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Novel Atmospheric Plasma Enhanced Silk Fibroin Nanofiber/Gauze Composite Wound Dressings

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Abstract

In this work, Silk Fibroin (SF) nanofibers were electrospun onto plasma-treated 100% cotton gauze bandages to form a novel silk-gauze composite wound dressing. Atmospheric pressure plasma pre- and post- treatments were used to increase the adhesion between the SF nanofibers and cotton substrates. The adhesion of the nanofibers to the substrates was assessed by qualitative and quantitative techniques. Plasma pre-treatment of the substrate with 100% helium and 99% helium/1% oxygen plasmas showed up to a 50% increase in the force required to peel off the nanofiber layer. This force was further increased up to 75% after pre- as well as post-plasma treatment of the composite bandages. Plasma pre-treatment of the gauze fabric prior to nanofiber deposition and post-treatment to the composite bandages significantly reduced degradation of the nanofiber layer during repetitive flexing. Air permeability and moisture vapor transport were significantly reduced due to the presence of a nanofiber layer upon the substrate. The results of surface elemental analysis showed that the adhesion and durability increase are mainly due to the active species generated by plasma on the surface of cotton substrate as well as on the surface of the silk fibroin nanofibers.

Keywords: Wound Healing; Adhesion; Silk Fibroin; Nanofibers; Wound Dressings; Bandages; Atmospheric Pressure Plasma

1 Introduction

An ideal wound dressing should provide an environment in which healing and regeneration of tissues can take place at the fastest rate with an acceptable cosmetic appearance [1]. Traditional textile-based wound dressings are cost-effective and highly absorbent, but usually unable

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to provide optimal wound healing conditions such as hemostasis, non-adherence, maintenance of a moist wound bed, etc. [1-2]. Advanced wound dressings, which have received great research interest in recent years, often incorporate multiple non-textile components including films, hydrocolloids, calcium alginate, and foam wound dressings, that provide enhanced functionalities at a significantly higher cost [3-4]. The goal of this research is to combine the advantages of biopolymer nanofibers and traditional wound dressing fabrics to build novel composite wound dressing systems with desirable wound care abilities and mechanical properties.

Polymers based on protein are of specific interest in healthcare applications because of their biocompatibility, combined strength and toughness. Silk Fibroin (SF) is a natural protein, mainly consisting of amino acids with small side groups, such as glycine, alanine and serine. It has shown excellent biocompatibility, biodegradability [6-13], high oxygen and water permeability [14-15], desirable drug permeability [16] and effective resistance against enzymatic degradation [17] in previous studies. These properties make SF a promising material for a broad range of biomedical applications, including surgical sutures [18], skin treatments [19-20], wound dressing materials [21], cell culture substrates [13], controlled drug-delivery, cosmetics, and food additives [21-22].

In recent years, wound dressings based on nanofibers demonstrated functional versatility, including desirable wound adherence, absorption, oxygen permeability, resorbability, and occlusivity [23-25]. Nanofiber webs have high surface-area-to-volume ratios, which render them effective as filters of contaminants, particulates, and microorganisms, and as matrices for controlled drug release. It was also reported that nanofibers can assist in hemostasis [26-27] due to their small interstices and high surface areas. As compared with conventional fibers, the high specific surface area of nanofibers has been shown to increase fluid absorption by up to 213% [28]. Highly-porous nanofiber wound dressings are ideal for respiration of cells and prevent wound desiccation at the same time [29]. According to Martindale [30], electrospun wound dressings can reduce scarring and encourage normal skin growth. However, widespread applications of nanofiber webs in wound dressings have been limited by their mechanical properties and difficulty in handling [31-32].

Researchers have studied processing parameters and morphology of SF nanofibers [33-35] electrospun using hexafluoroacetone, hexafluoro-2-propanol and formic acid as solvents. SF nanofibers proved to be excellent substrates for cell growth [36]. Xia et al. [37] have tried to improve the antibacterial properties by blending SF with other materials such as titanium dioxide. DermaSilk is a commercially available sericin-free silk fabric treated with an antibacterial finish, AEGIS AEM5772/5. This product has been used in the treatment of Atopic Dermatitis [38] and demonstrated excellent antibacterial properties. The effects of O_2 and methane plasmas on cell viability and water contact angles of silk nanofiber webs have been investigated [39]. However, studies on electrospinning of SF nanofibers on gauze fabric, adhesion between nanofibers and substrate, and mechanical properties of the nanofiber webs have not been reported.

Atmospheric pressure plasma technology has been widely used to modify the structures and properties of various materials including textiles and other polymers. Previous studies in our atmospheric plasma lab have shown that plasma treatment can i) Improve surface bonding or adhesive ability [40-42], ii) Increase mechanical strength by crosslinking [41-46], iii) Change fiber surface hydrophobicity [47], iv) Roughen fiber surfaces [48], and v) Increase crystallinity [48]. Recently, Vitchuli et al. [31] successfully utilized plasma technology to increase the adhesion between nylon nanofibers and substrates. Plasma treatment proved to be able to enhance the bond between nanofiber mats and textile substrates through the pre-deposition surface activation of textile substrates, and improve the nanofiber strength and bonding through post-deposition