

EMERGING TRENDS IN ELECTROSPUN POLYMERIC NANOFIBERS FOR CLINICAL WOUND MANAGEMENT

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Abstract

Chronic and non-healing wounds remain a major global healthcare challenge due to rising infection rates, treatment costs, and the growing prevalence of conditions such as diabetes. Conventional wound dressings often fail to provide adequate antibacterial protection, controlled drug delivery, and support for tissue regeneration. Recent advancements in nanotechnology, particularly electrospinning, have enabled the development of nanofibrous scaffolds that closely mimic the extracellular matrix, promoting enhanced cell proliferation, vascularization, and faster tissue repair for effective wound management, offering improved healing outcomes, reduced scarring, and enhanced tissue engineering potential while addressing the evolving demands of modern healthcare systems.

Keywords: *Electrospinning technology, Nanofibrous wound dressings, biopolymers, scaffold development.*

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1. INTRODUCTION

The largest organ in the body, the skin serves as a barrier to keeping off many kinds of harm. The epidermis and dermis are two layers. [1,2] The skin is exposed to a variety of biological and chemical substances, which can cause several skin disorders, including inflammation, allergies, and symptoms associated with cancer. Hemostasis, inflammation, proliferation, and remodeling are the four primary phases of wound healing, which is a complex and dynamic process of tissue regeneration. In the past, materials for wound dressings included plant fibers, animal fats, and honey pastes the goal is to restore the wound as aesthetically as possible while also achieving the highest healing rate.

2. WOUND AND WOUND HEALING PROCESS

An injury or rip on the skin's surface caused by mechanical, chemical, thermal, or other damage is called a wound. Acute and chronic wounds are the two categories of wounds based on wound healing processes. Traumas result in acute wounds, which typically recover in eight to twelve weeks. Chronic wounds are injuries caused by certain conditions, such as diabetes, malignancies, and serious physiological contaminations. Recurrence of the wounds is not

unusual, and healing of these wounds may take longer than 12 weeks [3]

PROCESS OF WOUND HEALING

Hemostasis, inflammation, proliferation, and regeneration are the four phases of the healing process

2.1 Hemostasis Phase

Collagen initiates internal and extrinsic coagulation cascades to halt the early bleeding during the hemostasis phase following skin injury. To reduce blood loss, thrombocytopenia aggregates and produces vasoconstriction, To facilitate cell communication synergy and aid in wound healing, several growth factors and cytokines are also released into the wound during this phase [4].

2.2 Inflammatory Phase

The immune system is protected from bacterial contamination by the inflammatory phase, which also eliminates microorganisms that have entered the wound after injury. A few hours after the lesion arises, pro-inflammatory cytokines such as interferon gamma (IFN- γ), tumor necrosis factor-alpha (TNF- α), and IL-1 activate endothelial cells in the blood capillary walls, which allow many neutrophils to transmigrate. [5].

2.2 Proliferative Phase

Neovascularization and re-epithelialization occur during this stage. It could take many weeks to finish that process. Neovascularization is influenced by

angiogenesis, which creates new blood vessels FGF, TGF- β , and VEGF also help the EC's integrin-mediated attachment to the extracellular matrix (ECM) and promote healing.

2.3 Remodelling Phase

The final stage in twisted recovery is redesigning, which restores the solid tissue's fundamental collagen organization., which would encourage wound contraction, lessen epithelialization, and avoid scarring [6].

3. ELECTROSPINNING NANOFIBRE TECHNOLOGY

Using an electromagnetic force on a polymer solution or molten polymer, the process of electrospinning creates incredibly thin threads. The three primary elements of electrospinning are a grounded conductive collector, a needle or spinneret, and a high-voltage electrical source Electrospinning has been widely employed to create nanofibrous materials that can be used as wound dressings since it is a simple process, provides a wide variety of material options, and is reasonably priced. By altering the physical and chemical properties of dressings, we can create highly customized dressings for wound healing applications. Electrospinning is a great and highly effective method for producing polymeric nanofibers.

3.1 Natural Polymer

Natural polymers are widely used in regenerative medicine for wound and burn dressings because they are structurally similar to the extracellular matrix, biodegradable, and biocompatible.[7]

3.2 Chitosan

It's amazing how well bandages made of chitosan can heal wounds. However, chitosan's low mechanical strength is the main obstacle to its use in wound healing.

3.3 Cellulose

Cellulose is a biopolymer made from glucose that is widely used by many businesses. Cellulose is found in both plants and bacteria, however because of its high purity and lack of byproducts, bacterial cellulose is preferred for industrial application.

3.4 Alginate

Alginate, an anionic polymer composed of β -D-mannuronic acid and β -L-guluronic acid, is found in brown sea algae. These dressings promote wound healing by exchanging ions such as salt and calcium [8]

3.5 Dextran

Dextran, a natural polymer, stands out for its notable wound healing and antimicrobial properties. Its ability to form films, hydrogels, or nanofiber enhances its utility in advanced wound dressings.

3.6 Agarose

A naturally occurring polymer, agarose, has antibacterial, anti-inflammatory, and wound-healing qualities in addition to the ability to create nanofibers. its anti-inflammatory qualities help regulate the immune system while wounds heal [9]

4. ELECTROSPINNING NANOFIBRE AND THEIR USE PRODUCTION OF WOUND DRESSING PRODUCTS

Formhals received a patent for his first invention, a device that used electricity to produce synthetic fibers, in 1934 Several polymers that are electro spun are shown in Compared to dressings made using traditional techniques, the materials used in electrospinning technology offer unique features. The following are these attributes:

- Hemostasis: The hemostasis phase can be aided by nanofibrous wound dressings due to their small pores and large effective surface area.
- Absorbability: The nanofibers' high surface area to volume ratio allows them to absorb 17.9–213% of water, compared to 2.3% for conventional film dressings.
- Semi-permeability: A nanofiber dressing's porous shape allows cells to breathe well, preventing the wound from drying out. Electro spun nanofibrous membrane wound dressings may also satisfy the need for high gas permeation [10].

5. ELECTROSPUN NANOFIBERS IN WOUND DRESSING

Electro spun nanofibers exhibit exceptional qualities in accelerating the healing of wounds. Their microstructure closely resembles the extracellular matrix (ECM) of the human body, which promotes cell adhesion, growth, and proliferation Furthermore, loading and conveying bioactive components like medications and growth hormones is facilitated by the vast surface area. Thus, the best option for wound dressings is electro spun nanofiber materials.

5.1 Polymer In Electrospun Wound Dressing

Nowadays, drug carriers can be successfully prepared by electrospinning hundreds of different polymers. Both natural and synthetic polymers have been extensively employed in related studies on electrospinning wound dressings. Simply put,

5.1.1 Natural Polymer

Natural polymers are widely used in electro spun wound dressings because of their non-toxic, biocompatible, and biodegradable qualities, particularly their inherent antibacterial qualities

- Gelatin, a naturally occurring protein biopolymer, is often pale-yellow transparent granules or flakes that are produced by hydrolyzing a portion of collagen.
- Silk fibroin (SF), a protein with a complicated structure, has been utilized as a sewing and textile material

5.1.2 Synthetic Polymer

More synthetic polymer types are used in electrospinning than natural polymers, these polymers are frequently employed as carrier materials for electrospinning wound dressings because of their superior mechanical, thermal, and spinnability qualities. Vinylpyrrolidone (NVP) is the monomer from which

polyvinylpyrrolidone It currently has a wide range of applications in wound dressings and prosthetic joints [11]

5.2 Bioactive Ingredients in Electrospun Wound Dressing

Antibiotic medications (ciprofloxacin (CIP), curcumin, metronidazole, tetracycline, gentamicin, and diclofenac), inorganic nanoparticles (nano silver particles, AgNP), zinc oxide, titanium dioxide (TiO₂), cerium oxide (CeO₂), natural materials (honey, essential oils, chitosan),

5.3 In Situ Electrospinning in Wound Dressing

In situ electrospinning can better cover wounds and is more comfortable and convenient to use than regular electrospinning. It is evident that the produced Zein/CEO nanofiber membrane facilitates wound healing in the mouse wound model.[12] The findings show that the membrane performs well in terms of breathability, water resistance, and antibacterial activity.

5.4 Application of Electrospinning Technology in Other Field

The benefits of electrospinning have garnered more interest in recent years. The use of electrospinning nanofibers has expanded due to the ongoing research of associated academics. It is essential to environmental protection (air filtration, water treatment), the energy and chemical industries (light-emitting devices, solar cells, and supercapacitor), biomedicine (drug delivery tissue engineering [13] and wound dressings),

6. ROLE OF MACROMOLECULES IMPERGNATED ELECTROSPUN NANOFIBERS A VERSATILE DRUG DELIVERY SYSTEM PARADIGM FOR WOUND HEALING

Electro spun nanofibers' superior biological properties make them highly promising for the treatment of wound healing. Nanofibers' architecture is like that of the human extracellular matrix (ECM), Since the mechanistic insight of nanofibers in wound healing effectively contributes to the air permeability and supports appropriate nutrient and oxygen exchange for cell respiration, the percentage of porosity of nanofiber mats directly affects the models of wound dressings. Therefore, using nanofibers to treat wounds may improve the potential for tissue repair, re-epithelialization, and vascularization in both acute and chronic wounds.

6.1 PROTEINS [PLANT AND ANIMAL DERIVED] LOADED NANOFIBERS

In conjunction with natural polymers, plant proteins like soy, zein, and pea proteins have been utilized to create electro spun nanofibers. Polymers include polycaprolactone (PCL), polyvinyl alcohol (PVA), and polyethylene glycol (PEO). Because of the nanofibrous polymeric matrix, soy protein-based electro spun nanofibers provide improved access to nutrients and oxygen

6.2 Drug Loaded Nanofibers

Nanofibers filled with drugs are useful in biomedical applications. For diabetic wound healing applications, nanofibrous mats are treated with gentamicin and recombinant human epidermal growth factors. The outcomes clearly show that the scaffold used to treat burn wounds can repair wounds.

6.3 Bioactive Molecules Loaded Nanofibers

Natural bioactive compounds or herbal extracts can be impregnated into electro spun nanofibers to create nanofibrous mats or models of wound dressings that promote wound healing. which is thought to be the most significant growth factor in tissue regeneration settings and in simulating fibroblast cell proliferation and migration, can be combined with aloe vera extract

7. APPLICATIONS

7.1 Biomedical Application of Electrospun Nanofibers

- Tissue engineering
- Vascular tissue engineering

7.2 Therapeutic Application of Different Macromolecule Nanofibre for Skin Tissue Regeneration and Restoration.

A developing multidisciplinary method that links chemical, biological, and engineering sciences to skin/tissue regeneration strategy is the role of tissue engineering in wound healing applications. To preserve or improve tissue functioning, tissue engineering concepts use growth factors, biomaterials, and living cells either separately or in combination.

8. CLINICAL RELEVANCE AND FUTURE PERSPECTIVES

Traditional folk medicine has found many herbs with proven wound-healing qualities, but wound healing is a complicated process. Crude plant extracts or isolated secondary metabolites have been employed in vitro research to further investigate their potential for wound healing in recent years. High porosity, variable fiber shape, surface function, and a very high specific surface area are all features of electro spun fiber material

9. CONCLUSION

New and important information regarding acute wounds and their healing phases was covered in the current review. Acute and chronic wounds are the two categories taken into consideration while classifying wounds. Physical, chemical, and thermal factors are involved in acute wounds, whereas some disorders, including diabetes, are the primary cause of chronic wounds. The five stages of wound healing-hemostasis, inflammation, migration, proliferation, and remodelling-were described. New advancements in this field have also been brought about by technological advancements. High porosity, variable fiber shape, surface function wound, and a very high specific surface area are all features of electro spun fiber material.

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11. AUTHOR CONTRIBUTIONS

All authors are contributed equally.

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The authors have no conflicts of interest to declare.

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15. REFERENCES

- Mahmoudi N, Eslahi N, Mehdipour A, Mohammadi M, Akbari M, Samadikuchaksaraei A, Simchi A. Temporary skin grafts based on hybrid graphene oxide-natural biopolymer nanofibers as effective wound healing substitutes: pre-clinical and pathological studies in animal models. *J Mater Sci Mater Med*. 2017;28(5):73. doi:10.1007/s10856-017-5874-y.
- Tottoli EM, Dorati R, Genta I, Chiesa E, Pisani S, Conti B. Skin wound healing process and new emerging technologies for skin wound care and regeneration. *Pharmaceutics*. 2020;12(8):735. doi:10.3390/pharmaceutics12080735.
- Moore K, McCallion R, Searle RJ, Stacey MC, Harding KG. Prediction and monitoring the therapeutic response of chronic dermal wounds. *Int Wound J*. 2006;3(2):89-98. doi:10.1111/j.1742-4801.2006.00212.x.
- Barrientos S, Stojadinovic O, Golinko MS, Brem H, Tomic-Canic M. Growth factors and cytokines in wound healing. *Wound Repair Regen*. 2008;16(5):585-601. doi:10.1111/j.1524-475X.2008.00410.x.
- Okur ME, Karantas ID, Şenyiğit Z, Okur NÜ, Siafaka PI. Recent trends on wound management: new therapeutic choices based on polymeric carriers. *Asian J Pharm Sci*. 2020;15(6):661-684. doi:10.1016/j.ajps.2019.11.008.
- Huang C, Xu X, Fu J, Yu DG, Liu Y. Recent progress in electrospun polyacrylonitrile nanofiber-based wound dressing. *Polymers (Basel)*. 2022;14(16):3266. doi:10.3390/polym14163266.
- Sarvani V, Elisha RP, Nama S, Pola LM, Rao CB. Process validation: an essential process in pharmaceutical industry. *Int J Med Chem Anal*. 2013;3(2):49-52.
- Zarrintaj P, Manouchehri S, Ahmadi Z, Saeb MR, Urbanska AM, Kaplan DL, Mozafari M. Agarose-based biomaterials for tissue engineering. *Carbohydr Polym*. 2018;187:66-84. doi:10.1016/j.carbpol.2018.01.060.
- Tan GZ, Zhou Y. Electrospinning of biomimetic fibrous scaffolds for tissue engineering: a review. *Int J Polym Mater Polym Biomater*. 2020;69(15):947-960. doi:10.1080/00914037.2019.1636248.
- Gindi S, Methra T, Chandu BR, Boyina R, Dasari V. Antiuro lithiatic and in vitro anti-oxidant activity of leaves of *Ageratum conyzoides* in rat. *World J Pharm Pharm Sci*. 2013;2:636-649.
- Nama S, Chandu BR, Awen BZ, Khagga M. Development and validation of a new RP-HPLC method for the determination of aprepitant in solid dosage forms. *Trop J Pharm Res*. 2011;10(4):489-495.
- Kiranmai M, Renuka P, Brahmaiah B, Chandu BR. Vitamin D as a promising anticancer agent. *Int J Res Pharm Chem*. 2012;2(2):636-649.
- Degapati RT. Novel approaches in transdermal drug delivery system. *J Multidiscip Res*. 2025;5(1):20-25.