

Electrospun Polymeric Mats loaded with antimicrobial compounds for wound healing

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I. INTRODUCTION

Wound healing is a controlled biological process, restoring the structural and functional integrity of damaged tissues, due to injury.

Acute wounds generally heal through molecular events.

However, Chronic wounds such as ulcers and burnt parts do not progress at normal healing stages.

Electrospinning has emerged as nanotechnology based fabrication techniques for producing ultrafiltrate polymeric fibres.

Traditional wound healing methods lag biological functions

Bioactive agents provide sustained antimicrobial activity

Considerable research has focused on developing advanced wound dressings capable of actively participating in the healing process.

It has desirable characteristics from high surface area to volume ratio, interconnected porosity

Electrospinning has emerged as one of the most promising nanotechnology-based fabrication techniques for producing ultrafine polymeric fibers that closely resemble the architecture of the native extracellular matrix (ECM). Electrospun polymeric mats possess desirable characteristics including high surface area-to-volume ratio, interconnected porosity, excellent oxygen permeability, and tunable mechanical properties. These structural features promote cell adhesion, proliferation, migration, and nutrient exchange, making electrospun nanofibers highly suitable as wound dressing materials.

II. WOUND HEALING PROCESS

2.1 Hemostasis

It is immediately initiated following tissue injury.

Blood vessel damage triggers vasoconstriction.

Activated platelets release numerous signalling molecules including PDGF, TGF-beta, Epidermal Growth factor and VEGF.

Activation of coagulation cascade provides a scaffold for an incoming inflammatory cell.

2.2 Inflammatory Phase

It begins within hours after injury and typically lasts several days

Neutrophils recruit to woundside, where they eliminate microorganisms through phagocytosis

Macrophages are the dominant immune cells

Macrophages promote tissue repair by releasing anti-inflammatory cytokines.

2.3 Proliferative Phase:

It occurs between 3 and 14 days post injury

Fibroblasts migrate into wound and synthesize ECM proteins,

Angiogenesis restores oxygen and nutrient supply through formation of new blood vessels

Angiogenesis migrate across wound surface to re establish the epidermal barrier

Myofibroblasts reduce wound size and facilitate tissue closure

2.4 Remodeling Phase:

Successful wound healing requires precise regulation of inflammation, angiogenesis, collagen deposition, and extracellular matrix remodeling. Disruption of any of these events may result in chronic wounds or excessive scar formation.

Matrix metalloproteinases (MMPs) regulate extracellular matrix remodeling by degrading excess collagen and facilitating proper tissue organization.

Although healed tissue regains significant mechanical

strength, it doesn't achieve the strength of uninjured skin.

III. WOUND INFECTION AND ANTIMICROBIAL RESISTANCE

Microbial infection is one of the factors delaying the wound healing

Open wounds provide a favorable environment to bacteria infections.

One of the greatest challenges in wound management is biofilm formation. Biofilms are highly organized microbial communities embedded within a self-produced extracellular polymeric matrix that firmly adheres to wound surfaces. Biofilms protect bacteria from host immune responses and significantly reduce the effectiveness of antibiotics by limiting drug penetration and promoting bacterial dormancy. Consequently, biofilm-associated infections often become persistent and difficult to eradicate

The excessive and inappropriate use of antibiotics has accelerated the emergence of antimicrobial resistance (AMR), posing a major global public health concern. Resistant pathogens such as MRSA and multidrug-resistant *P. aeruginosa* have become increasingly prevalent in chronic wound infections. These bacteria employ multiple resistance mechanisms including enzymatic antibiotic degradation, alteration of drug targets, activation of efflux pumps, and reduced membrane permeability.

Localized antimicrobial delivery through electrospun polymeric mats offers several advantages over conventional systemic antibiotic therapy. By delivering antimicrobial agents directly to the wound site, higher local drug concentrations can be achieved while minimizing systemic toxicity and reducing the risk of antibiotic resistance development. Furthermore, incorporating multiple antimicrobial agents or combining antibiotics with metal nanoparticles and natural bioactive compounds may produce synergistic antimicrobial effects against resistant bacteria and biofilms.

IV. ELECTROSPINNING TECHNOLOGY

It is used to fabricate continuous polymeric fibres with diameters from micrometres to nanometres

The apparatus contains four components:

(i) High Voltage power supply

(ii) A Syringe

(iii) Syringe Pump

(iv) Grounded collector

A Polymer solution is pumped through the needle while a high electric field is applied between a needle tip and collector.

Electrostatic forces overcome the surface tension of polymer solution, resulting in a charged polymer jet is ejected towards a collector.

Fiber Morphology and diameter are influenced by polymer concentration, molecular weight, viscosity, electrical conductivity and needle-to-collector distance.

Chitosan, Collagen, Gelatin, Silk Fibronin, and Alginate, as well as synthetic polymers successfully electrospun into wound dressings.

Hybrid polymer systems combine the excellent biocompatibility of natural polymers with superior mechanical strength and processing of synthetic polymers

Different electrospinning techniques are deployed to improve drug loading and controlled release.

Electrospun polymeric mats possess characteristics desirable for wound healing, including high porosity, interconnected pore networks and efficient gas exchange.

V. ADVANCES AND CHALLENGES

(i) Advances:

- Small electrospun mats stimuli responsive fibres can provide controlled antimicrobial release, with respect to wound conditions.
- Coaxial electrospinning enables core-shell fibres for better drug protection
- Multifunctional dressing can combine antimicrobial, anti-inflammatory, anti-oxidant and tissue regeneration.
- Silver, zinc oxide, and other nanoparticles provide broad-spectrum antimicrobial activity
- Plant extracts, essential oils, and antimicrobial peptides alters towards antibiotics
- Multilayered structures improve mechanical properties, drug delivery and tissue integration

(ii) Challenges

- Difficulties in producing uniform nanofibrous mats on a large scale

- During fabrication, antimicrobial compound may lose activity
- High concentrations of nanoparticles cause cytotoxicity
- Sterilization alters antimicrobial activity
- Wrong usage of antimicrobial results in resistance
- Before clinical use, Clinical trials and standardization must be required

VI. CONCLUSION

It represents a polymeric approach for advanced wound management.

Polymeric Mats have high surface area, porosity, ECM-like architecture and ability to incorporate therapeutic agents for both infection control and tissue regeneration.

The incorporation of antibiotics, nanoparticles, antimicrobial peptides and natural bioactive compounds can provide localized antimicrobial activity and controlled release.

Despite challenges, continued research in electrospinning and biomaterials engineering is expected to improve the performance of these wound dressings.

Overall, anti-microbial loaded electrospun polymeric mats have considered potential as next-generation wound dressings for treating infected and chronic wounds.