Development and study on mechanical properties of small diameter artificial blood vessel by using electrospinning and 3d printing

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Abstract. The small diameter artificial blood vessel is synthesized with a diameter less than or equal to 6 millimetres. This technique has been used in coronary artery bypass grafting to treat coronary artery disease. Currently, the problem of coronary artery disease is still common, in addition to aortic aneurysm caused by the incompatibility of mechanical properties between the artificial blood vessel and the local blood vessel in the patient's body. This research aims to solve the aforementioned problems using electrospinning and 3D printing technologies, as many types of materials are supported, all parameters are easy to change, and the cost is low. In this report, we describe a design for a small diameter polylactic acid (PLA) vascular graft fabricated by electrospinning with solutions of PLA in AC/DMF (1:1) 10, 12 and 15% w/v at 4 mm. The electrospun PLA nanofibers are tested for their morphology, contact angle, and seam strength. As the results, the fibres are still no same direction alignment due to insufficient rotation speed. The filament holding force is in the range of 1.90-2.71 N and the contact angles are greater than 90° because the samples are not wettable and have hydrophobic property. Further on, we will investigate other required properties, such as cell culture and other mechanical properties. Furthermore, we will compare the results with 3D printed artificial blood vessels with small diameter.

1. Introduction

Cardiovascular diseases (CVDs) are one of the leading causes of death around the world. In 2016, 17.3 million people died from cardiovascular related reasons. Plaque formation in the arteries can affect the cardiovascular system, which is the cause of CVDs. Generally, bypass surgery is performed to allow peripheral or coronary revascularization. Although large diameter (inner diameter (ID) $>$ 6 mm) artificial vessels have been successfully used for bypass surgery, small diameter (inner diameter (ID) $\leq$ 6 mm) artificial vessels are still unsuccessful [1]. Most of the causes of poor performance of small diameter grafts are adverse biological responses, including delayed reendothelialization, surface thrombosis, and neointimal hyperplasia (IH) [2].

Tissue engineering is an interesting option for vascular grafts and for the production of small diameter vessels using biodegradable scaffolds Technologies for vascular grafts that resemble the structure of blood vessels. Electrospinning and 3D printing technology is widely used for this purpose, as this technique allows the fabrication of nano- to micro-scale structures and provides control over the composition and mechanical properties of the scaffolds [3].

The aim of this research is to develop and investigate the fabrication of scaffolds for vascular grafts using electrospinning and 3D printing, and to test the morphological and mechanical properties for the fabrication of small diameter vascular grafts. Moreover, the importance of 3D printing is able to determine the patterns of blood vessel as desire for the patient, who got damage in specific part of the blood vessel. The developed small-diameter vascular graft be mechanical testing which are young's modulus, tensile stress, elongation at break, compliance, burst pressure, suture retention, and contact angle for wetting capability that is an important property for cell culture of vascular graft. Finally, researchers expect to achieve new technical methods and conditions for synthesizing small-diameter artificial blood vessel by two early methods, including artificial blood vessel with proper mechanical properties for utilizing in coronary artery bypass grafting.

2. Materials and methods

2.1. Materials

Poly (lactic acid) (PLA) (Shenzhen eSUN Industrial, China). The PLA was dissolved in a 1:1 solvent mixture of 99.8% Dimethylformamide (DMF) (Sigma-Aldrich, Germany) and 99.5% Acetone (AC) (RCI Labscan, Thailand).

2.2. Preparation of PLA solutions

The polymer solutions for electrospinning were prepared by dissolving PLA in AC and DMF (50/50 v/v). PLA was dissolved to obtain solutions with concentrations 10, 12 and 15% w/v. To preparation the solutions concentration, the PLA were weighted and put in a glass bottle before added AC and DMF at a volume ratio of 1:1. All solutions were magnetically stirred at 120 °C for 4 h, until complete dissolution of the polymer.

2.3. Electrospinning process

In this work, a vertically rotating drum collector was used for electrospinning to fabricate nanofibers for small diameter artificial blood vessels. The electrospinning setup consisted of a high-voltage power supply, a syringe pump, and 10-mL syringe attached PTFE (Polytetrafluoroethylene) tube with an 18-G needle that cutting out the sharp tip of the needle on the other side of tube. The prepared solutions 4 ml were loaded into the syringe and injected at a constant flow rate of 6 mL/hr. The distance between the needle tip and the collector and the applied voltage were fixed at 15 cm and 15 kV, respectively. The speed of the collector was changed to 200, 350 and 450 rpm for the orientation of the nanofiber morphology studied. After the fabrication process, the electrospun PLA nanofibers were wrapped with longitudinally around a small diameter rod of 4 mm (see figure 1).

2.4. Characterization of vascular grafts

The surface morphology of the electrospun PLA nanofibers was characterized using a JEOL model JSM- 6010LV scanning electron microscope (SEM) with an accelerating voltage of 10 kV. Prior to observation, the entire sample was coated with gold sputter for 1 min (JEOL model JFC-1100E). The contact angle of electrospun PLA nanofibers were observed using a homely setup. The square (1 × 1 cm) electrospun PLA nanofibers were placed on a glass slice and the water was dropped on it. The diameters of the electrospun PLA nanofibers and the contact angle between water and the surface of the electrospun PLA nanofibers were measured manually using ImageJ analysis software.

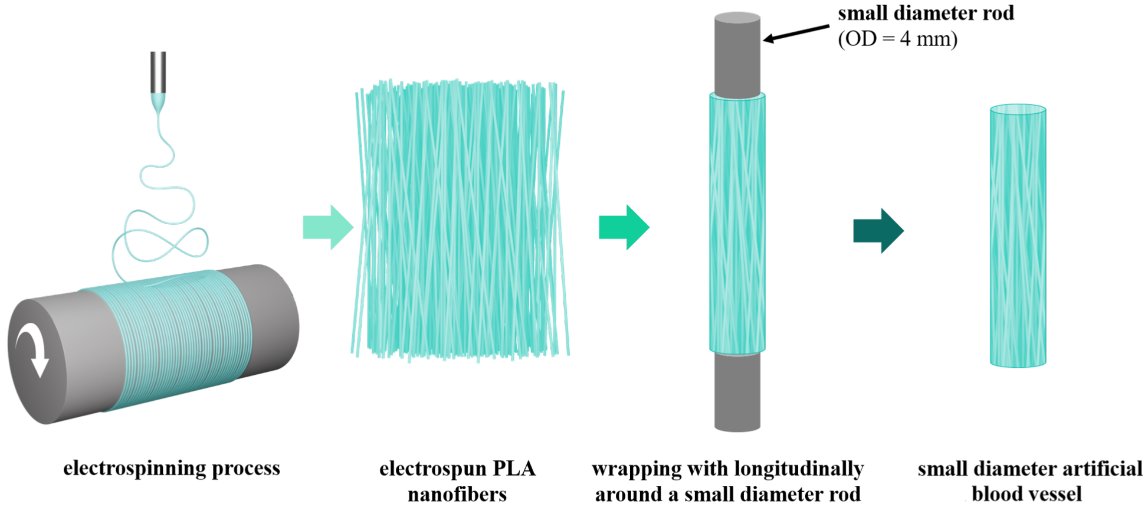

Figure 1. The process for fabricating small diameter artificial blood vessels with electrospun PLA nanofibers.

2.5. Suture retention testing

For the suture retention test, electrospun PLA nanofibers were cut into rectangles with 10 × 20 mm. The lower end was attached with a loading weight bag. The PTFE monofilament was passed through a 0.5 mm hole and 2 mm from the top end of the specimen. The suture loop was extended by adding the load to the bag until the membrane was broken (see figure 2). The SRS was defined as the maximum force measured during the test, which refers to the resistance of grafts to tearing out a suture. So, the maximum load weight can be converted into a force using Newton's second law ($\sum \vec{F} = m\vec{a}$).

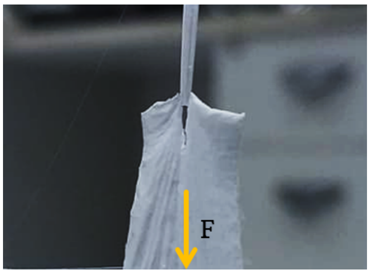

Figure 2. The rectangular specimen 20 × 10 mm with a single suture placed at a distance of 2 mm from the edge of the specimen for testing the suture retention testing.

3. Results and discussion

3.1. Surface morphology

The surface morphology of the electrospun PLA nanofibers of three concentrations was characterized using SEM, as shown in figure 3(B). As the result, all samples are inhomogeneous and do not show the same orientation direction. There are some beads and noticeable defects, as shown in SEM figure. Their average diameters are listed in table 1.

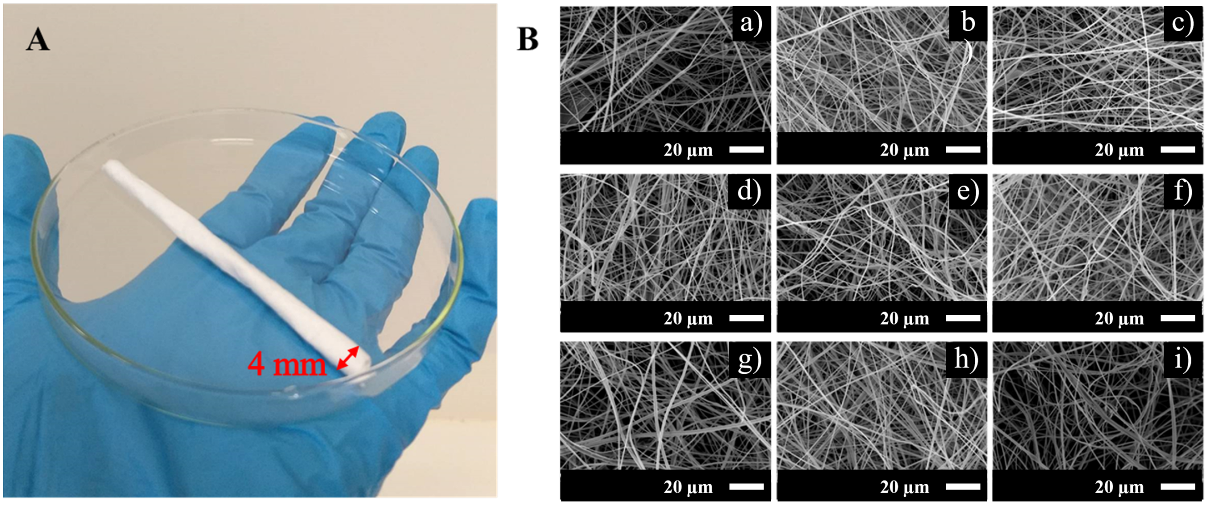

Figure 3. A) The electrospun PLA nanofibers wrapped with longitudinally around a small diameter rod of 4 mm and B) SEM image of PLA nanofibers (1000x) of (a-c) 10 w/v%, (d-f)12 w/v% and (g-i)15 w/v% concentration with 200, 350 and 450 rpm speed of collector, respectively.

Table 1. The average PLA fibres diameter with difference speed of collector, nm.

PLA Concentration (%w/v)	200 rpm	350 rpm	450 rpm
10%	722 ± 57	607 ± 35	740 ± 54
12%	736 ± 50	720 ± 42	766 ± 39
15%	1129 ± 84	965 ± 64	1009 ± 80

3.2. Contact angle
The PLA electrospun nanofibers were examined wetting capability by measuring the contact angle of water. The tested specimens are in rectangular shapeas, shown in figure 4. The contact angle of PLA nanofibers with rotation speed collector at 200 rpm are 124°, 89° and 139° for the PLA solutions with concentration of 10, 12 and 15%w/v, respectively.

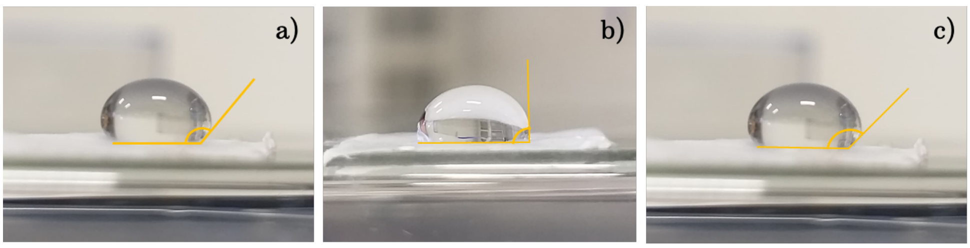

Figure 4. Water droplets on PLA nanofibers from solution (a) 10, (b) 12 and (c) 15 % w/v.

3.3. Suture retention
The SRS of vascular grafts was measured by adding weight loading until the specimens ruptured, that is, by the maximum force measured during the test, which refers to the resistance of the

grafts to tearing out a suture. The SRS of PLA nanofibers from solutions with concentration of 10, 12 and 15%w/v at higher collector speed (450 rpm) was much greater than at lower (200 rpm) and the SRS has also relative to concentration (10%w/v; 1.96, 0.75 N, 12%w/v; 1.90, 2.40 N and 15%w/v; 2.53, 2.71 N). In the generally required for successful implantation and long-term use of a vascular graft, the sufficient SRS must be above the threshold of 2.0 N [4].

4. Conclusion

This study is mainly focused on development and study on mechanical properties of small diameter artificial blood vessel by using electrospinning for cardiovascular tissue engineering.

PLA nanofibers diameter and fibre alignment of the vascular were optimized using different PLA concentration, PLA volume and rotation speed. As the results, the fibres are still none same direction alignment. That may be the insufficient rotation speed. There were somewhat typical results in the fibre diameter at the rotation speed of 350 rpm. This may be due to a malfunction of the instrument used. Suture retention strength was similar to previously measured human saphenous vein suture retention strength (1.92 $\pm$ 0.02 N), and human arteries suture retention strength (1.92 $\pm$ 1.16 N) [5]. The contact angles are more than 90° because the specimens have non wetting capability and present hydrophobic property. So, the PLA graft needs a surface modification such as plasma treatment [6] for increase wetting capability before cell culture process the results of this study show that the small diameter PLA artificial blood vessel can be an attractive substitute for a biocompatible and biodegradable artificial blood vessel [7].

In further we will study other required features i.e., cell culture, and other mechanical properties which are young's modulus, tensile stress, elongation at break, compliance, burst pressure. In addition, we will compare the results to 3D printed small diameter artificial blood vessel.

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