Influence of polyvinyl alcohol molecular weight on the electrospun nanofiber mechanical properties

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Abstract

Polyvinyl Alcohol (PVA) is a biodegradable and biocompatible synthetic polymer which has sufficient mechanical properties for tissue engineering application. In this study, the influence of PVA molecular weight on electrospun nanofibers was investigated. Electrospun PVA nanofibers were produced by electrospinning process with constant parameter setting. The molecular weight of PVA was varied. Four different molecular weights of PVA were used, i.e. 60k Da, 124 k Da, 145 k Da and 200 k Da. For each molecular weight of PVA used, 2 samples of solution with concentration of 5% w/v and 10% w/v were prepared. Mechanical properties of electrospun PVA nanofibers including tensile strength, Young’s modulus, and contact angle were the response variables for the experiment. The results revealed electrospun PVA nanofibers with molecular weight 200k Da in a 10% w/v concentration of solution have the highest tensile strength and modulus of 29.8 ± 0.3 MPa and 78 ± 1 MPa, respectively. It was also hydrophilic as indicated by its low contact angle of 35.73˚ ± 0.48˚.

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1. Introduction

Polyvinyl Alcohol (PVA) is a semi-crystalline polymer that possesses good thermal and chemical stability [1]. PVA has a good water solubility and is a nontoxic polymer. It is a synthetic polymer which is biocompatible and
Nomenclature

PVA  Polyvinyl Alcohol

biodegradable. Due to its characteristics, it has drawn great attention and is used widely as a main material in tissue engineering application [2-7].

In this study, PVA is produced in the form of electrospun mat. Electrospun PVA mats were developed by using electrospinning process. Electrospinning is a simple technique which has the ability to produce fibers with diameters in nanometer scale, namely nanofibers. The diameter of the nanofiber formed is in the range of 100-500 nm. Electrospinning has also been used widely in tissue engineering application because it is capable of fabricating fibers having similar dimensions with extracellular matrix, critical structure and instructive component in all tissues [8].

The aim of this study is to investigate the influence of PVA molecular weight on the electrospun nanofibers mechanical properties. The molecular weight of PVA was varied while the parameter settings for electrospinning process are kept constant. For each molecular weight, 2 different types of solution concentration of 5% w/v and 10% w/v were produced. The purpose of having two different solution concentrations is to investigate the relationship between solution concentrations with the mechanical properties of electrospun PVA nanofibers. The mechanical properties involved in this study consist of tensile strength and young modulus. The hydrophilicity of the electrospun PVA nanofibers was also investigated.

2. Materials and Methods

2.1. Materials

Reagents used in this study included the following: Polyvinyl Alcohol (PVA) with molecular weight 60 kDa, 124 kDa, 145 kDa and 200 kDa of analytical grade.

2.2. Preparation of PVA solution.

Aqueous PVA solution with 5% w/v and 10% w/v were prepared by dissolving PVA polymer powder in deionized water at 80°C with constant stirring for at least 4 h.

2.3. Electrospinning PVA Nanofiber

PVA solution was pumped through the tube to the needle (inner diameter of 0.60 mm) of the electrospinning machine by using a syringe pump. The function of the syringe pump is to make sure the flow of polymer is constant and controllable. The needle was connected to a high DC voltage power supply ranged from 35 kV. The flow rate used was 1.0 ml/h and the distance from the tips to the collector was 8.0 cm. The grounded counter electrode was attached on the rotating collector. The speed of rotating collector is 1500 rpm. The electrospun nanofibers were collected using rotating collector which was wrapped with an aluminium foil. The entire electrospun nanofiber mat obtained was dried under vacuum for 24 hours in order to remove residual solvent. Figure 1 shows the schematic diagram of electrospinning process.

Fig.1. The schematic diagram of electrospinning process.
2.4. Tensile Test

The electrospun PVA nanofiber mats was cut into a dumb bell shape according to ASTM D638-10 Type V and the tensile strength test was performed using a LRX Tensile Machine at a 10 mm/min crosshead speed at room temperature. Five samples measurements were performed so as to ensure the reproducibility of the data.

2.5. Contact Angle Test

Optical contact angle measurement system (CAM 101 optical Contact Angle Meter, KSV Instruments) was used to determine the surface hydrophilicity of the electrospun PVA nanofiber mats. Frame interval was set at 1000 ms while the number of frames was set at 20 frames. The water was dropped onto the cut electrospun PVA nanofiber mats from a microsyringe with a stainless steel needle at room temperature and the reaction was recorded by live video of that machine to investigate the contact angle of the electrospun PVA nanofiber mats. Five measurements were performed at different locations so as to obtain the average contact angle for each electrospun PVA nanofiber mats.

3. Results and Discussion

3.1. Mechanical Properties

Table 1 shows the mechanical properties results of the electrospun PVA nanofibers with different amounts of PVA molecular weights. Findings revealed that increases in PVA molecular weight will increase the mechanical properties of fibers in terms of tensile strength and modulus. The increase in molecular weight reflects longer polymer chains of PVA which commonly translates to improved mechanical properties. The results are in line with previous studies which also showed that molecular weight increased the mechanical properties of polymer [9].

Table 1. Mechanical Properties of electrospun PVA nanofibers

| Molecular Weight (k Da) | Tensile Strength (MPa) | Young’s Modulus (MPa) | Contact Angle (°) |
|------------------------|------------------------|-----------------------|-------------------|
|                        | 5% w/v | 10% w/v | 5% w/v | 10% w/v | 5% w/v | 10% w/v |
| 60                     | 16.8 ± 0.4 | 20.5 ± 0.9 | 54.0 ± 0.6 | 55.5 ± 0.3 | 34.62 ± 0.51 | 35.37 ± 0.69 |
| 124                    | 23.6 ± 0.7 | 26.2 ± 1.3 | 60.1 ± 0.7 | 69.6 ± 0.9 | 35.81 ± 0.73 | 35.60 ± 0.84 |
| 145                    | 25.1 ± 0.5 | 28.5 ± 0.3 | 65.7 ± 1.1 | 76.0 ± 0.4 | 36.72 ± 0.98 | 34.82 ± 0.57 |
| 200                    | 27.0 ± 0.2 | 29.8 ± 0.3 | 68.0 ± 0.4 | 77.9 ± 0.8 | 34.69 ± 0.52 | 35.73 ± 0.48 |

Table 1 also shows that the higher solution concentration (10% w/v) has higher mechanical properties compared to the lower solution concentration (5% w/v) for all the different molecular weights of PVA. Lower concentration of PVA tends to produce smaller diameter nanofibers because the larger amount of solvent presents in the solution tend to evaporate during spinning leaving the polymer. Subsequently, the mechanical properties of electrospun PVA nanofibers were lowered.

It should be noted that although higher mechanical properties were obtained from PVA with high molecular weight at high concentration, the difficulty during the spinning process also increases. This is because the higher PVA molecular weight and the higher its concentration, the higher also its viscosity. Spinning high viscosity solutions is difficult because the solution does not flow well and extra force is required to extrude it from the syringe. Another point is that the increase in tensile strength and modulus with the increase in molecular weight seems saturating beyond 145 kDa (Fig. 2). It is suggested that even higher molecular weight will give no significant increase in mechanical properties any further.
3.2. Contact Angle

Results of contact angle measurement which are also stated in Table 1 also show that the entire electrospun PVA nanofibers were hydrophilic. The difference in molecular weight and solution concentration does not affect the hydrophilicity of PVA. This supports the notion that PVA is a biocompatible material and is suitable for tissue engineering.

4. Conclusion

The results showed that molecular weight and solution concentration have an influence on the mechanical properties of electrospun PVA nanofiber. Increase in molecular weight and solution concentration increase the tensile strength and modulus of the fiber mat. However, the positive effect on mechanical properties diminishes beyond 145kDa molecular weight. It is noted that higher molecular weight and solution concentration of PVA have consequence in increasing the viscosity, and this may cause difficulty in the electrospinning process. Contact angle measurements revealed that all the tested electrospun PVA nanofibers were highly hydrophilic, and this property is insensitive to molecular weight solution concentration.

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