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Physical Properties of Polyvinyl Alcohol Electrospun Fiber Mat

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ABSTRACT

PVA fiber has been interested because of its nontoxic, biocompatible properties and also chemical and thermal stability. PVA electrospun fiber mat was prepared with electrospining technique in this study. The process parameters were investigated their effect on the morphological characteristic, diameter and number of fiber per area of prepared fiber mats. These process parameters comprised polymer concentration (8, 10 and 12% w/w PVA), electrical potential (15, 20 and 25 kV) and distance (10, 12.5 and 15 cm between the tip of the nozzle and collector device). Polymer concentration was the main factor affected the morphological characteristic, diameter, number of fiber per area of PVA electrospun fiber. The increased collector distance did not diminish the defect of bead formation. However the longer oblong beaded fiber was evident as the collector distance was increased because the time interval for polymer stretching was longer. To obtain the desired PVA fiber the suitable electrospinning condition should be: 10% w/w PVA solution, electrical potential 20 kV and the collector distance of 15 cm. Increased spinning voltage could change the curve to stretched fiber. The obtained electrospun fiber mat exhibited the homogeneous distribution, high swelling and weight loss which it showed the potential ability for using as the wound dressing material.

Keywords: Polyvinyl alcohol, electrospun fiber mat, physical properties.

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INTRODUCTION

Electrospinning has been used in polymer industry since 70 years ago and it has been recently utilized to produce the electrospun nanofiber for tissue engineering. It is one of the fabrication techniques employed for producing the fiber mats which have exhibited amazing characteristics owing to their small size, high porosity and high surface-to-volume ratio with vast possibilities for surface functionalization [1]. Thus, electrospun fiber mat has become promising devices for several biomedical applications such as drug delivery system, wound dressing and sponge for tissue engineering. The electrospinning technique represents attractive approaches to polymer biomaterial processing since it is the convenient and effective method which utilizes a high voltage source to inject a charged polymer solution or melt and then accelerated toward a collector of opposite polarity. Single or multiple charged jets are eventually ejected from the tip of Taylor cone as the electric field strength overcomes the surface tension of the pendent droplet. The jet travels through the atmosphere allowing the employed solvent to evaporate, thus leading to the deposition of solid polymer fibers on the prepared target [2]. Various polymers have been used as the material for fabrication into nanofiber with this technique such as poly lactide-glycolide, polycaprolactone, poly (ethylene oxide), polyvinyl alcohol, collagen, silk protein and other peptides [3]. An addition of polyvinyl alcohol could modify the property of nanofiber produced from carboxymethyl chitin [4]. The fabrication of polyvinyl alcohol (PVA) nanofiber with dual vertical wire technique has been reported [5]. The classical process is rather complex with the resulting fiber characteristic being influenced by numerous materials, design, and operating parameters [6]. Processing variables especially spinning voltage and polymer concentration were the most important affected the morphology of polyethylene oxide electrospun nanofiber [7]. The fiber morphological characteristics were apparently evident depending on the polymer concentration, applied electrical potential and deposition distance [8].

The aim of this study is to study the effect of polymer concentration, electrical potential and distance between tip of nozzle and collector device on the physical properties of PVA electrospun fiber mats fabricated with classical electrospining technique.

MATERAILS AND METHODS

Materials

Polyvinyl alcohol, 97.5-99.5% hydrolyzed, was purchased from Fluka Co., Ltd. This polymer was dissolved in deionized water to make solutions.

Methods

Fiber mat preparation by electrospinning

An initial weighed amount of PVA powder was dissolved in deionized water to obtain the 8, 10 and 12% w/w PVA solutions by gently stirred for 4 h at 80°C in order to obtain clear solution. Electrospinning of the as-prepared solutions was carried out by connecting the emitting electrode of positive polarity from a Gamma High-Voltage Research ES30PN/M692 high voltage DC power supply to the solutions filled in a standard 50-ml syringe, the open end of which was attached to a blunt gauge-20 stainless steel needle (OD = 1.2 mm), used as the nozzle, and the grounding electrode to a home-made rotating metal drum (OD = 12 cm) was covered with aluminum foil to used as the fiber collection device. The voltage was controlled by the high voltage power supply. Electrical potential of 15, 20 and 25 kV was applied across a fixed distance of 10, 12.5 or 15 cm between the tip of the nozzle and the outer surface of the drum. The feed rate of the solutions was controlled at 0.1 ml/h by means of a Kd Scientific syringe pump. Electrospinning was carried out in room conditions.

Characterizations and testing

Prior to electrospinning, the as-prepared solutions were measured for their viscosity and conductivity using a viscometer (VISCO STAR Plus) and a conductivity meter (Oakton CON 6/TDS 6 Conductivity/TDS meters), respectively. The measurements were carried out at 25°C and average values for each solution were calculated from at least three measurements.

Morphological appearance of the fiber mats was observed by a JEOL JSM-6380LV scanning electron microscope (SEM). The fiber mats samples were sputtered with a thin layer of gold prior to SEM observation. The number of fiber per μm^2 was determined. Diameters of the individual fibers in the as-spun fiber mats were measured directly from the SEM images using a SemAphore 4.0 software (n=30).

The percentage of swelling and the percentage of weight loss of the fiber mats were measured in a phosphate buffer pH 6.8 solution at temperature of 25°C for 24 h (n=6). The excess adsorbed medium on the swollen fiber mat was wiped out with a filter paper. The calculation was conducted according to the Eq. (1) and Eq. (2), respectively:

$$Swelling\ (\%) = \frac{M - M_i}{M_i} \quad (1)$$

$$Weight\ loss\ (\%) = \frac{M_i - M_d}{M_i} \quad (2)$$

where M was the weight of each sample after submersion in the buffer solution for 24 h, M_d was the weight of the sample after submersion in the buffer solution for 24 h in its dry state, M_i was the initial weight of the sample in its dry state.

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RESULTS AND DISCUSSION

The viscosity and conductivity of PVA solution were increased evidently as the polymer concentration was increased (Table 1). By comparison, the viscosity and conductivity of deionised water which was employed as the solvent was very low and those of polymer solutions were rather high. Clearly, cross-sectionally round fibers were obtained for the electrospun fabricated with the 10% w/w PVA solution (Fig. 1). There were the combination of beaded fiber in the electrospun mat prepared using 8%w/w PVA solution whereas the larger fibers without beads was obtained in the case of system prepared using the 10 and 12%w/w PVA solution. The bead formation in the fiber was occurred due to the evidence of droplets during electrospray and thereafter they were deposited on the fiber. In the case of higher concentrated polymer solutions, the charged jet did not break up into small droplets. Smallest PVA fiber was evident when the lower concentration PVA solution was used (Fig. 2). This is because of the lowest solution viscosity could accelerate the stretching of the polymer during electrospinning. An adding the higher PVA to solution affected the viscosity of the solution and resulted in increasing the fiber diameter. The charged jet from high concentrate solution could withstand the coulombic stretching force therefore the smooth with larger as-spun fibers could be obtained [9]. In addition, the low solvent in the charged jet of concentrate polymer solution was dried more easily which cumbered the elongation and thinning of fibers [8]. The high concentration solution exhibited high viscosity and also high surface tension, thereafter the stretching ability was reduced. Typically, the solution viscosity increased with increasing solution concentration according to a power-law relationship and an increase in the solution viscosity should result in the formation of fibers of larger diameters [7]. The collector distance during electrospinning did not apparently affect the diameter of prepared fibers when the electrical potential of 20 kV was applied. The number of fiber per area was also decreased as the polymer concentration was increased (Table 2) owing to the formation of larger fiber.

The diameter and number of fiber per area were rather similar for the fibers prepared with 8% w/w PVA solution and different collector distance of electrospinning as present in Fig. 3. For the fiber obtained from 10%w/w PVA solution, the same evidence was also found (Fig. 4 and Table 3). The similar result has been also reported previously [9]. Because the difference value of distance was rather small the apparent of this effect on fiber characteristic was not found. However some research work reported the slightly larger diameter of PVA fiber as the collector distance increased [8]. But some research has reported the decrease of fiber diameter when the distance was increased due to the increased total path trajectory of the charged jet and uniform stretching of the jet [10]. Typically, the lower number of fiber per area should be obtained when there was the larger distance between the tip of nozzle and collection device since the stretched polymer deposited in larger area and thereafter there was the lower repetition of fiber deposition. The oblong beaded fibers were found when the distance was higher because the time interval for polymer stretching was longer. However the increased distance did not solve the formation of beaded fibers prepared with electrospinning.

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Table 1 Viscosity and conductivity of PVA solutions (n=3).

PVA solution (%w/w)	Viscosity (cP)	Conductivity (µS)
0	0.9	0.5
8	467.9	1087
10	961.0	1275
12	2162.9	1585

Table 2. Effect of PVA concentration on number of fiber/area of PVA electrospun fiber prepared using the different collector distance and voltage potential of 20 kV.

Distance (cm)	PVA solution (%w/w)	Number of fiber (/1 µm^2)
10	8	9
	10	6
	12	3
12.5	8	10
	10	7
	12	2
15	8	9
	10	7
	12	4

Table 3. Effect of collector distance on number of fiber/area of PVA electrospun fiber prepared from 10%w/w PVA solution.

Electrical potential (kV)	Distance (cm)	Number of fiber (/1 µm^2)
15	10	6
	12.5	5
	15	5
20	10	6
	12.5	7
	15	7
25	10	6
	12.5	5
	15	6

Table 4. Effect of voltage potential on number of fiber/area of PVA electrospun fiber prepared at the collector distance of 12.5 cm.

PVA solution (%w/w)	Electrical potential (kV)	Number of fiber (/1 µm^2)
8	15	7
	20	10
	25	11
10	15	5
	20	7
	25	5
12	15	3

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	20	2
	25	1

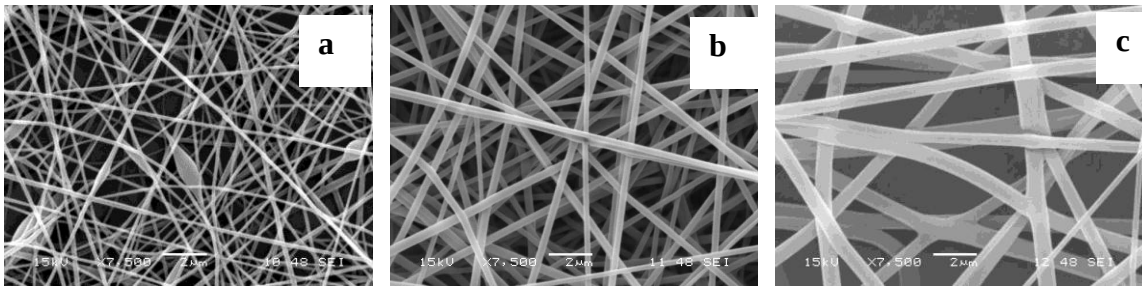

Fig 1. SEM micrograph of PVA electrospun fiber prepared from the PVA solution at concentration of a) 8 %w/w, b) 10 %w/w and c) 12 %w/w using the collector distance of 15 cm and voltage potential of 20 kV (at magnification of 7500).

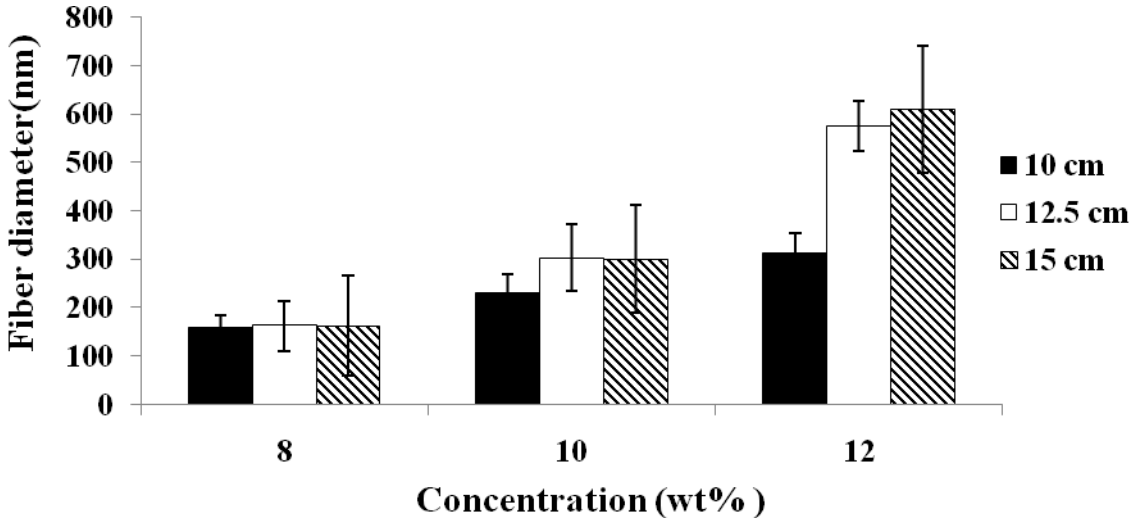

Fig 2. Effect of concentration on diameter of PVA electrospun fiber prepared using the different collector distance and voltage potential of 20 kV (n=3).

ISSN: 0975-8585

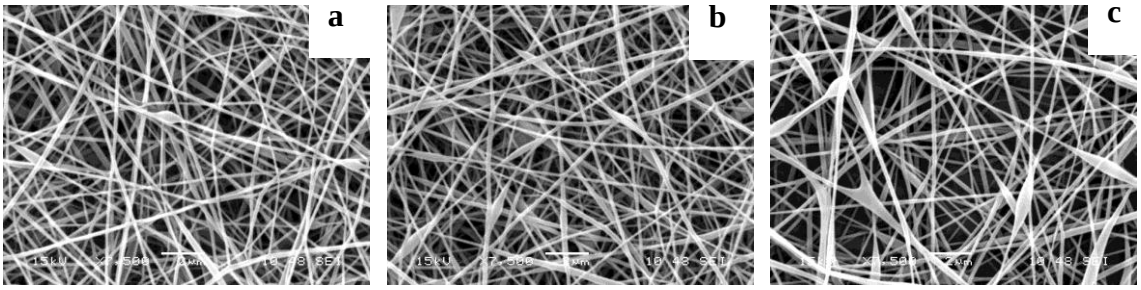

Fig 3. SEM micrograph of PVA electrospun fiber prepared from the solution at concentration of 8 wt% using the different collector distances a) 10 cm, b) 12.5 cm and c) 15 cm; voltage potential of 25 kV (at magnification of 7500).

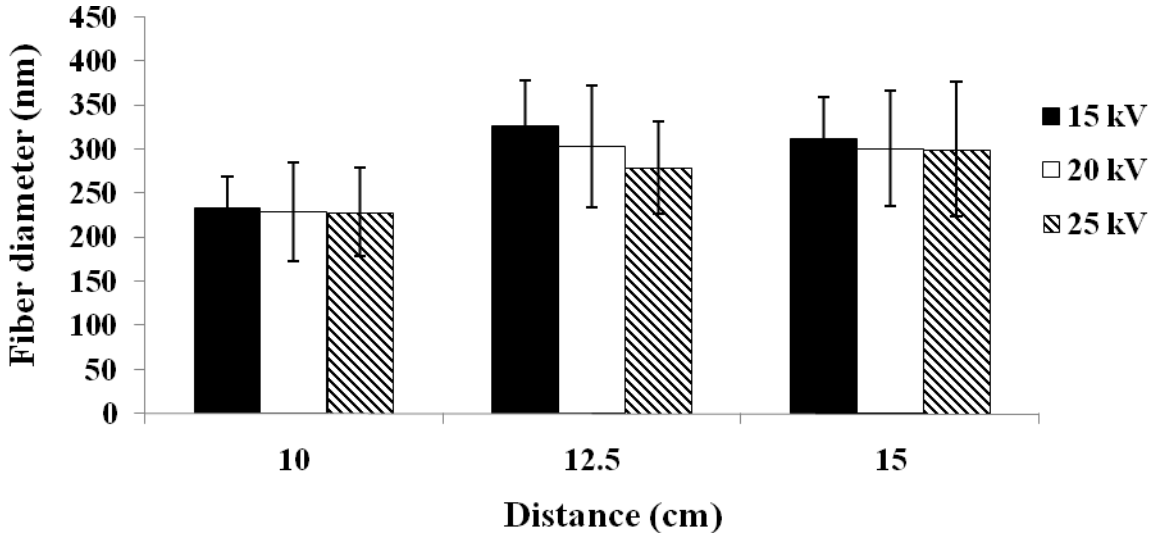

Fig 4. Effect of collector distance on diameter of PVA electrospun fiber prepared from10%w/w PVA solution..

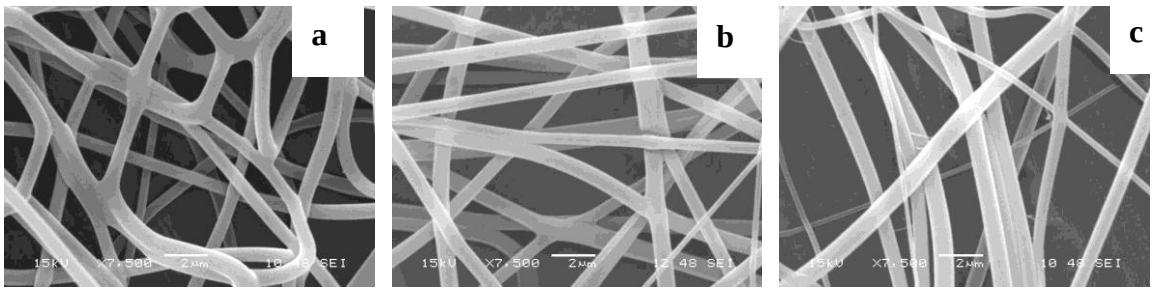

Fig 5. SEM micrograph of PVA electrospun fiber prepared from the solution at concentration of 12 wt% using the collector distance of 15 cm at different voltage potential of a) 15 kV, b) 20 kV และ c) 25 kV (at magnification of 7500).

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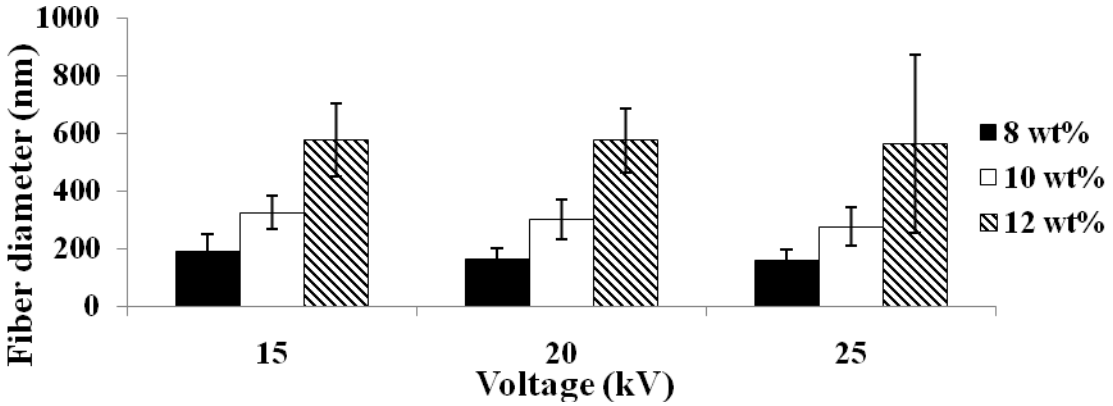

Fig 6. Effect of voltage potential on diameter of PVA electrospun fiber at the collector distance of 12.5 cm.

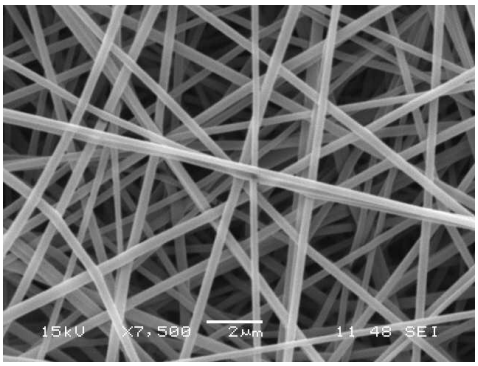

Fig 7. SEM micrograph of PVA electrospun fiber prepared from 10 %w/w PVA solution using the collector distances of 15 cm and voltage potential of 20 kV (at magnification of 7500).

The effect of electrical potential on diameter and number per area of PVA fiber were shown in Fig. 5, 6 and Table 4. The diameter and number of fiber per area were rather similar for the fibers prepared with different electrical potential of electrospinning. Some report claimed that the spit ability of charged droplets was enhanced owing to the increasing the electrostatic force [8]. But someone mentioned that the increasing the coulombic repulsion force with increase in the applied electrical potential resulted the decreasing the fiber diameter whereas the increasing the electrostatic force with increase in the applied electric potential promoted the increasing the fiber diameter [10]. However the higher electrical potential could change the curve fiber (Fig. 5 a) to the stretched fiber (Fig. 5 b) but for the electrical potential of 25 kV the obtained mat contained the fibers with different size. Typically the increasing spinning voltage could elongate the jet and also drawn more solution out of the nozzle [11]. The change from curve to stretched fiber should be the effect of elongation with increasing voltage. However the unbalanced effect resulted that the prepared fiber exhibited wide size distribution when high voltage was applied.

From the above results, the suitable condition to prepare the PVA electrospun fiber was the 10%PVA solution using electrical potential 20 Kv and the distance between tip of nozzle and collection device of 15 cm. The obtained electrospun fiber prepared with that condition was continuous and homogeneous in size and dispersion as shown in Fig. 7. The percentage of swelling and the percentage of weight loss of the fiber mats in a phosphate buffer pH 6.8 at 24 h were 223.53% and 45%, respectively. The rather high swelling and weight loss of PVA electrospun fiber were due to the hydrophilic characteristic of PVA. Phosphate buffer pH 6.8 was the hydrophilic solvent which was miscible with PVA therefore this medium was absorbed and promoted the polymer network swelling. PVA is a semicrystalline hydrophilic polymer with good chemical and thermal stability. Additionally, it exhibits the highly biocompatible and nontoxic nature [12, 13]. Therefore the prepared PVA electrospun fiber should be potentially employed in fields of medical, cosmetic, pharmaceutical industries.

CONCLUSION

The polymer concentration was the main factor affected the morphological characteristic, diameter, number of fiber per area of PVA electrospun fiber produced with electrospining technique. Increasing the PVA concentration, the fiber size was increased, and the amount of the fiber defect as bead formation was reduced. To obtain the desired PVA fiber with smooth and uniform the suitable electrospinning condition should be: 10%PVA solution, electrical potential 20 kV and the distance between tip of nozzle and collection device of 15 cm. The obtained electrospun fiber exhibited the high swelling and weight loss which it showed the potential application as the wound dressing material.

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