation. To increase hydrophilicity, PCL needs to be combined with other hydrophilic polymers or medications.[45]Rutin and quercetin-loaded synthetic chitosanoligosaccharide/polycaprolactone nanofiber membranes.[46] The authors provided evidence to support their claim that adding chitosan oligosaccharides to PCL improves the hydrophilicity of nanofiber membranes and provides a moist milieu conducive to wound healing. According to experimental results, the produced nanofiber membrane shown strong antibacterial, hydrophilic, and antioxidant properties and may improve wound healing. By combining hydrophilic cellulose acetate with PCL, created kiwi-fruit extract (KE) loaded nanofibers and examined their capacity to promote burn wound healing.[47] In the test of wound healing effect for more than 21 days, PCL/CA/KE nanofiber dressing had a better effect than KE. In addition, PCL/CA/KE effectively promoted the proliferation of fibroblasts.[44] Prepared electrospun nanofiber mats using PCL and a-lactalbumin (ALA). The wettability and mechanical properties of nanofiber wound dressings were improved by adjusting the mass ratio of ALA to PCL. The results proved that the prepared nanofibers had a significant effect on promoting wound healing and reducing scar.[45]

4.2.2 Poly (vinyl alcohol)

One type of synthetic polymer that exhibits semi-crystalline characteristics is polyvinyl alcohol, or PVA. [46] Hydrogels, films, scaffolds, and nanofibers are just a few examples of the medical biomaterials that make advantage of its exceptional hydrophilicity, biocompatibility, and biodegradability. I am the electrospun nanofiber mats were created by Morais et al. by combining nystatin, green propolis extract, CS, and PVA.[47] Wound exudates may be more effectively absorbed by the biodegradable nanofiber mat thanks to the enhanced water absorption and swelling capacity made possible by the combination of PVA and CS. created molybdenum nanoparticle-doped PVA nanofiber scaffolds. The experimental findings demonstrated that the nanofiber scaffold exhibited remarkable biocompatibility and was compatible with red blood cells. With a diameter greater than 7 mm, the bacteriostatic circle demonstrated superior antibacterial activity. Polyvinyl alcohol nanofibers combined with metal nanoparticles have been shown to enhance cell development, according to their research.[46,47]

4.2.3 Polyethylene oxide.

Poly (ethylene oxide) (PEO) is a kind of synthetic polymer, which shows excellent biocom- partibility, biodegradability, and water solubility.[47] Used PEO, PCL, and silver sulfadiazine to prepare nanofibers with core–shell structure.[48] PEO mixed with silver sulfadiazine as the core layer (Fig. 7A(a)). The prepared core–shell nanofibers showed sudden drug release in the initial stage (Fig. 7A(c)). This is because PEO tends to absorb water and expand, resulting in the release of drugs too quickly. With the gradual degradation of the core layer, the release curve gradually tended to be stable, and the long-term sustained release of silver sulfadiazine was realized. Used CS and PEO to prepare nanofiber burn dressings loaded with ZnO nanoparticles (Fig. 7B). Because it was too difficult to spin with a single CS solution, the author added PEO to improve the spinnability of the CS solution. The results showed that the prepared nanofibers had good anti- bacterial activity, biocompatibility, and stability.[49]

4.2.4 Poly (vinyl pyrrolidone

One type of synthetic polymer that exhibits semi-crystalline characteristics is polyvinyl alcohol, or PVA.[50] Hydrogels, films, scaffolds, and nanofibers are just a few examples of the medical biomaterials that make advantage of its exceptional hydrophilicity, biocompatibility, and biodegradability.[51] The electrospun nanofiber mats were created by Morais et al. by combining nystatin, green propolis extract, CS, and PVA.[51] Wound exudates may be more effectively absorbed by the biodegradable nanofiber mat thanks to the enhanced water absorption and swelling capacity made possible by the combination of PVA and CS. Ramkumar et al. created molybdenum nanoparticle-doped PVA nanofiber scaffolds. The experimental findings demonstrated that the nanofiber scaffold exhibited remarkable biocompatibility and was compatible with red blood cells. With a diameter greater than[7] mm, the bacteriostatic circle demonstrated superior antibacterial activity. Polyvinyl alcohol nanofibers combined with metal nanoparticles have been shown to enhance cell development, according to their research.[52]

4.2.5 Polyurethane

The biomedical profession has made extensive use of polyurethane because of its high tensile strength and remarkable biocompatibility.[52] Figure 7C shows the composite nanofiber dressings that Guo et al. made using polyurethane and marine polysaccharides, which were loaded with ginsenoside Rg3. As seen in Figure 7C(c) and (d) fibroblast and keratinocyte development was markedly enhanced by this composite dressing. The composite nanofiber dressing significantly improved burn wound healing after 21 days of therapy in a rat model with third-degree burns. Composite dressings outperform traditional dressings in several respects, including wound healing potential.Acid polylactic. Polylactic acid (PLA) is a polyester polymer made from lactic acid, which has several promising applications in tissue engineering and medication administration due to its high biodegradability and excellent biocompatibility. Using chitosan and polylactic acid, Liu et al. created biodegradable nanofiber dressings that were loaded with astragal side IV.[53] Nanofiber dressings made of a combination of hydrophobic polylactic acid and hydrophilic chitosan can withstand the penetration of foreign aqueous solutions while gradually absorbing wound exudate. The antibacterial efficacy of the produced dressings mostly originates from the synergistic impact of astragal side IV and chitosan, while PLA has limited antimicrobial activity on its own. They were able to demonstrate that their wound dressing was both safe and effective in promoting wound healing and inhibiting the growth of germs.[54]

4.2.6 Polylactic acid.

Polylactic acid (PLA) is a polyester polymer made from lactic acid, which has several promising applications in tissue engineering and medication administration due to its high biodegradability and excellent biocompatibility. Using chitosan and polylactic acid, Liu et al. created biodegradable nanofiber dressings that were loaded with astragal side IV.[134] Nanofiber dressings made of a combination of hydrophobic polylactic acid and hydrophilic chitosan can withstand the penetration of foreign aqueous solutions while gradually absorbing wound exudate. The antibacterial efficacy of the produced dressings mostly originates from the synergistic impact of astragal side IV and chitosan, while PLA has limited antimicrobial activity on its own. They were able to demonstrate that their wound dressing was both safe and effective in promoting wound healing and inhibiting the growth of germs.[55]

5. DRUGS LOADED IN ELECTROSPUN NANOFIBER BURN DRESSINGS

In order to enhance the performance of nanofiber burn dressings, various therapeutic and antimicrobial agents are incorporated into the nanofibers, including plant extracts, small molecule drugs, and nanoparticles. Table-2 Classification of nanofiber-loaded drugs according to their biological effects. These compounds have different functional performances, *e.g.*, accelerating wound healing, antibacterial, preventing scar formation, and multi-function. They can be loaded into the nanofibers alone, but can also be encapsulated jointly for a synergistic effect.[56]

Table 2 Bioactive compounds loaded on electrospun nanofiber dressings

Biological effect	Bioactive compounds
Accelerate wound healing	Curcumin
	Ginsenoside Rg1
	Kiwi extract
	Bromelain
Antibacterial	Allicin
	Berberis lycium extract
	Gymnema sylvestre extract
	Silver sulfadiazine
	Zinc oxide
Reduce scar formation	a-Lactalbumin
	Ginsenoside Rg3
Multifunction	Quercetin/rutin
	Lavender essential oil
	Astragaloside IV

5.1 Accelerate wound healing

5.1.1 Curcumin.

Turmeric is a perennial herb widely used in Asia. Curcumin is the main bioactive component of turmeric, which has many properties, such as anti-inflammation, anti- oxidation and anti-infection. Persistent bacterial infection in the process of wound healing will cause long-term chronic inflammation, which will seriously affect the speed of wound healing. Curcumin, a natural active ingredient, can reduce wound inflammation by decreasing pro-inflammatory factors expression. Using PCL/CS as shell, zein (ZE) and curcumin (CUR) as core. Prepared PCL/CS graft copolymer-zein- curcumin (PCL/CS-ZE-CUR) electrospun nanofibers. In the antibacterial experiment, the total infection rate of the traditional dressing group decreased by 13.8%, while the new nanofiber dressing group decreased by 78.2%, which proved the antibacterial activity of the new nanofiber dressing. Judging from the healing of the burn wound, PCL/CS-ZE-CUR electro- spun nanofiber dressing had a better therapeutic effect than traditional dressing. Curcumin's excellent ability of anti- inflammation and scavenging oxygen free radicals can accelerate wound healing and is expected to provide beneficial improvements for wound management.[56,57]

5.1.2 Ginsenoside Rg1.

Ginsenoside Rg1 is a kind of pro- to panaxatriol saponin extracted from traditional Chinese medicine Ginseng, which has anti-inflammatory, antioxidant, and neuroprotective activities. produced a double- layer structure electrospun asymmetric fiber membrane containing ginsenoside Rg1.*In vitro*, cytotoxicity tests showed that ginsenoside Rg1 could promote the migration of human umbilical's vein endothelial cells and the formation of capillaries (Fig. 8A(b)). The experimental results *in vivo* showed that the fiber membrane could regulate inflammatory factors and growth factors, and it also achieved anti-inflammation and promoted collagen deposition (Fig. 8A(d)). The prepared asymmetric wettable membrane inhibits pro-inflammatory factors by enhancing the expression of anti-inflammatory factors, promotes macrophage M2 polarization, and inhibits macrophage M1 polarization. This also explains why the wound dressing they prepared can accelerate wound healing (Fig. 8A(c)).[57,58]

5.1.3 Kiwi extract.

Kiwi extract (KE) contains a variety of bioactive components, such as phenols, vitamins C and E, which are considered to have anti-aging, anti-inflammatory, and antioxidant effects. Prepared nanofibers containing polycaprolactone, cellulose acetate (CA), and kiwi- fruit extract (PCL/CA/KE). PCL/CA/KE nanofibers have 30% higher water absorption than PCL/CA. The results of cell experiment *in vitro* showed that PCL/CA/KE nanofibers had no cytotoxicity and effectively promoted the proliferation and attachment of fibroblasts. The authors used a mouse burn model to test the ability of nanofiber membranes to promote wound healing. After 21 days, the ability of PCL/CA/KE to promote burn wound healing was significantly higher

than burn wound healing. Bromelain's that in the control group. The completion of the epithelialization process and the significant reduction of inflammatory cells better prove that PCL/CA/KE nanofiber is an effective dressing to promote Pineapple is a tropical fruit loved by people around the world. Bromelain, which is extracted from the stems, leaves, and fruit of the pineapple plant, also has great appeal. Research shows that bromelain has anti-inflammatory, antioxidant, immunomodulatory, cardioprotective, and anti-cancer proper- ties.[58] In addition, bromelain is widely used in the food industry, cosmetics, and pharmaceutical industries due to its unique pharmacological and chemical properties. Combined the therapeutic properties of bromelain and ZnO nanoparticles with the structural properties of silk fibroin to prepare a wound dressing with antibacterial properties. The results of antibacterial experiments showed that bromelain did not affect the antibacterial activity of excipients, and it was ZnO nanoparticles that made the dressing have antibacterial activity. However, compared with pure silk fibroin nanofibers, bromelain can accelerate the removal of necrotic tissue to promote wound re-epithelialization.

5.2 Antibacterial

5.2.1 Allicin.

Garlic contains a thiosulfate called allicin. Among the many health benefits of allicin are its antibacterial, cholesterol-lowering, blood pressure-lowering, and anti-tumor activity. According to certain studies, allicin redoxes with glutathione and protein mercaptan groups, which is crucial for allicin's biological action.[59] The concentration of allicin can be controlled to inhibit or kill any kind of bacteria, fungus, or cell. Molla-ghadimi created nanofiber wound dressings by mixing allicin into PCL and SF. Expanding the antibacterial activity of nanofibers is the role of allicin. The inhibitory zone diameter of bacterial growth was measured in the antibacterial test. The allicin-containing nanofiber's inhibitory band expanded to more than 3 mm when compared to the blank sample, suggesting a strong antibacterial activity.[60]

5.2.3 Berberis lycium extract.

Phenols, alkaloids, and other bioactive substances found in Berberis lyceum have been shown to have anti-inflammatory, antibacterial, and antioxidant properties. A polyvinyl alcohol/montmorillonite electrospun nanofiber made from Berberis lycium root extract was disclosed by Khan.[56, 60] According to experimental findings, the nanofibers containing 0.8 g of the extract had the strongest antibacterial activity. And the inhibitory effect on *Pseudomonas aeruginosa* was better than that of *Staphylococcus aureus*. Compared with the control group, the wound treated with nanofibers with extract showed the best healing effect and reduced inflammation. Because the extract has anti-inflammatory and antibacterial activity, it quickly enters the stage of cell proliferation after a short period of inflammation.[61]

5.2.3 Gymnema sylvestre

is a slow-growing medicinal wooded plant with effective anti- obesity and anti-diabetes actions.[62] Additionally, the extract has antibacterial, anti-inflammatory, anti-high cholesterol, and anti-sugar properties. The coaxial nanofibers using minocycline hydrochloride in the shell layer and G. sylvestre extract in the core layer.[63] Gram-positive bacteria clearly benefit from the extract's and minocycline hydrochloride's combination action, which improves the permeability of the bacterial cell wall {Fig. 8B(a)}. Compared to the untreated control group, the treated core-shell nanofiber mats effectively accelerated the wound's healing process {Fig. 8B (b) and (c)}.

5.2.4 Silver sulfadiazine.

The silver ions released from silver sulfadiazine are an effective antibacterial agent that can eliminate a variety of bacteria including Gram-positive and Gram-negative bacteria. Dressings containing silver sulfadiazine are often chosen for burn wound management.[64] Singh et al. prepared core–shell nanofibers loaded with silver sulfa- diazine using PEO and PCL. When the concentration of silver sulfadiazine is greater than 5 mg ml−1, bacterial growth will be completely inhibited {Fig. 8C (a)}. The results showed that the core–shell nanofibers loaded with silver sulfadiazine had higher cell proliferation ability and no toxicity to cell growth {Fig. 8C (b)}. Compared with the control group, there was no obvious inflammation in the wound images of the nanofiber group {Fig. 8C(c)}.[65]

5.2.5 Zinc oxide

The tremendous development of nano- technology has led to a wide range of applications of metal and its oxide nanoparticles in the fields of biology, medicine, chemistry and environment. Among the many metals and its oxide nanoparticles, zinc oxide nanoparticles have attracted attention for their many distinctive properties. In the biomedical field, zinc oxide nanoparticles exhibit excellent anticancer, antibacterial, and antioxidant properties, as well as the potential to promote wound healing. A hyaluronic acid-silk fibroin core–shell nanofiber dressing with ZnO encapsulated in the core layer was designed for burn treatment by Hadisi.[66] The results showed that the addition of ZnO improved the antimicrobial properties of the nanofiber dressing, which inhibited both Escherichia coli and Staphylococcus aureus, with an antimicrobial effect of more than 14 days. Although high concentration of ZnO will have better antibacterial effect, it will also be toxic to the cells. In vitro and in vivo studies have shown that 3 wt% ZnO promotes cell proliferation, collagen deposition, and effectively improves burn wound healing. ZnO nano- particles possess significant antimicrobial properties and are not prone to the

problem of bacterial resistance, and thus can be used as a viable alternative to antibiotics.[67]

5.3 Reduce scar formation

5.3.1 Alpha-lactalbumin (ALA)

is an acidic small molecule globular protein found in mammalian whey.[68] Its main function is to promote the synthesis of lactose in the mammary gland. The abundant tryptophan in a-lactalbumin is an important precursor for the synthesis of the neurotransmitter serotonin. Serotonin can promote the proliferation and migration of fibroblasts and keratinocytes, thereby promoting wound healing. Guo et al. explored the role of ALA in accelerating burn wound healing and reducing scar formation by synthesizing electrospun nanofiber pads of a-lactalbumin and polycaprolactone. The results showed that the wound treated with ALA/PCL dressing showed higher collagen deposition and collagen fibers were more mature than other groups. Studies have shown that mature collagen fibers can promote extracellular matrix reconstruction and skin tissue growth. Compared with the control group, myofibroblasts were significantly reduced in the ALA/PCL nanofiber mat group. In addition, on day 12 after treatment, collagen I had a higher expression level than collagen III. All of the above results can prove that ALA/PCL nanofiber pads can significantly promote wound healing and reduce scars.

5.3.2 Ginsenoside Rg3. 20(R)

ginsenoside Rg3 is a tetracyclic triterpene saponin present in red ginseng and has a wide range of pharmacological activities, such as cardiovascular regulation, antioxidant and anti-cancer.[61] An experiment by Tang et al. showed that ginsenoside Rg3 could significantly reduce the expression of interleukin-6 (IL-6), connective tissue growth factor (CTGF), tumor necrosis factor a (a-TNF) and a- smooth muscle actin (a-SMA), and enhance the expression of anti-fibrosis genes such as transforming growth factor-b (TGF- b).Thus, reducing the production of collagen and the accumulation of extracellular matrix. Guo et al. prepared composite nanofibers blended with polyurethane and marine poly- saccharides loaded with ginsenoside Rg3 and tested their ability to inhibit scar formation. The results confirmed that the nanofiber dressing loaded with ginsenoside Rg3 can effectively adjust the ratio of type I collagen and type III collagen to inhibit the formation of wound scars. The composite nanofiber dressing has great advantages in promoting burn skin healing and inhibiting scar formation.[68-70]

5.4 Multifunction

5.4.1 Quercetin/rutin.

Quercetin is a bioactive substance produced by the hydrolysis of rutin, and it is also the most studied flavonoid. Studies have shown that quercetin/rutin can remove oxidizing substances produced by inflammation and promote wound healing.[70-72] Zhou et al. reported a new nanofiber membrane composed of polycaprolactone, chitosan oligosaccharide, and quercetin/rutin.[73] The antioxidant experiment showed that quercetin/rutin had a certain oxygen-free radical scavenging ability. The antibacterial activity of nano- fiber membrane was studied with Staphylococcus aureus and Escherichia coli. The results showed that the inhibitory effect of the nanofiber membrane on Staphylococcus aureus was better than that of Escherichia coli. This result may be due to the unique outer membrane structure of E. coli that blocks the infiltration of external drug molecules. All in all, this new type of nanofiber membrane has good antibacterial and antioxidant activity but also has a certain hydrophilic ability, so it is an ideal burn dressing.[62]Lavender essential oil. Lavender has a long history of use, and its essential oil shows excellent pharmacological properties, which has attracted special attention.[62] Lavender essential oil is considered to be one of the most commonly used over-the-counter herbs for the treatment of mental disorders, anxiety, and depression.[63] Studies have shown that lavender essential oil can enhance the activity of proteins involved in wound tissue remodeling and accelerate wound contraction.[73-74] Sofi et al. prepared polyurethane electrospun nanofibers loaded with lavender essential oil and silver nanoparticles simultaneously. Lavender essential oil improves the hydrophilicity of polyurethane rice fiber, provides an environment similar to the extracellular matrix for cell proliferation, and improves the vitality of fibroblasts. The results of antibacterial activity showed that lavender essential oil and silver nanoparticles had significant synergistic antibacterial effects. All in all, lavender essential oil has potential therapeutic value for burn wound healing, and it has great potential in the preparation of wound dressings. Astragal side IV is one of the important bioactive substances in the traditional Chinese medicine plant Astragalus membranous, which has been proven to have the properties of anti-inflammation, anti- oxidation, anti-cancer, anti-hypertension, and anti- fibrosis. Astragaloside IV can inhibit oxidative stress and extracellular matrix deposition.[75] During the wound healing process,

5.4.2 Astragaloside IV:

Promotes wound healing and reduces scar formation by reducing collagen deposition and reducing the expression of inflammation. Zhang et al. prepared silk fibroin/gelatin electrospun nanofibers loaded with Astragalo- side IV and tested their effect on wound treatment.[64] The results showed that the ratio of I/III collagen in the nanofiber dressing group loaded with Astragaloside IV was close to that of normal skin, which decreased the expression level of a-smooth muscle actin and inhibited scar formation. Silk fibroin/gelatin nanofiber dressings loaded with Astragaloside also accelerate wound healing by promoting angiogenesis, increasing the number of wound macrophages, and improving local anti- inflammation.

6. CONCLUSIONS AND PERSPECTIVES

Burns are an uncontrollable accident that can have a major impact on a patient's physical and mental well-being. Nanofiber dressings are frequently used to treat burn wounds. Because it is inexpensive and easy to use, electrospinning is frequently utilized to create nanofibers.[76] Because of their distinct structure and physicochemical characteristics, electrospun nanofibers exhibit significant promise in accelerating wound healing. First, the common types of electrospun nanofibers are introduced in this review.[63] Blending electrospinning, emulsion electrospinning, coaxial electrospinning, side-by-side electrospinning, and triaxial electrospinning are developments in electrospinning technology. Among these, core-shell nanofibers have the ability to regulate medication release rates and provide continuous, long-term drug delivery. Second, both synthetic and natural polymers that are utilized to electrospin nanofibers are evaluated. Natural polymers, which are typically derived from plants or animals, have the potential to encourage skin regeneration because they are biocompatible and resemble natural tissue matrix. Nevertheless, natural polymers have poor film-forming qualities and must be blended with other polymers to improve them. To enhance the overall characteristics of electrospun nanofibers, researchers typically select natural and synthetic polymers with robust mechanical qualities. Lastly, this research presents the bioactive materials encased in nanofiber dressings. By incorporating antibiotics, natural active ingredients, and nanoparticles, nanofibers exhibit biological activity that can both prevent bacterial infection and hasten wound healing.[77] The use of electrospun nanofibers in burn wound dressings still faces numerous obstacles.[78] Chronic inflammation and microbial infection will affect how quickly wounds heal. Choosing the right dressing is crucial given the intricacy of the burn wound healing process. At the moment, many are worried about whether nanofiber dressings can prevent scarring in addition to its antibacterial qualities and ability to speed wound healing. Researchers try to make nanofiber dressings more useful by using a variety of materials, however numerous clinical trials are still required to prove the safety and efficacy of nanofiber dressings.[79]

Nanofibers are becoming more and more popular in biomedicine, and they have a wide range of potential uses in wound care. The application of nanofiber dressings to clinical burns is mentioned in passing in this review. To increase the therapeutic impact and lower the cost, it will be necessary to further develop nanofiber fabrication methods and find other bioactive chemicals in the future. Since wound dressing is a specialized applied field, advancements in electrospinning technologies and their combinations with other traditional chemical and physical procedures, such as electro spraying, is always welcome.[80]

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