Journal of
Gynecology and Women's Health
ISSN 2474-7602

Juniper Publishers
key to the Researchers

Mini Review
Volume 24 Issue 2 - November 2022
DOI: 10.19080/JGWH.2022.24.556133

J Gynecol Women's Health

Use of Silk Fibroin as Wound Dressings - An Innovative Concept

Gokarneshan N* and Akshaya A

Department of Fashion Design, Hindustan Institute of Technology and Science Chennai, India

Submission: October 18, 2022; **Published:** November 08, 2022

***Corresponding author:** Gokarneshan N, Department of Fashion Design, Hindustan Institute of Technology and Science Chennai, India

Abstract

New applications for medical biotextiles have been identified with the development of nanotechnological manufacturing technologies. Combination of nanotechnology and biotextile technology has resulted into a new field called bionanotextiles. Bionanotextiles are used in many areas which include wound dressings, bandages and tissue scaffolds. Silk fibroin (SF) from the cocoon of Bombyx mori, is one of the most favourable wound dressing materials due to its unique properties including biocompatibility, permeability, biodegradability, morphologic flexibility, and proper mechanical properties. The modification of antimicrobial properties of SFs can provide a barrier for bacterial penetration as wound dressing materials. In the present study, antibacterial polyethylenimine (PEI) (10, 20 and 30% (w/w)) was blended with SF and bionanotextiles were successfully fabricated by electrospinning. In addition, silk fibroin nanofibers were also functionalized with sulphate group in order to test whether they exhibit an antibacterial activity or not. Fibroin based bionanotextiles were characterized by scanning electron microscope (SEM), Fourier transform infrared spectroscopy (ATR-FTIR), differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). The cytotoxicity evaluations were carried out by L929 fibroblasts with MTT assay. The indirect cytotoxicity results demonstrate that all fibroin and PEI/fibroin extracts have no cytotoxicity on L929 cancer cell line. PEI/fibroin bionanotextiles showed strong antibacterial activities against gram positive Staphylococcus aureus and gram negative Pseudomonas aeruginosa.

Keywords: Silk Fibroin; Polyethylenimine; Antibacterial Polymeric Blends; Bionanotextile Wound Dressing; Electrospinning

Introduction

Medical textiles are used in many areas which also include bandages, wound dressings, surgery sutures, cartilage regeneration, artificial skin, heart valves, cardiac patches and preventive clothing [1-3]. The 1990s term of the "biotextiles" was defined as "structure composed of textile fibers and designed for use in a specific biological environment (e.g. surgical implant) where its performance depends on its interaction with cells and biological fluids as measured in terms of its biocompatibility and biostability" [4]. With the development of nanotechnology, the use of fibers and textiles in medicine has dramatically increased. Recent technologies have allowed traditional functionality of textiles to be extended. Nanotechnology and material science have added smart properties (e.g. high surface area, high productivity at low cost) to new generation textiles [5]. The "bionanotextile" term is defined as biopolymeric based textile produced by nano technological manufacturing method.

Silk has been used in textile industries for centuries. The silk protein from silkworm Bombyx mori contains two fibroin proteins held together by a glue-like protein called sericin. When sericin is presented to a body, it is detected as an antigenic factor by T-cells and causes immunologic reactions. Therefore sericin is needed to be removed from the cocoon fibers by a process called degumming. These degummed B. mori silk fibers exhibit unique properties as biomaterials [6-11]. Silk fibroin (SF) is one of the most favourable wound dressing materials due to their unique properties including good biocompatibility, permeability, biodegradability, morphologic flexibility and proper mechanical properties [12].

Wound healing process is complex and involves the interactions between cells, extracellular matrix components and growth factors. Different natural polymer-based engineered wound dressings which substitute in the form of film, gel, sponges, and electrospun mats of chitosan, fibrin, elastin, gelatin, and hyaluronic acid are known to be used for wound healing stimulation [13]. The ideal wound dressing should perform following functions: Absorb excess exudates of wound, provide

thermal insulation and mechanical protections, prevent bacterial contaminations, allow gaseous and fluid exchanges, be non adherent to the wound and easily removable without irritation, provide some debridement action and be nontoxic, nonallergic, nonsensitizing, sterile and nonscaring. Open wounds are generally infected by micro-organisms such as bacteria, fungi, and viruses. The first step in infection is adherence of bacteria to wound interface [14,15]. In order to overcome this problem antibiotics, antimicrobial agents such as metallic nanoparticles have been utilized in wound healing applications.

Electrospun nanofibers with incorporated antibacterial agents such as chitosan [16,17], silver nanoparticles [18,19], zinc oxide [20,21], and chlorhexidine [22,23] have demonstrated potential use in bio-medical applications. Antibiotic-resistant bacterial infections have increased considerably in recent years. Traditional antibiotics are generally ineffective on bacterial infections. Therefore recent studies have focused on the new antimicrobial agents such as polymers, lipids and peptides. Host defense peptides have shown potential as alternatives to the currently available antibiotics. However these peptides have challenges, such as bioavailability and high product cost [24]. Wide range of metallic nanoparticles have been developed and used to modify textile fibers for their antimicrobial activity [25-27]. Recently silver nanoparticles have gained much interest because of their broad spectrum of antimicrobial activity. Incorporated silver wound textiles and catheters are used in biomedical applications [28]. Even with the wide usage of Ag nanoparticles in wound dressings, there are few reports about their cytotoxicity and genotoxicity and these reports show that Ag based cytotoxicity varies depending on the particle size [29,30]. The disadvantages of silver ion eluting systems are temporary antimicrobial activity and silver ions based cytotoxicity. To solve this problem scientists are working on nonleaching and permanent antimicrobial surfaces.

Antimicrobial synthetic polymers have gained much popularity owing to the permanent antimicrobial activity, especially the cationic compounds which are promising candidate materials for biomedical applications. PEI (polyethylenimine) is a polycationic and antimicrobial polymer [31-35]. PEI has been utilized as drug carrier in biomedical applications because of their ability to enter cells or permeabilize cell membranes [24]. On the other hand, it has been used in gene therapy applications [36,37], filtration technologies [38] and tissue engineering [39]. Electrospinning is an effective technique which can be utilized to produce useful ultrafine bio nano textiles. Due to their large surface area, bionanotextiles have received much interest in various applications such as medical textiles, filtration and drug delivery systems [40]. In comparison to conventional wound dressing materials bionanotextiles produced by electrospinning technology have advanced properties. These properties are controlled liquid evaporation, excellent oxygen permeability and prevention of bacterial infections with ultrafine pores. Porous structure of bionanotextiles absorb wound exudates efficiently and prevent wound drying up [3].

In the literature there are many studies about electrospinning of silk fibroin, but reports on electrospinning of PEI are relatively scarce. In this study, for the first time in literature, it was aimed to fabricate PEI/fibroin antibacterial bionanotextiles serving as wound dressings with stable, non-leaching antibacterial activity. For this purpose polyethylenimine (PEI) was added to silk fibroin and hydrophilic polycationic, and antibacterial composite bio nanotextiles were fabricated by electrospinning technique. On the other hand, previous studies have demonstrated that the sulfated silk fibroin has anticoagulant activity [41,42]. Highly sulfated biomolecules such as heparin are widely used as an antimicrobial agent [43]. Also in the light of this information silk fibroin nanofibers were functionalized with sulphate group in order to test their antibacterial activity.

The morphological, chemical, thermal characterizations of bionanotextiles were done by scanning electron microscopy (SEM), Fourier transform infrared (ATR-FTIR) spectroscopy, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), respectively. Moreover, cytotoxicity studies of the bionanotextiles were performed and their antibacterial activities against Pseudomonas aeruginosa and Staphylococcus aureus were evaluated.

Technical Details

The materials used include cocoons belonging to Bombyx mori species, polyethylenimine, formic acid, dialysis membrane, NaHCO3, CaCl2, glutaraldehyde, methanol, Pyridine, Dulbecco's modified Eagle's medium, fetal bovine Serum, L-glutamine, trypsin-EDTA, penicillin–streptomycin solution, MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide), S. aureus and P. aeruginosabacterium, tryptic soy agar. Regenerated silk fibroin solution has been prepared. The nano fibre has been electrospun. In order to increase the stability of the fibres, the electrospun mats have been treated by methanol and also exposed to glutaraldehyde vapour. Methanol was used as a solvent to induce the structural change from amorphous to β sheet conformation and crystallization. Methanol was used as a solvent to induce the structural change from amorphous to β sheet conformation and crystallization. The electrospun silk based bionanotextiles have been further cross linked by glutaraldehyde. Then the bionanotextiles were rinsed with MQ water [38]. Surface morphologies of bio nano textiles were observed on scanning electron microscope. ATR-FTIR analysis was performed. Thermal analysis was done with Differential scanning calorimetry (DSC), Thermogravimetric analysis. Static contact angle measurements of bio nano textiles treated with 90% (v/v) methanol and glutaraldehyde vapor cross-linked have been determined. The cytotoxicity of the bio nano textiles was evaluated. Antibacterial activity of the bio nano textiles was tested against gram-positive S. aureus and gram negative P. aeruginosa.

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

Bionanotextile Morphology

Several parameters affect the fiber morphology, polymer concentration in solution, flow rate, applied voltage, tip to collector distance, diameter of the needle, polymer/solvent dielectric constant, etc. When fibroin and sulfated fibroin polymer solutions were prepared by low concentrations (8% (w/w)) bead formation was observed (Figure 1a). In our study we found that polymer concentration is the most important parameter for forming smooth and uniform fibers. To overcome this problem fibroin concentrations were increased and optimized to 13% (w/v). Fibroin bionanotextiles had an average diameter of 246 ± 6nm (Figure 1b). All other electrospinning parameters, including the distance between the tip and collector, solution flowrate, and syringe and needle diameters were held constant (voltage: 20kV, distance: 20cm, flow rate: 0.1mL/min). Fibroin is a candidate material which offer unique properties including good biocompatibility, biodegradability, morphologic flexibility to be used as biomaterial. However, its only deficiency is the lack of antimicrobial activity. It is well known that silk fibroin has good viscosity and the addition of silk fibroin into other polymer solutions can significantly improve the spinnability of the polymers [44].

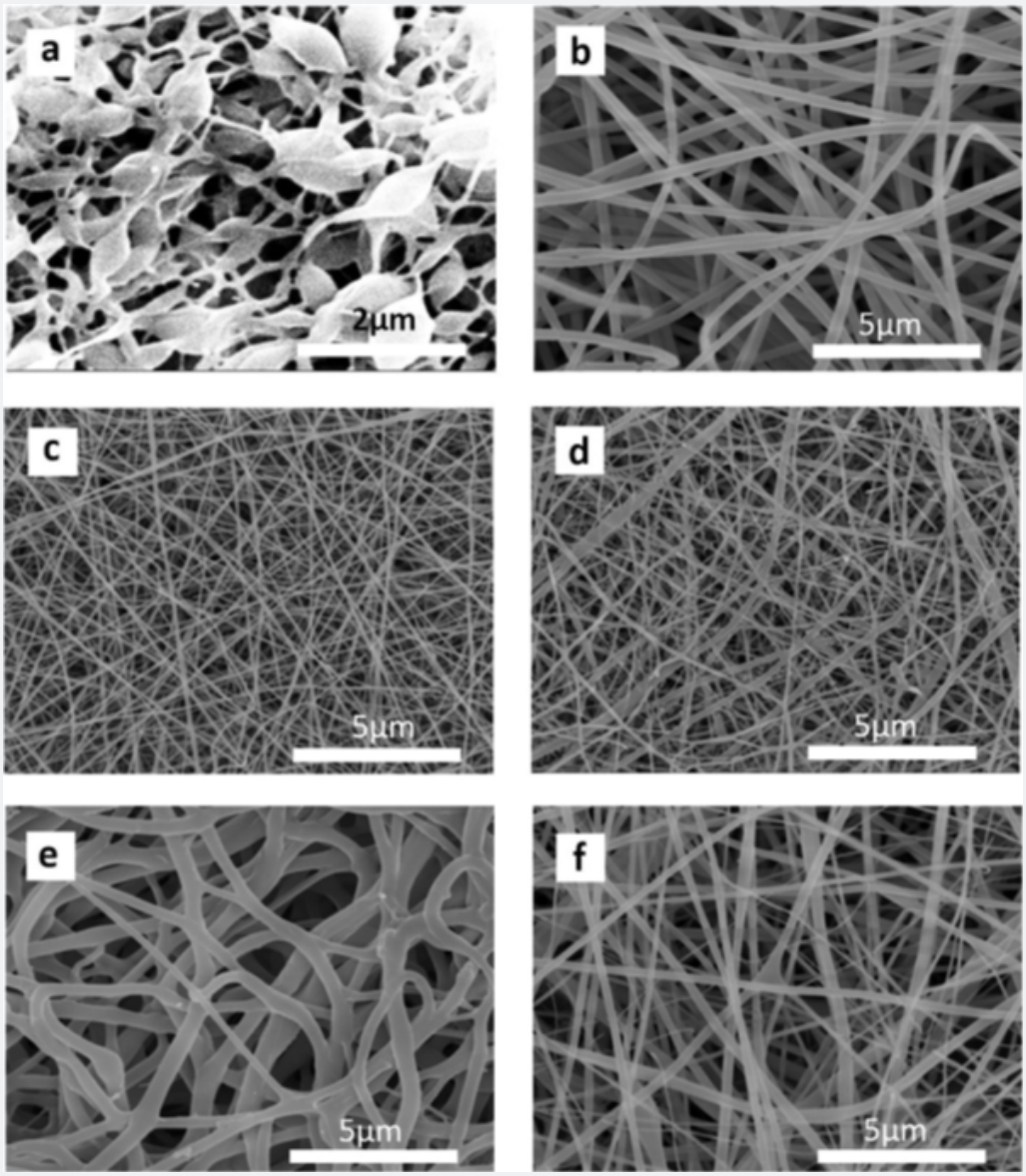

Figure 1: SEMimages of the bionanotextiles. (a) 8% (w/v) fibroin bionanotextiles with bead formation, (b) smooth and homogeneous 13% (w/v) Fib, (c) PEI10/Fib, (d) PEI20/Fib, (e) PEI30/Fib and (f) 13% (w/v) S/Fib bionanotextiles (voltage: 20 kV, distance: 20 cm, flow rate: 0.1 mL/min, magnification: 20,000×.

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

There is only one report about electrospinning of PEI in the literature [39]. In this study we mixed PEI and fibroin to improve spinnability of PEI. When we mixed PEI and fibroin at 13% (w/v) concentration beads were observed among the nanofibers. The polymer concentration is directly related to the viscosity, surface tension, and conductivity of the polymer solution. As mentioned above the polymer concentration is a critical parameter to control morphology of nanofibers [38]. To improve spinnability of polymer solutionwe increased concentration of polymer to 15% (w/v) and by this optimization we managed to overcome bead formation. All other parameters were held constant (voltage: 20 kV, distance: 20 cm, flow rate: 0.1mL/min). Different concentrations of PEI (10, 20 30% (w/w)) were added to fibroin solution and made into fibers by electrospinning without any bead formation. PEI is a cationic active polymer and it is expected that the addition of cationic charges would increase the charge density in polymer solution and result in thinner fibers compared to fibroin bionanotextiles [44]. PEI10/Fib bionanotextiles had an average fiber diameter of 144 ± 5nm and membranes showed a porous structure with smooth fiber orientation (Figure 1c). At a PEI/fibroin weight ratio of 20:80 (Figure 1d), the average fiber diameter increased to 210 ± 4nm. Following the increase in concentration of PEI to 30:70, average fiber diameter increased to 236 ± 9nm (Figure 1e). It is due to the fact that, charged polymers possesses a significantly larger atomic radius than other polymers, and consequently, higher positive charges in electrospinning solutionmay result in instabilities in the electrospinning jet [44]. High concentration of PEI in water (more than 50% w/v) might decrease the surface tension of polymer solution and significantly affect the solution viscosity. Regarding this, when the concentration of PEI was higher than 30%, bead formation was observed and average fiber diameter was increased accordingly (Figure 1).

PEI is soluble in several solvents such as ethanol, methanol, chloroform, or hot water [45]. For this reason, in this study PEI containing bionanotextiles were crosslinked with GA instead of methanol treatment. Conventional crosslinking approach of immersing polymers into aqueous GA solution is not feasible for crosslinking the present nanoscale thin bionanotextiles. At first stage PEI/fibroin bionanotextiles were exposed to glutaraldehyde vapor for 24h but results of SEM analysis show that the fiber structure has been corrupted during the vapor treatment. To determine optimum crosslinking condition, bionanotextiles were exposed to GA vapor for a timescale of 0.5, 1, 3, 6, 12 and 24h. It was found that the bionanotextiles treated in the GA vapor up to 0.5 and 1h could be totally dissolved in the 37 °C water thus, crosslinking in GA vapor for 3 h was selected to crosslink bionanotextiles. Vapor of aqueous GA (25%) solution contains water vapor. Higher GA concentration and increased cross-linking time can change morphology of bionanotextiles. After long exposure time to GA vapor, the nanofibers were swollen and flattened because of the vapor phase [38,46]. Results show that with PEI concentrations of 10, 20 30% (w/w), nanofiber diameter was increased to 175 ± 12, 350 ±8 and 392±14 respectively after 3 h of crosslinking. Average diameters of bionanotextiles with changing exposure time to glutaraldehyde vapor time have been determined, which may be attributed to the swelling of PEI/fibroin bionanotextiles in GA vapor. SEM images of the crosslinked bionanotextiles with changing time scale are shown in Figs. 2 and 3. It is well known that methanol, is highly effective in the crystallization of SF from random coil to β-sheet transition. We investigated the influence of the methanol treatment on the secondary structure of bionanotextiles by means of ATR-IR, DSC and TGA [47] (Figure 2&3).

Structural Characteristics of Bionanotextiles

ATR-FTIR measurements were implicated in order to determine the conformational changes of bionanotextiles treated with methanol and glutaraldehyde vapor. The infrared spectral region between 1700 and 1500 cm-1 usually used for the analysis of different secondary structures of silk fibroin. The peaks at 1610-1630, 1695–1700 and 1510– 1520cm−1 are characteristic of silk II, secondary structure of silk fibroin, whereas the absorption at 1648–1654 and 1535–1542 cm−1 are characteristic for silk I conformation. It is found that for the Fib and Fib-G bionanotextiles, amide I band shows one strong peak at 1651 cm−1 and amide II band shows one peak at 1534 cm−1 that is corresponded to silk I structure. The β-sheet structure is observed for samples immersed in methanol (Fib-M) with peaks at 1626 and 1518 cm−1. This result proves that bionanotextiles have silk I structure. Otherwise, cross-linked PEI/fibroin bionanotextiles (PEI10/Fib-G, PEI20/Fib-G, and PEI30/Fib-G) show silk I structure peaks at 1654 and 1535 cm−1. FT-IR spectra of sulfated fibroin showed a strong absorption at around 1200 cm−1 that is attributed to stretching vibrations of the SO2 group.

Thermal Analysis

TGA results on fibroin, PEI/fibroin and S/fibroin bionanotextiles have been determined. For all samples curves can be divided in two regions. Region I recorded to loss of water and occurs at 100 °C. The second weight loss occurs in 270-370 °C. In region II high mass loss was observed and it's related to fibroin degradation. This is associated with the breakdown of peptide bonds. It is found that the amorphous samples of silk fibroin (fibroin, PEI/fibroin-G and S/fibroin) showed faster degradation curve and lower thermal stability than other crystalline sample (fibroin-M).

The DSC thermograms of bionanotextiles have been determined. DSC thermograms of Fib and Fib-G silk fibers displayed two endothermic peaks, one at around 80 °C is due to loss of water, and another at 270 °C is attributed to the thermal degradation of amorphous bionanotextiles (Fib and Fib-G). On the other hand, Fib-M showed an endothermic peak at 280 °C without exothermic transition.

This behavior is related to β-sheet structure of sample Fib-M and consistent with IR results. DSC thermograms of cross-

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

linked PEI/fibroin bionanotextiles (PEI10/Fib-G, PEI20/Fib-G, and PEI30/Fib-G). They show similar peaks like amorphous samples (Fib and Fib-G), one of them at around 190 °C is due to glass transition (Tg) of amorphous samples and another at 272 °C is attributed to the thermal degradation of amorphous bionanotextiles. Sulfated bionanotextiles showed two endothermic peaks, one at around 80 °C is due to loss of water, and another peak at 270 °C is related to degradation of silk I structure. At the end of the experiments PEI20/Fib bionanotextiles were selected for the next steps because of their smooth and homogeneous morphology. Macroscopic images of bionanotextiles.

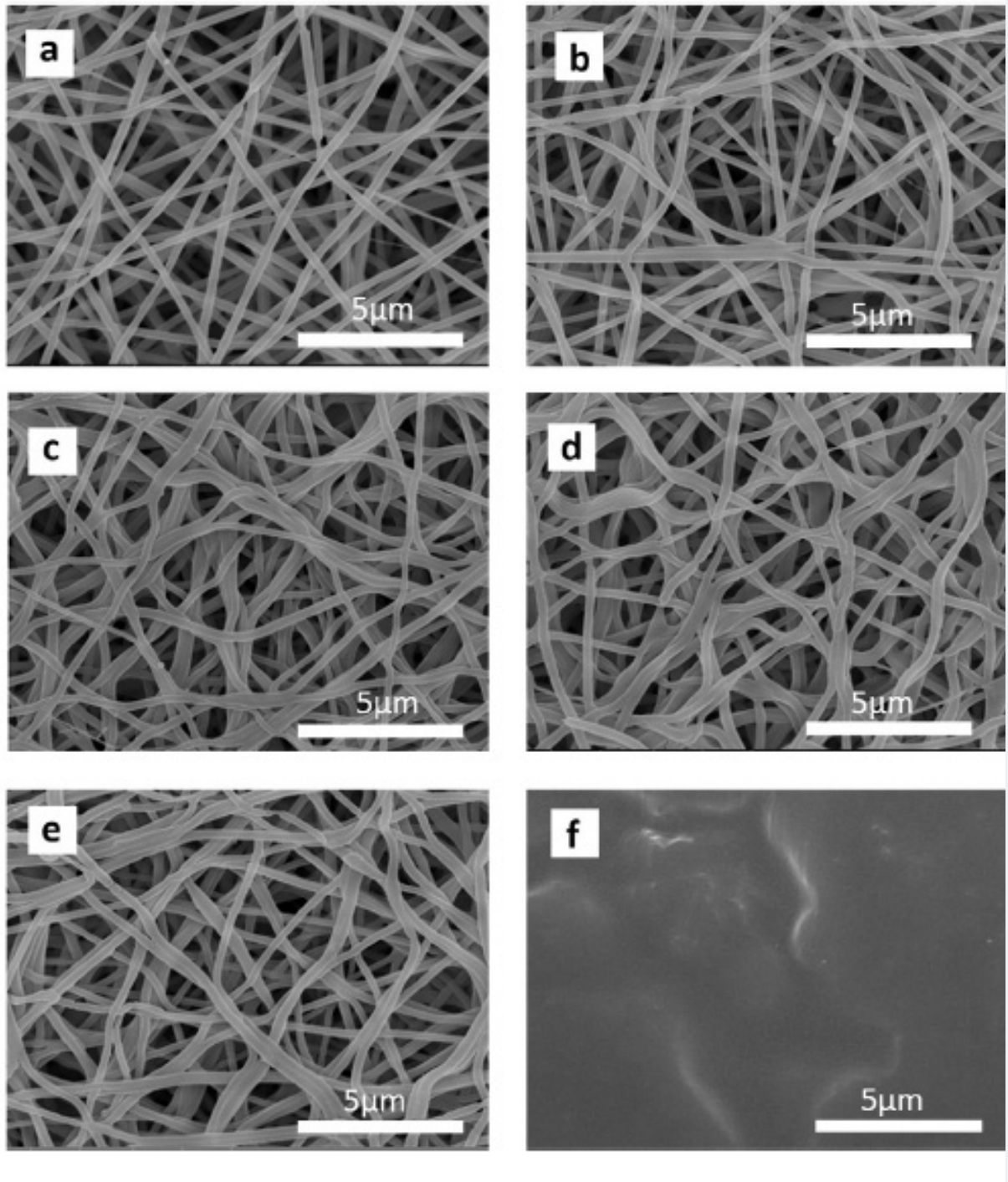

Figure 2: SEM images of 13% (w/v) Fib bionanotextiles were cross-linked in glutaraldehyde vapor for different time intervals. (a) 0.5 h, (b) 1 h, (c) 3 h, (d) 6 h, (e) 12 h and (f) 24 h (magnification: 20,000×).

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

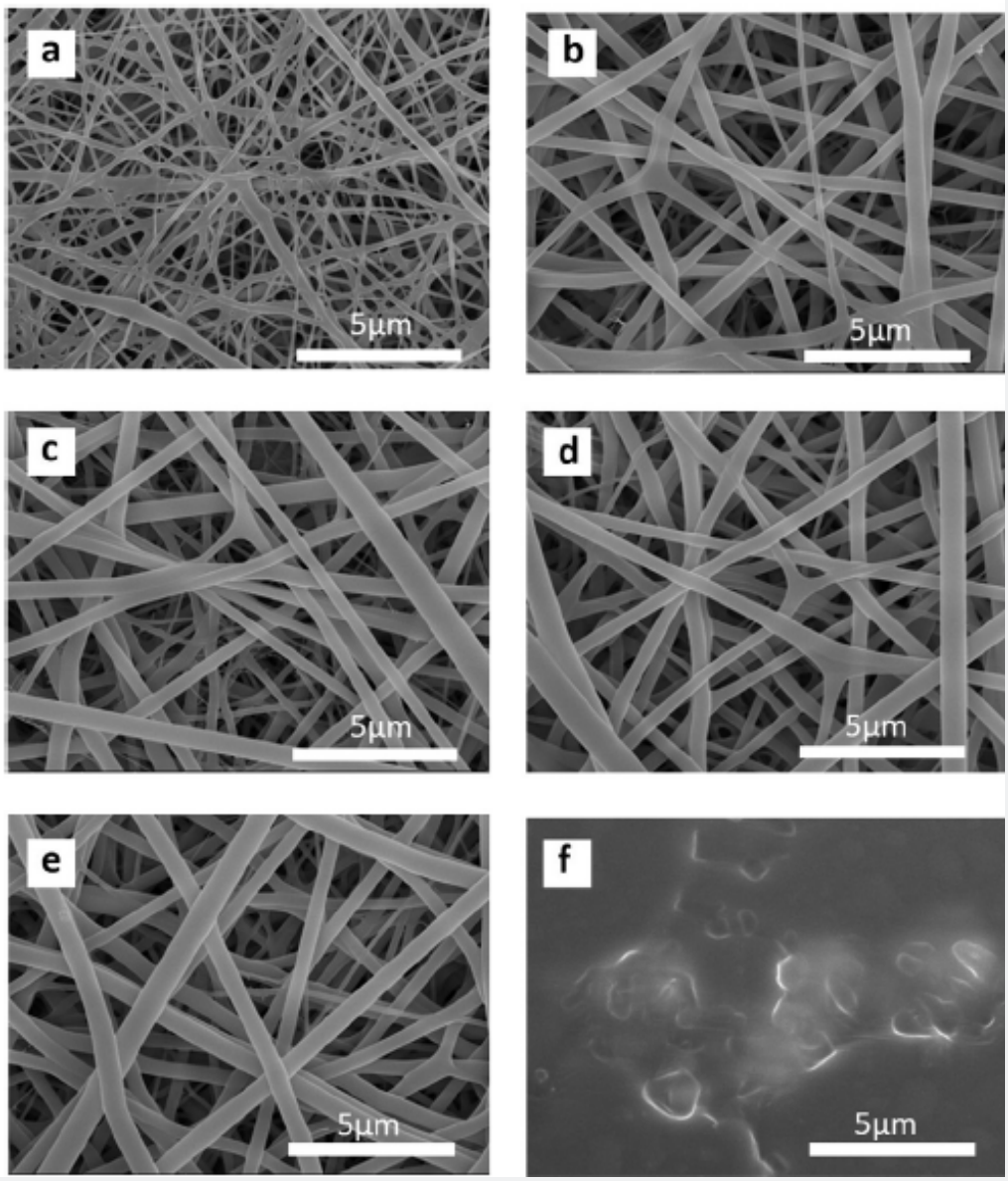

Figure 3: SEMimages of PEI20/Fib bionanotextileswere cross-linked in glutaraldehyde vapor for different time intervals. (a) 0.5 h, (b) 1 h, (c) 3 h, (d) 6 h, (e) 12 h and (f) 24 h (magnification: 20,000×).

Surface Hydrophilicity

Wetting is an important property of a wound dressing surfaces. To investigate surface properties of bionanotextiles a water droplet was placed on the bionanotextile surface and contact angle measurement was read. Measurement of water contact angle on Fib-M surface was 100 °C indicating that silk fibroin is a hydrophobic material. S/Fib-M's contact angle was measured as 54°. These results show that S/Fib is more hydrophilic than fibroin-M because of its sulfate groups [48]. On the other hand, PEI10/Fib-G, PEI20/Fib-G and PEI30/Fib-G have contact angles of 109 °C, 142 °C and 155 °C, respectively. Compared to surfaces of bionanotextiles, PEI/fibroin samples showed the highest contact angle measurement and hydrophobic property. A water droplet placed on this surface remains spherical and the reason is that glutaral dehydereacted polyethylenimine (PEI-G) is more hydrophobic cationic polymer than polyethylenimine (PEI) [49]. Hydrophobicity of methanol treated silk fibroin materials (Silk II) showed a significantly higher contact angle than non-methanol treated materials (Silk I) [50].

A number of reports indicate that primary and secondary amine groups of PEI can be modified with stearic acid and glutaraldehyde. In this reactions carboxylic groups, of these

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

molecules react with amine groups in PEI and thismodification can causewater contact angle larger than 150 °C [51]. In this study glutaraldehyde vapor was used in order to cross-link PEI and fibroin bionanotextiles. GA reacts with amine groups in PEI and fibroin and this reaction results in more hydrophobic bionanotextiles compared to other crystalline samples. Contact angle measurements have been determined.

Cell Viability

Cytotoxicity of the bionanotextiles was evaluated using MTT assay after 72h of extraction. The absorbance of the MTT crystals was read at wavelength of 570nmin a microplate reader. Cell viability was evaluated by counting percent viable cells after incubating them with bionanotextile extracts. Several researchers have reported PEI to be cytotoxic in many cells, but the molecular mechanism of its cytotoxicity hasn't been defined yet. PEI in its protonated form has been widely used as a gene delivery agent due to its high charge density from the protonated amines. Recent reports indicate that PEI based scaffolds with an excessive amount of positive charges are highly toxic in vivo while lower amounts of cationic charge are favorable [39,52]. Cell viability of PEI10/Fib and PEI20/Fib composite bionanotextiles, cross linked with GA vapor, was increased but in comparison to control group no significant difference was explicit. The reason was that PEI was positively charged and the cells were with the negative charge, and accordingly the electrostatic force between them would improve their adhesion.

At the same time, cells use amide groups as energy sources and they are also good for cell viability. On the contrary, cell growth and proliferation were decreased in the extract of PEI30/Fib membranes due to the fact that PEI30/Fib contains excessive amount of positive charges compared to others.

Antibacterial Activity

The antibacterial activity of bionanotextiles against gram-positive S. aureus and gram negative P. aeruginosa was tested by using AATCC Quantitative Test Method 100-1999 and viable cell-counting method. Antibacterial activity results have been determined. Polyethylenimine (PEI) containing materials have been widely used in biomedical applications due to their long-term antimicrobial activity with no developed resistance, minimal cytotoxicity to mammalian cells and biocidal ability for a broad spectrum of microorganisms [53]. PEI has an antimicrobial activity because of its polycationic structure and its interaction with microbialmembranes would result in their disruption due to the polycationic structure [54,55]. The results demonstrate that Fib-M bionanotextiles don't show antibacterial activity against P. aeruginosa and S. aureus. However PEI containing bionanotextiles (PEI10/Fib-G, PEI20/Fib-G and PEI30/Fib-G) show high antibacterial activity against P. aeruginosa and S. aureus. In comparison to control group it was noticed that therewas no growth on the electrospun PEI10/Fib-G, PEI20/Fib-G and PEI30/Fib-G nanofibers. The antibacterial investigations demonstrated that PEI/Fib bionanotextiles could prevent adherence of the gram-positive or gram-negative bacteria. In contrast, about S/Fib-M bionanotextile bacterial colonies decreased from 3.94 × 103 CFU/mL to 1.1 × 102 CFU/mL against P. aeruginosa and for S. aureus no antibacterial activity was observed. Results showed that growth of bacterial colonies was too much (Too Numerous To Count) for S. aureus. Briefly, antimicrobial activity of bionanotextiles indicated that PEI is an effective and non-leaching antimicrobial agent to inhibit growth of gram-positive S. aureus and gram negative P. aeruginosa, when it is mixed with silk fibroin. Bionanotextiles which were designed in this study as wound dressing material, could be handled and produced easily.

Conclusion

New generation antibacterial bio nano textiles are the most advanced and efficient wound dressing materials in comparison to other conventional materials such as sponges, hydrocolloids and hydrogels. Bio nano textiles, due to their very high surface area to volume ratio, have excellent abilities such as controlled release of therapeutic drugs, a very high increase in adherence and proliferation of cells, etc. All these characteristics have highly extended bio nano textile applications on different wounds. In this study Fib, S/Fib and PEI/Fib composite bio nano textiles were successfully generated by electrospinning and all bio nano textiles were stabilized by methanol and GA vapor treatments. Optimum crosslinking time of 3 h was accepted for glutaraldehyde vapor treatment. Changes in the structure of the silk based bio nano textiles stabilized by different post-treatment methods were analyzed by ATR-FTIR, TGA and DSC. While Fib, Fib-G, PEI10/Fib-G, PEI20/Fib-G, PEI30/Fib-G and S/Fib bio nano textiles have silk I structure (random coil), Fib-M, S/Fib-M bio nano textiles have silk II structure (β-sheet). All of ATR-FTIR, TGA and DSC data are consistent with each other. Antibacterial activity and cytotoxicity results reveal that PEI containing bio nano textiles exhibit good antibacterial properties and ability to prevent bacterial adhesion over a long period of time.

References

1. Almeida LR, Martins AR, Fernandes EM, Oliveira MB, Correlo VM, et al. (2013) New biotextiles for tissue engineering: development, characterization and in vitro cellular viability. Acta Biomater 9(9): 8167-8181.
2. Sant S, Iyer D, Gaharwar AK, Patel A, Khademhosseini A, et al. (2013) Effect of biodegradation and de novo matrix synthesis on the mechanical properties of valvular interstitial cell-seeded polyglycerol sebacate-polycaprolactone scaffolds. Acta Biomater 9(4): 5963-5973.
3. Zahedi P, Rezaeian I, Ranaei-Siadat SO, Jafari SH, Supaphol P, et al. (2010) A review on wound dressings with an emphasis on electrospun nanofibrous polymeric bandages. Polym Adv Technol 21(2): 77-95.
4. Sumanasinghe RD, King MW (2003) J Text Appar Technol Manag 3: 1-13.
5. Coyle S, Wu Y, Lau KT, De Rossi D, Wallace G, et al. (2007) Smart Nanotextiles: A Review of Materials and Applications.

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

MRS Bull 32: 434–442.

6. Altman GH, Diaz F, Jakuba C, Calabro T, Horan RL, et al. (2003) Silk-based biomaterials. Biomaterials 24(3) 401-416.
7. Vepari C, Kaplan DL (2007) Silk as a Biomaterial. Prog Polym Sci 32(8-9): 991-1007.
8. Zhang YQ, Tao ML, Shen WD, Mao JP, Chen Yh, et al. (2006) J Chem Technol Biotechnol 81: 136-145.
9. Hardy JG, Scheibel TR (2010) Composite materials based on silk proteins. Prog Polym Sci 35(9): 1093-1115.
10. Zhang YQ, (2002) Applications of natural silk protein sericin in biomaterials. Biotechnol Adv 20(2): 91-100.
11. Bayram C, Demirbilek M, Yalçın E, Bozkurt M, Doğan M, et al. (2014) Appl Surf Sci 288: 143-148.
12. Wharram SE, Zhang X, Kaplan DL, McCarthy SP (2010) Macromol Biosci 10: 246-257.
13. Kundu J, Mohapatra R, Kundu S (2011) Silk fibroin/sodium carboxymethylcellulose blended films for biotechnological applications. J Biomater Sci Polym Ed 22(4-6): 519-539.
14. Pruitt BA, McManus AT, Kim SH, Goodwin CW (1998) World J Surg 22: 135-145.
15. Kong HH (2011) Skin microbiome: genomics-based insights into the diversity and role of skin microbes. Trends Mol Med 17(6): 320-328.
16. Torres-Giner S, Ocio M, Lagaron J (2008) Development of Active Antimicrobial Fiber-Based Chitosan Polysaccharide Nanostructures using Electrospinning. Eng Life Sci 8(3): 303-314.
17. Ignatova M, Starbova K, Markova N, Manolova N, Rashkov I, et al. (2006) Electrospun nano-fibre mats with antibacterial properties from quaternised chitosan and poly (vinyl alcohol). Carbohydr Res 341(12): 2098-2107.
18. Xu X, Yang Q, Wang Y, Yu H, Chen X, et al. (2006) Eur Polym J 42(): 2081-2087.
19. Son WK, Youk JH, Lee TS, Park WH (2004) Macromol. Rapid Commun 25: 1632-1637.
20. Anitha A, Brabu B, Thiruvadigal DJ, Gopalakrishnan C, Natarajan T, et al. (2012) Electrospun zein nanofibers incorporating cyclodextrins. Carbohydr Polym 87: 1065-1072.
21. Rajendra R, Balakumar C, Ahammed HAM, Jayakumar S, Vaideki K, et al. (2010) Use of zinc oxide nano particles for production of antimicrobial textiles. Int J Eng Sci Technol 2(1): 202-208.
22. Chen L, Bromberg L, Hatton TA, Rutledge GC (2008) Polymer 49: 1266-1275.
23. Scaffaro R, Botta L, Sanfilippo M, Gallo G, Palazzolo G, et al. (2013) Combining in the melt physical and biological properties of poly(caprolactone) and chlorhexidine to obtain antimicrobial surgical monofilaments. Appl Microbiol Biotechnol 97(1): 99-109.
24. Gibney KA, Sovadinova I, Lopez AI, Urban M, Ridgway Z, et al. (2012) Poly(ethylene imine)s as antimicrobial agents with selective activity. Macromol Biosci 12(9): 1279-1289.
25. Ren G, Hu D, Cheng EW, Vargas-Reus MA, Reip P, et al. (2009) Characterisation of copper oxide nanoparticles for antimicrobial applications. Int J Antimicrob Agents 33(6): 587-590.
26. Hernández-Sierra JF, Ruiz F, Cruz Pena DC, Martínez-Gutiérrez F, Martínez AE, et al. (2008) The antimicrobial sensitivity of Streptococcus mutans to nanoparticles of silver, zinc oxide, and gold. Nanomedicine 4(3): 237-240.
27. Stanić V, Dimitrijević S, Antić-Stanković J, Mitrić M, Jokić B, et al. (2010) Synthesis, characterization and antimicrobial activity of copper and zinc-doped hydroxyapatite nanopowders. Appl Surf Sci 256(20): 6083-6089.
28. Rai M, Yadav A, Gade A (2009) Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv 27(1): 76-83.
29. Ahamed M, Karns M, Goodson M, Rowe J, Hussain SM, et al. (2008) DNA damage response to different surface chemistry of silver nanoparticles in mammalian cells. Toxicol Appl Pharmacol 233(3): 404-410.
30. Park MVDZ, Neigh AM, Vermeulen JP, de la Fonteyne LJJ, Verharen HW, et al. (2011) The effect of particle size on the cytotoxicity, inflammation, developmental toxicity and genotoxicity of silver nanoparticles. Biomaterials 32(36): 9810-9817.
31. Beyth N, Yudovin-Farber I, Bahir R, Domb AJ, Weiss EI, et al. (2006) Antibacterial activity of dental composites containing quaternary ammonium polyethylenimine nanoparticles against Streptococcus mutans. Biomaterials 27(21): 3995-4002.
32. Kenawy ER, Worley SD, Broughton R (2007) The chemistry and applications of antimicrobial polymers: a state-of-the-art review. Biomacromolecules 8(5): 1359-1384.
33. Lee HJ, Lee SG, Oh EJ, Chung HY, Han SI, et al. (2011) Antimicrobial polyethyleneimine-silver nanoparticles in a stable colloidal dispersion. Colloids Surf. B: Biointerfaces 88(1): 505-511.
34. Lin J, Qiu S, Lewis K, Klibanov AM (2002) Bactericidal properties of flat surfaces and nanoparticles derivatized with alkylated polyethylenimines. Biotechnol Prog 18(5): 1082-1086.
35. Milovi NM, Wang J, Lewis K, Klibanov AM (2005) Surpassing nature: rational design of sterile-surface materials. Biotechno Bioeng 90: 715–722.
36. Jeon O, Yang HS, Lee TJ, Kim BS (2008) J Control Release 132: 236–242.
37. Fortune JA, Novobrantseva TI, Klibanov AM (2011) Highly Effective Gene Transfection *In Vivo* by Alkylated Polyethylenimine. J Drug Deliv, pp. 1-6.
38. Fang X, Xiao S, Shen M, Guo R, Wang S, et al. (2011) Fabrication and characterization of water-stable electrospun polyethyleneimine/polyvinyl alcohol nanofibers with super dyesorption capability. New J Chem 35(2): 360–368.
39. Khanam N, Mikoryak C, Draper RK, Balkus KJ (2007) Acta Biomater 3: 1050–1059.
40. Sill TJ, Recum HA (2008) Electrospinning: applications in drug delivery and tissue engineering. Biomaterials 29(13): 1989-2006.
41. Xiao ZS, Yanchun L, Palumbo FS, Luo Y, Prestwich GD, et al. (2004) In situ crosslinkable hyaluronan hydrogels for tissue engineering. Biomaterials 25(7-8): 377–383.
42. Li X, Liu H, Zhou G, Fan GH, Fan Y, et al. (2011) Biomaterials 32: 3784-3793.
43. Malmsten M, Davoudi M, Schmidtchen A (2006) Bacterial killing by heparin-binding peptides from PRELP and thrombospondin. Matrix Biol 25(5): 294-300.
44. Son WK, Youk JH, Lee TS, Park WH (2004) The Effects of Solution Properties and Polyelectrolyte on Electrospinning of Ultrafine Poly(Ethylene Oxide) Fibers. Polymer 45: 2959–2966.
45. Xu X, Zhang JF, Fan Y (2010) Fabrication of cross-linked polyethyleneimine microfibers by reactive electrospinning with in situ photo-cross-linking by UV radiation. Biomacromolecules 11(9): 2283–2289.

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133

46. Destaye AG, Lin CK, Lee CK (2013) Glutaraldehyde vapor cross-linked nanofibrous PVA mat with in situ formed silver nanoparticles. ACS Appl Mater Interfaces 5(11): 4745-4752.

47. Wang M, Jin HJ, Kaplan DL, Rutledge GC (2004) Health & Environmental Research Online (HERO). Macromolecules 37(18): 6856–6864.

48. Wenk E, Murphy AR, Kaplan DL, Meinel L, Merkle HP, et al. (2010) The use of sulfonated silk fibroin derivatives to control binding, delivery and potency of FGF-2 in tissue regeneration. Biomaterials 31(6) 1403–1413.

49. Gölander CG, Eriksson JC (1987) Journal of Colloid and Interface Science. J Colloid Interface Sci 119: 38-48.

50. Hofmann S, Wong Po Foo C, Rossetti F, Textor M, Vunjak-Novakovic G, et al. (2006) Silk fibroin as an organic polymer for controlled drug delivery. J Control Release 111(1-2): 219-227.

51. Ren S, Yang S, Zhao Y, Yu T, Xiao X, et al. (2003) Surf Sci 546: 64-74.

52. Moghimi SM, Symonds P, Murray JC, Hunter AC, Debska G, et al. (2005) A two-stage poly(ethylenimine)-mediated cytotoxicity: implications for gene transfer/therapy. Mol Ther 11(6): 990-995.

53. Xia B, Dong C, Lu Y, Rong M, Lv YZ, et al. (2011) Thin Solid Films 520: 1120–1124.

54. Wiegand C, Bauer M, Hipler UC, Fischer D (2013) Nitric oxide integrated polyethylenimine-based tri-block copolymer for efficient antibacterial activity. Int J Pharm 456: 165-174.

55. Semih Ç, Erdoğdu C, Özalp M, Ulubayram K (2014) Materials Science and Engineering C.

DOI: 10.19080/JGWH.2022.23.556133

How to cite this article: Gokarneshan N, Akshaya A. Use of Silk Fibroin as Wound Dressings - An Innovative Concept. J Gynecol Women's Health 2022: 24(2): 556133. DOI: 10.19080/JGWH.2022.23.556133