Methods of Electrospun Nanofibers Design for Wound Dressing Applications

A Scientific Literature Review (2022)

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1 Introduction

There are four stages to skin wound recovery: inflammation, proliferation, maturation, and remodeling [1]. The field of wound dressing design has been primarily focused on allowing the first phase, inflammation, to occur without bacterial infection. Ideal candidates for wound dressings may even facilitate the relevant cells to arrive on the scene. The dressing must be porous to allow for comfortable wear, but also have swelling capabilities to absorb wound exudate, which is fluid that comes from the injury site due to inflammation.

2 Main Content

The following sections will introduce three designs of nanofibrous mat and the ways in which they were modified for enhanced properties or capabilities. Scanning Electron Microscopy (SEM) images of all three final nanofiber mats are shown in Figures 1-3 below.

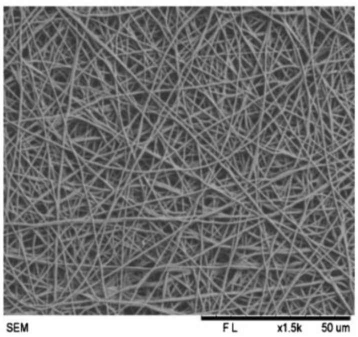

Figure 1: Polyurethane (PU) nanofibrous mat with ginger extract from [1].

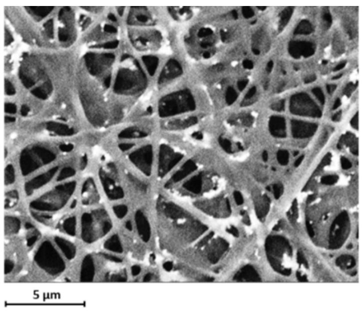

Figure 2: P(3HB)/P(3HO-co-3HD) nanofibrous mat dip-coated in silver nanoparticles from [2].

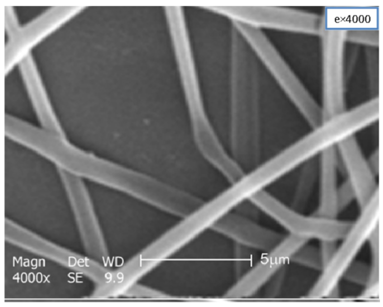

Figure 3: Poly(vinyl alcohol) /poly(vinyl acetate) nanofibrous mat loaded with ciprofloxacin HCl from [3].

2.1 Electrospinning Nanofibers

The nanofibrous mats designed in this field are primarily synthesized using a technique called electrospinning, which can importantly produce porous materials. Electrospinning is a fiber manufacturing process that uses a high-voltage electric field to overcome the surface tension of solution in a syringe and shoot the solution out toward a grounded collector. Often times, the collector is wrapped in foil so that the foil can be removed and laid out to dry until the fibers can be collected. The needle is typically placed a distance away from the grounded collector on the order of 10cm. This method can produce flexible and porous fibers, ideal for body-contact wound dressing applications.

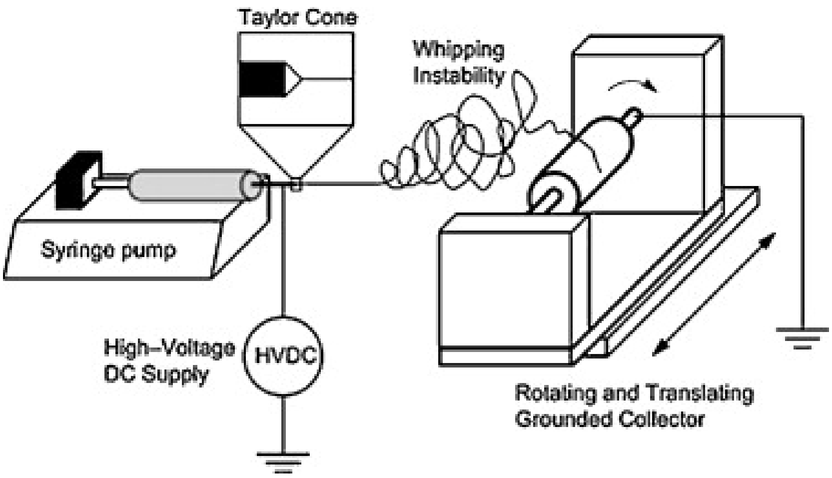

Figure 4: A common horizontal electrospinning set up for electrospinnning nanofibers. This image is taken directly from [4].

The solutions covered in this review are polyurethane (PU) and P(3HB)/P(3HO-co-3HD) solutes in dimethylformamide (DMF) solvent [1] [3] and PVA-PVAc solvent in aqueous acetic acid solution diluted with distilled water [5].

2.2 Treatment for Higher Biocompatibility

One approach that researchers have taken to improve the portfolio of wound dressings available is by adding ginger extract, a natural material. [1] prepared a pure polyethlene (PU) solution (9 wt%) and a ginger solution (4wt %) of 120mL of ginger extract in 3 mL DMF. The final solution was made by stirring the two solutions in a ratio of 8:1 (v/v). After being spun into a PU/ginger extract nanofibrous mat, the sample was tested in a coagulation assay, a test of blood changing from liquid to semi-solid state, and determined to have decreased blood clotting time compared to a control sample of pure PU. Similarly, in a hemolytic assay where the sample was co-incubated with red blood cells, the hemolytic index was determined to be 0.96%, lower than benchmark of 2% that is recommended for biocompatability by [2].

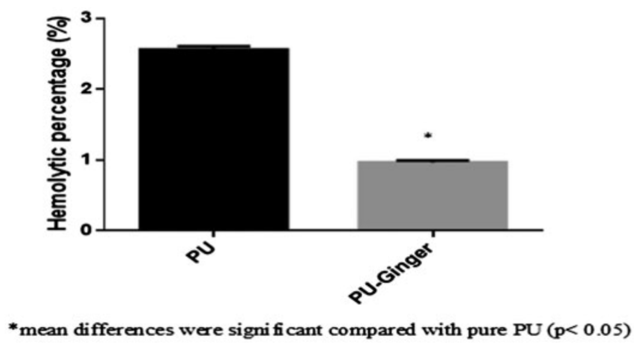

Figure 5: This figure is directly from [1] and shows the effectiveness of adding ginger to the PU base: the hemolytic index has been lowered siginificantly.

2.3 Treatment for Enhanced Wound Recovery Rate

Another route has been to consider the body's natural immune response cells from the beginning of the solution-creation stage. [3] chose biocompatible and elastomeric poly(3-hydroxybutyrate) (P(3HB)) (prone to fiber fusion during the electrospinning process) mixed with brittle poly(3-hydroxyoctanoate-co-3-hydroxy decanoate) (P(3HO-co-3HD)) in a ratio of 1/3 (w/w). The combined effect is a balance between elastic and brittle behavior.

[3] explains their choice of silver nanoparticle (AgNP) coatings by describing metals' antimicrobial and anti-inflammatory properties and silver nanoparticles' low toxicity, specifically. Experimenting with several ways of dip-coating AgNP, the researchers determined that quickly dipping and immediately removing the P(3HB)/P(3HO-co-3HD) nanofibers from AgNP solution three times resulted in the most uniform fibers.

The result of the silver dip-coated mat vs the control composite mat was a well-timed up-then-down regulation of proinflmmatory cytokines, which are important proteins necessary for cell signaling during the body's initial response to wounds: inflammation. The promotion of cytokines called TNF-α calls on flammatory cells that help form plateletes to reduce bacterial invasion and infection processes. Essentially, the body's natural response works in tandem with the wound dressing at a cell-level, shown graphically as data below in Figure 6. The resulting nanofibrous mat is biodegradable, flexible, and porous.

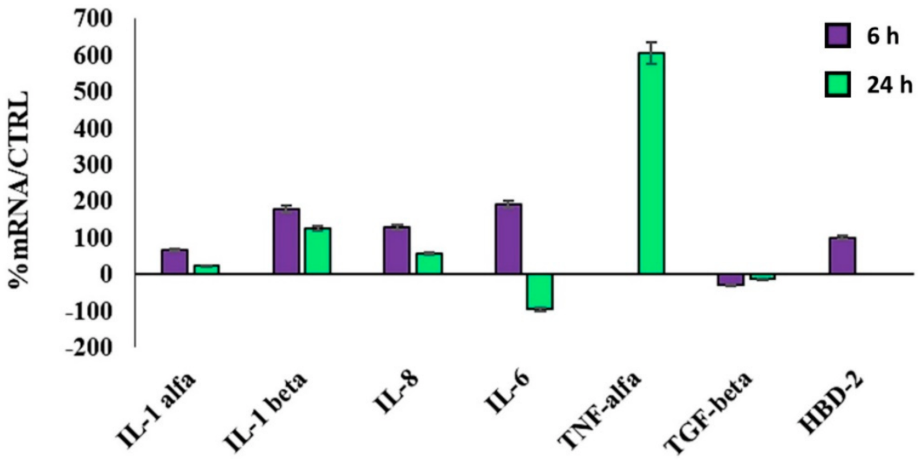

Figure 6: This figure is directly from [3] and shows the influence of the prototype wound dressing on key proinflammatory cytokines' presence surrounding the wound.

2.4 Treatment for Effective Controlled Drug Release

The last approach covered in this review is more dynamic and involves loading a poly(vinyl alcohol)/poly(vinyl acetate) (PVA/PVAc) nanofibrous mat with ciprofloxacin Hcl (CipHCl). The composite mat materials were chosen for the two components' contrasting hydrophyllic (PVA) and hypophyllic (PVAc) characteristics that work together as a two-phase initial (PVA) and sustained (PVAc) release system. The time scales of this biphasic drug are ideal for eliminating bacteria before they profilerate soon after the wound forms, then preventing further proliferation if infected during the following week.

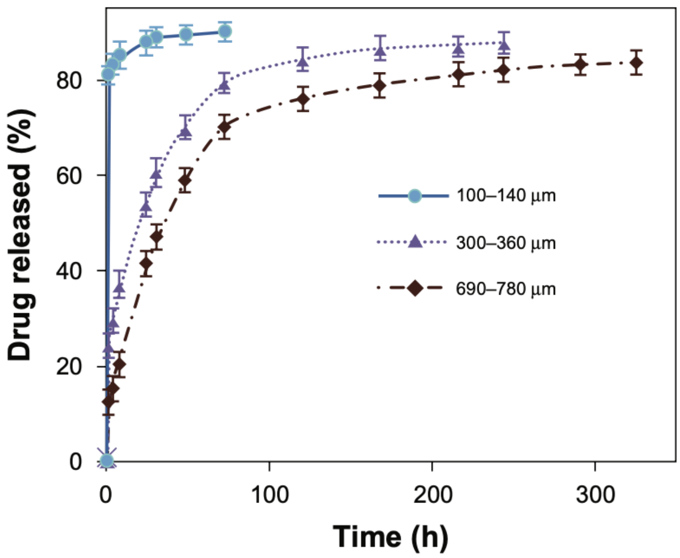

Figure 7: This figure is directly from [5] and illustrates the initial jump in drug released, then gradual increase of the CipHCl-loaded PVA/PVAc mats for varying fiber thicknesses.

3 Conclusion

Main factors that influenced the final behaviors of each of the nanofibrous mats included the ratio of component polymers [3], the thickness of the mats [5], and pore diameters [1]. Future work could involve combining multiple approaches, discovering more biodegradable composites, or using other metal coatings, such as copper, gold, ZnO, CuO and TiO as mentioned in [3]. Whatever the additional functions of the nanofibrous mats may be, electrospinning appears to be the most favorable and effective method for producing a base material to work from.

References

[1] M. Mani, S. Jaganthan, and A. Ismail, "Appraisal of electrospun textile scaffold comprising polyurethane decorated with ginger nanofibers for wound healing applications," *Journal of Industrial Textiles*, vol. 49, no. 5, pp. 648–662, 2019.

[2] A. Manikandan, M. Mani, S. Jaganathan, *et al.*, "Formation of functional nanofibrous electrospun polyurethane and murivenna oil with improved haemocompatibility for wound healing," *Polymer Testing*, pp. 106–113, 2017.

[3] O. I. Kalaoglu-Altan, "Silver nanoparticle-coated polyhydroxyalkanoate based electrospun fibers for wound dressing applications," *Materials*, vol. 14, 2021.

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[5] M. Jannesari, J. Varshosaz, M. Morshed, and M. Zamanil, "Composite poly(vinyl alcohol)/poly(vinyl acetate) electrospun nanofibrous mats as a novel wound dressing matrix for controlled release of drugs," *International Journal of Nanomedicine*, vol. 6, pp. 993–1003, 2011.