Manufacturing Technology and Characteristics of Nerve Conduits Made of Poly(lactic acid) Braids

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Abstract

The nerve system has the upmost role in coordinating the actions of an animal. It is, therefore, important to repair the damaged nerve to restore its functions. In this study, we braided poly(lactic acid) ply yarn into a tubular structure using a 16-spindle braiding machine, aiming at making a nerve conduit. The results showed that the poly(lactic acid) braid obtains the maximum tensile stress when the ratio of take-up gear and braid gear is 60/50. The extensibility of the produced braid makes it a suitable conduit for nerve regeneration.

Introduction

Synthetic conduits have been used to fill the gap between ends of broken nerve, to guide and to promote never regeneration. A variety of materials, such as collagen,[1] polytetrafluoroethene,[2] silicone,[3] polyethylene,[4] polycaprolactone,[5] polyglycolic acid,[6] and poly(lactic-co-glycolic acid),[7] have been used to fabricate the nerve conduit. Textile technology have showed promising potential in biomaterials design. For instance, Lin et al. have been used textile technology in designing wound dressings,[8-11] artificial bone[12-14], and surgical suture.[15]

In this study, we braided poly(lactic acid) ply yarn into a tubular structure using a 16-spindle braiding machine, aiming at making a nerve conduit. The braid has high porosity and permeability and is suitable to serve as a nerve conduit for nerve regeneration.

Experimental

Fabrication of poly(lactic acid) ply yarn

As the first step of the preparation, 150-Denier poly(lactic acid) ply yarn was produced by a doubler based on 75-Denier poly(lactic acid) filaments (maximum tensile strength 3.9 g/D, elongation 30 %, UNITIKA LTD., Japan) Then the 150-Denier poly(lactic acid) ply yarn were twisted by the rotor twister to enhance fiber cohesion. To prevent ply yarn from detwisting, the yarn was placed in an oven at 65 °C for an hour.

Fabrication of poly(lactic acid) nerve conduit

The braid was then fabricated using a 16-spindle braiding machine, onto which the poly(lactic acid) ply yarn was loaded. The gear ratio was changed to obtain braids with different braid angles. With an increase of the number of take-up gear teeth, the rolling speed of sample becomes slower and the structure of the resulting braid becomes tighter. To investigate the effects of braid angles on the stability of the braid, varying ratios of the take-up gear and braid gear (120/50, 100/50, 80/50, and 60/50) were set during braiding.

To obtain a tubular structure, a capillary (O.D: 2 mm) was inserted as a mandrel during braiding. If the poly(lactic acid) braid underwent no thermosetting, the structure could slip easily by external forces. In order to fix the structure, the hollow braid was placed in an oven at 100 ℃ for 20 min. Finally, the capillary was removed, resulting in a poly(lactic acid) tube.

Mechanical properties test

To obtain optimal manufacturing conditions, the maximum tensile stress of braids fabricated at different braiding conditions was analyzed. The maximum tensile stress of the poly(lactic acid) braid was examined by a mechanical testing system (Instron 5566, U.S.A.). The extension rate is 0.6 mm/min. For each manufacturing condition, the maximum tensile strength was tested for 10 times for the average.

Contact angle test

Previous reports showed that the hydrophilicity of poly(lactic acid) can be enhanced by alkali refining.[13] The poly(lactic acid) braid was melted into a form of membrane in an oven at 169 ℃ for 60 sec. The membrane is then treated with NaOH solution in an ultrasonic cleaner (LEO-50, MICRO-LAB CO., LTD., Taiwan), washed, and dried at room temperature for one day. The membrane was then cut into species of 1×4 cm^2, tested its hydrophilicity using a contact angle meter (FACE, Japan). Based on the results of the contact angle, we can decide the optimal alkali refining parameters.

Cytotoxicity test

In this study, the indirect cytotoxicity method was employed according to ISO10993-12. Schwann cells were cultured in the poly(lactic acid) nerve conduit extract for 24 and 48 hours. Schwann cells were further incubated for 24 h and relative viable cell number was determined by MTT assay, based on the principle that metabolically active cells interacted with a tetrazolium salt in an MTT reagent to produce a soluble formazan dye, which absorbed light at the wavelength of 550 nm. The MTT solution was removed and replaced with DMSO to dissolve the formazan. The color intensity was measured using a spectrophotometer (ELx800TM Bio-Tek，USA) at the absorbance of 550 nm.

Results and Discussion

Braid angle and porosity

Figure 1 showed that the braid angle increased as the number of teeth of the take-up gear increased.

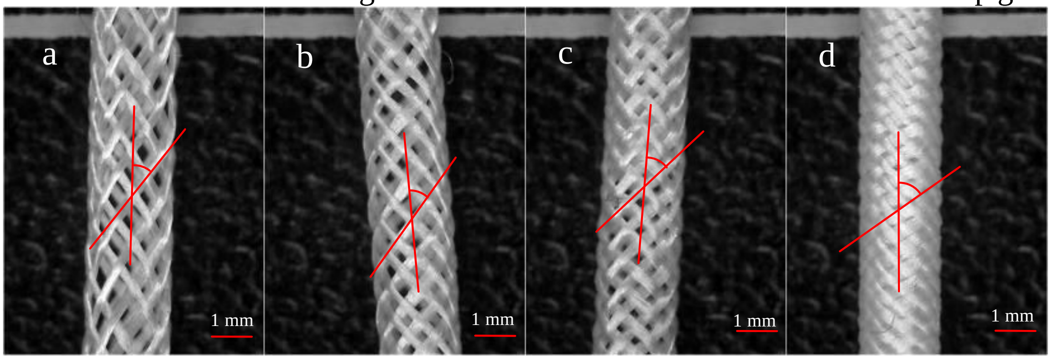

Figure 1. Micrographes of poly(lactic acid) nerve conduits fabricated using different take-up gears: number of teeth of the take-up gear used: 60(a), 80(b), 100(c), and 120(d).

Table 1 showed that the porosity of the poly(lactic acid) nerve conduit increased from 77.2 % to 82.8 % as the number of teeth of the take-up gear increased. The porosity of the conduit can promote transfer of the nutrient and waste across the wall.

Table 1. The braid angle and porosity of poly(lactic acid) nerve conduits made at different ratios of the take-up gear and braid gear (120/50, 100/50, 80/50, and 60/50). The length, I.D., and O.D. of the sample were 50 mm, 2 mm, and 2.3 mm, respectively.

Number of teeth of the take-up gear	120	100	80	60
Braid angle	44.64±5.02	39.61±5.49	35.50±2.36	28.98±2.92
Porosity (%)	77.2 ±0.1	80.6 ±0.1	81.2 ±0.4	82.8 ±1.9

Mechanical properties

Figure 2 showed that the maximum tensile stress of the poly(lactic acid) nerve conduit decreased as the number of teeth of the take-up gear increased from 60 to 120. Using a take-up gear with more teeth increased the braid angle of the conduit. The change of structure resulted in change in mechanical properties of the conduit. That is, the maximum tensile stress increased if the yarn tends to align to the axial direction.

Figure 3 showed that the maximum broken displacement of the poly(lactic acid) nerve conduit increased as the number of teeth of the take-up gear increased. If the yarn tends to align to the axial direction, the stiffness in axial direction increased and thus the capacity of strain energy decreased. That is, it is easier for such a conduit to be broken by axial force.

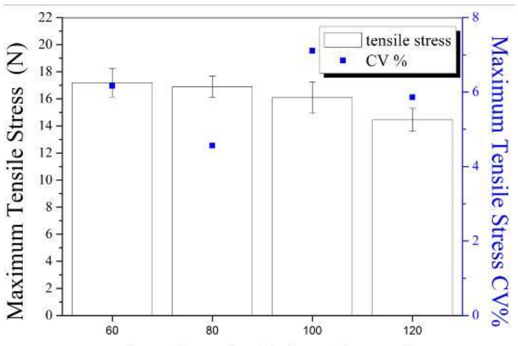

Figure 2. Effects of number of teeth of the take-up gear on the maximum tensile stress of the conduit.

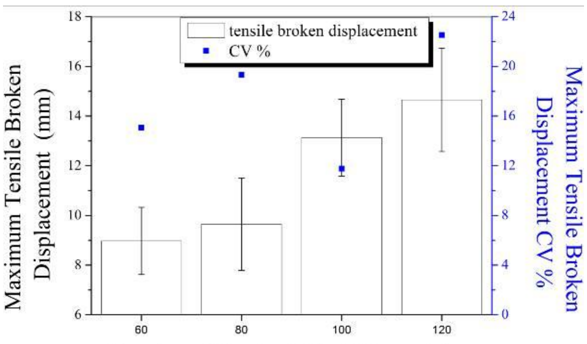

Figure 3. Effects of number of teeth of the take-up gear on maximum tensile broken displacement.

Cytotoxicity test

Figure 4 demonstrated that cell viability was not affected by the poly(lactic acid) nerve conduit extract and that the effectiveness of alkali refining on removal of oiling agent on the surface of poly(lactic acid) nerve conduit. Aside the oiling agent, it is well known that poly(lactic acid) have great bio-compatibility. [12-15]

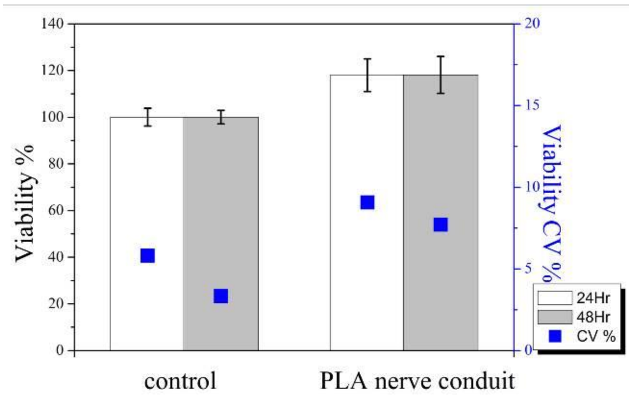

Figure 4. Viability of Schwann cells cultured in poly(lactic acid) nerve conduit extract for 24 and 48 hours compared to control cells.

Conclusion

In this study, we successfully fabricated the poly(lactic acid) nerve conduit using textile technology. The hollow braid obtained the maximum tensile stress and extensibility when the ratio of take-up gear and braid gear is 60/50. These properties are essential for it to be used as a conduit for nerve regeneration. Furthermore, the braided structure had great porosity (82.8 ±1.9 %), which can promote transfer of nutrient and waste across the wall.

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