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Preparation and biocompatibility evaluation of polypropylene mesh coated with electrospinning membrane for pelvic defects repair

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ABSTRACT

Composite mesh with different materials composition could compensate for the drawbacks brought by single component mesh. Coating a membrane layer on the surface of macroporous mesh is a common method for preparing composite medical mesh. Electrospinning and dipping methods were introduced to form the two kinds of membrane-coated PP meshes (electro-mesh and dip-mesh); several properties were measured based on subcutaneous implantation model in rat. The results revealed that continuous tissue ingrowth could be observed for electro-mesh only with evidences of strength increase (electro-mesh: 0 week − 13.1 ± 0.88 N, 2 week − 16.87 ± 1.39 N, 4 week − 22.04 ± 2.05 N) and thickness increase (electro-mesh: 0 week − 0.437 ± 0.023 mm, 2 week − 0.488 ± 0.025 mm, 4 week − 0.576 ± 0.028 mm). However, no tissues were observed for dip-mesh in the first 2 weeks, both on macroscopic level and microscopic level, proved by strength data (dip-mesh: 0 week − 13.36 ± 1.06 N, 2 week − 13.4 ± 1.33 N, 4 week – 18.61 ± 1.89 N) and thickness data (dip-mesh: 0 week − 0.439 ± 0.018 mm, 2 week − 0.439 ± 0.019 mm, 4 week − 0.502 ± 0.032 mm). Electro-mesh had larger surface area decrease (10.74 ± 1.22%) than that of dip-mesh (2.78 ± 0.52%). The adhesion level of electro-mesh (medium adhesion) was also higher than that of dip-mesh (mild adhesion). Even if showing differences in several properties, both meshes were similar under histological observation, with the ability to support fresh tissues ingrowth. Considering operation environment, electro-mesh seems more suitable than dip-mesh with a rapid tissue growing, medium adhesion rate for repairing pelvic floor defects.

1. Introduction

About 19% of women who are under 80 require pelvic organ prolapse surgery (Løwenstein et al., 2015), and around 12% of the middle aged women specific for those after one single vaginal birth suffer from stress urinary incontinence (SUI) (Epstein et al., 2007). Pelvic muscles play a vital role in supporting pelvic organs and continence control system. Once damaged, gynecological diseases such as POP and SUI may occur, along with adverse effects on sexual, physical health and professional activities (Riesco et al., 2010). Therefore, pelvic muscles damage has been regarded as a root cause of POP and SUI, and implantation of a mesh to strengthen the muscle is an effective medical treatment (Özdemır et al., 2015). In this method, a mesh is commonly implanted in vaginal position as a support, with a higher success rate than the traditional self-tissue repair (Rudnicki et al., 2016).

Currently, the most widely-used mesh is a lightweight mesh with special textile structure and polypropylene (PP) monofilaments composition. Large pores is demonstrated to be good for cell infiltration from research of the pore-size effect on mesh property by Klinge et al. Klinge et al. (2002). Moreover, lightweight mesh with large pores has a decreasing risk of complications including erosion, chronic pain and dyspareunia; patient life quality could be improved then (Liang et al., 2015). Therefore, lightweight macroporous PP mesh is considered to be an ideal type for POP treatment and has been widely used in clinical repairs.

In spite of showing excellent performances, PP mesh's biocompatibility is poorer than some degradable material mesh, may induce complications, such as inflammation and infection (Falagas et al., 2007).,(Mistrangelo et al., 2007) In order to improve its performance, modifications are proposed by combining advantages of non-absorbable materials' mechanical stability and absorbable materials' good biocompatibility (Schnuriger et al., 2011).,(Amid, 2003) Coating of a membrane on the surface of the mesh is a common method to achieve this goal. Several kinds of composite meshes were reported, but with

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significantly different purpose and functions. For example, Parietene Progrip® (Sofradim Production, Coviden, France) was composed of a polylactic acid (PLA) membrane and PP mesh base, with objective of self-bonding between mesh and defects (Gruber-Blum et al., 2014). However, Zhang et al. Zhang et al. (2013) produced a mesh same with PLA membrane, but with an expect of anti-adhesion to intracorporeal organs. The membrane-coated meshes could have totally different features, even opposite functions by using different manufacturing ways.

In order to find an effective and suitable coating method for application in pelvic repairing area, the requirements of weakened soft tissues were expressed in two parts. Firstly, mesh is able to adhere to the surrounding tissues tightly, then the damaged pelvic muscles could be stably strengthened. Secondly, mesh used for implantation should be soft, light and thin, so patients will not feel strong foreign body sensation. In other words, the addition of membrane layer should not bring obvious effect on the thickness and weight of the composite mesh. Based on that, electrospinning is considered as a promising processing method to meet the above-mentioned requirements, because it can produce extremely fine fibers with diameter from 5 nm to 1 μm and the formed membrane has high specific surface area and high porosity. Moreover, electrospinning is widely used in tissue engineering; its good biocompatibility was proved earlier.

In this work, a membrane with composition of PLA and PCL (polycaprolactone) was coated on PP mesh base by using electrospinning method. Traditional dipping method was used as control. The two types of composite meshes were implanted in onlay position of rats; mesh-tissue were taken out and measured 2 and 4 weeks post-operation for biocompatibility evaluation.

2. Materials and methods

2.1. Materials

PLA ($Mw = 10^5$) and PCL ($Mw = 8 \times 10^4$) were purchased from Yisheng New Material Co., LTD (Shengzhen, China). Dichloromethane (DCM), N,N-Dimethylformamide (DMF) were analytical pure grade provided by Damao chemical reagent factory (Tianjing, China).

Two different structure PP meshes used as a support base for membrane layer were fabricated by State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, Donghua University. The PP meshes are characterized by different pore shapes, interlocked using 0.1 mm PP monofilaments. The first PP mesh with rhombus-size pores were knitted with a structure called pillar/inlay stitch [Fig. 1(a)]. The second PP mesh with hexagon-size pores were called modified locknit stitch [Fig. 1(b)]. The weight of rhombus pore-shape PP mesh was 41.19 g/m^2; the thickness was 0.412 mm; the porosity was 68.53%. The weight of hexagon pore-shape PP mesh was 35.97 g/m^2; the thickness was 0.387 mm; the porosity was 63.40%. Testing method for mesh porosity was described in a previous study, by using computer image processing program to calculate the ratio of pore area to total area (Lu et al., 2014).

2.2. Fabrication procedure

One of the two-layer composite mesh in this work was produced by electrospinning method. The ingredient of top layer was PLA/PCL microfibers. The support base layer PP mesh with rhombus pores.

2.2.1. Preparation of PLA/PCL solutions

The preparation method of PLA/PCL solutions for electrospinning were discussed before in our earlier study (Lu et al., 2015). That PLA and PCL polymers were mixed with weight ratio of 7:3. The solvents were DCM/DMF mixture with a ratio of 4/1. The concentration of the solution was 8% wt/v.

2.2.2. Fabrication process of membranes

PLA/PCL solutions were electrospun to microfibers deposited on the surface of PP mesh. Smooth membrane could be formed along with the solvents volatilization. The processing parameters were also carefully discussed before (Lu et al., 2016a, b). That flow rate was 0.6 ml/h; the voltage was 12 kV; the receiving distance was 15 cm; the aluminum foil with a PP mesh stick on was used as receiving device.

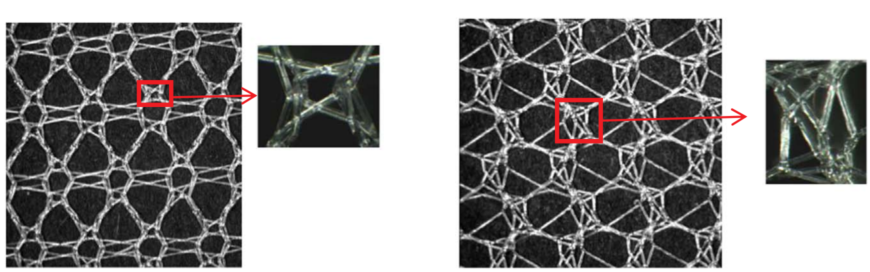
The dipping-method was adopted for forming a different membrane-coated mesh (dip-mesh). Membrane layer ingredient was as same as that of electro-mesh, but support base layer was different by choosing hexagon pore-shape PP mesh. In preparation process, PP mesh was first immersed in PLA/PCL solution for 10 s and then taken out to dry at room temperature. A smooth membrane could be formed after solution completely volatilization. It is noteworthy that the dip-mesh should be flatly placed during volatilization for obtaining a uniform thickness.

Fig. 2 shows fabrication process of membrane-coated meshes. Overall, the electro-mesh and dip-mesh had similar macroscopic morphologies, a white opaque membrane on a macroporous mesh surface. However, dip-mesh had extremely larger weight and stiffness proved by our previous study (Lu and Zhang, 2016).

2.2.3. Specifications of electro-mesh

The PLA/PCL white membrane tightly filming a support base, consisting electro-mesh's two-layer structure (Fig. 3). The front side and back side were shown difference. Through electron microscopy observation under 8000 magnification, numerous microfibers were randomly arranged in the membrane layer.

Some basic parameters of meshes were measured. The thickness of electro-mesh and dip-mesh was 0.439 ± 0.018 mm, 0.437 ± 0.029 mm, respectively. Their weight was 42.56 ± 1.28 g/m^2 and 65.34 ± 2.15 g/m^2, respectively. The electrospinning membrane layer occupied 3.22% while dipping membrane occupied 36.96% of the total weight of composite mesh. The average pore size of electro-mesh and dip-mesh was 6.46 ± 0.79 μm and 4.89 ± 2.55 μm, respectively. The average diameter of microfiber in the electrospinning



(a) Rhombus pore-shape mesh (b) Hexagon pore-shape mesh

Fig. 1. Structure of two PP meshes used as support base in membrane-coated composite mesh.