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Preparation of poly(vinyl alcohol) modified polypropylene mesh and its antiadhesion efficacy in experimental hernia repair

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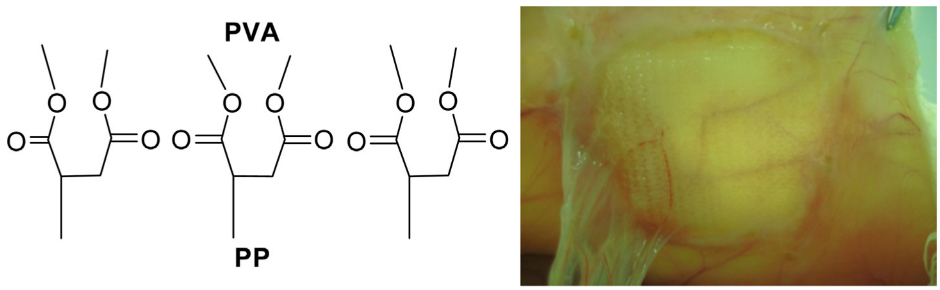
HIGHLIGHTS

- PP mesh was coated with PVA to repair rabbit hernia.
- PVA-coated PP mesh showed better anti-adhesion properties.
- PVA-coated PP mesh led to less inflammation.

GRAPHICAL ABSTRACT



PP-g-PVA mesh (left) and its antiadhesion efficacy (right)

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ABSTRACT

In surgical hernia repair, the intraabdominal adhesion formation needs to be prevented. As currently used prosthetic mesh materials, antiadhesion properties of polypropylene (PP) still be highly desirable. In the present study, we developed a new type of polypropylene (PP) hernia mesh, namely, polyvinyl alcohol (PVA) modified PP mesh (PP-g-PVA). The native PP mesh was first activated with O_2 plasma for 30 s, and then reacted with benzoyl peroxide (BPO) and maleic anhydride for 2 h, finally grafted with PVA in phosphorus pentachloride (PCl5) solution in pyridine. The chemical group changes on the surface of PP was monitored by X-ray photoelectron spectroscopy (XPS) spectra, and analysis results confirmed that the PVA was effectively grafted onto the PP.

Antiadhesion efficacy and complications of PP-g-PVA mesh were evaluated through repairing rabbit abdominal wall defect at implantation time point of 7 days, 1 month and 3 months. Cross-sections of the mesh parietal peritoneum overlap were examined histologically and graded for inflammation reaction. Compared with the control groups (native PP mesh), a very strong ability to resist peritoneal cavity adhesions ($P < 0.05$) was observed in the experimental groups (PP-g-PVA mesh), and however, there was no significant increase in the inflammation formation ($P > 0.05$). This PVA-modified PP mesh displayed a rather satisfying antiadhesion property in animal abdominal wall defect repair.

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1. Introduction

Polypropylene (PP), polyethylene (PE) and other polyolefins have become increasingly important material. Due to its excellent balanced biocompatibility and mechanical properties, PP is qualified for a board range of applications, such as in industry, medicine, daily consumption and etc. [1–3]. As one of the most popular materials applied in medicine, especially for hernia repair, polypropylene-based mesh was initially used to reinforce abdominal wall [4–6] in the late 1950s. Hernia is Latin and means “rupture”. Hernia is a tear or opening in the muscles of the abdominal wall, through which organs in the abdominal cavity can protrude and forme a sac. There are usually different kinds of hernias, such as inguinal hernia, umbilical hernia and incisional hernia. 80 percent of all hernias are inguinal hernias [7,8]. The PP mesh, used as hernia repair prosthesis, achieves satisfying results in the majority of cases with lower recurrence rates. However, PP mesh has its inherent shortcomings, that is to say, PP mesh hernia repair can cause many complications, including some common slight complications, like seroma, misfeeling and restriction of abdominal wall mobility, and other unusual serious ones, like bowel rupture and mesh erosion into caecum, which significantly limited its application in hernia repair [9–11]. The disadvantages of PP mesh would be due to its non-polar nature and low surface free energy [12].

Nowadays, in order to improve surface properties of PP mesh, a number of surface chemical modification techniques, including oxygen plasma treatment, were employed [13–16]. In the past decades, there were several examples of PP modified with polymers to improve polypropylene’s surface adhesion, wetability, printability and biocompatibility. The sodium hyaluronate- or agarose-coated PP mesh can effectively reduce the formation of intra-abdominal adhesion [17,18]. Poly(lactic acid) (PLA) also can be coated on PP mesh through physically or chemically grafting, where the plasma is very simple and effective grafting method [19,20].

Polyvinyl alcohol (PVA) is nontoxic and noncarcinogenic, and has already been used for numerous surgical applications, such as linings in artificial hearts and contact lenses [21,22]. PVA membrane can perform as antiadhesion barrier, and significantly reduce the number and severity of adhesions in the animal test groups [23]. Kaur and his co-workers grafted PVA onto PP through intercrosslinking reaction with the help of benzoyl peroxide (BPO) and gamma rays [24]. Inspired by the above these studies, in this present study, we attempted to graft PVA onto the polypropylene mesh with the help of oxygen plasma and BPO, and applied it in repairing rabit abdominal wall defect hernia model to demonstrate that whether this new mesh can show better performances.

2. Materials and methods

2.1. Materials

Polyvinyl alcohol (PVA) (M_η = 30,000) were purchased from China National Pharmaceutical Group Corporation (Sinopharm) (Shanghai, China). Polypropylene (PP) mesh was obtained comercially. The native PP meshes with a size of about 3.5 cm × 3.5 cm were tailored. Benzoyl peroxide (BPO) and phosphorus pentachloride (PCl_5) were purchased from Wanqing Chemical Company. Dichloride methane (CH_2Cl_2) was dried with CaH_2, and PCl_5 was used as received.

2.2. Mesh modifications

The modification of PP was carried out according to reference 25 [25]. PP mesh was first cut into pieces with a size of 3.5 cm × 3.5 cm. These PP mesh samples were first extracted with CH_2Cl_2 for 24 h to remove the additional antioxidants and other soluble additives, and then dried under vacuum at 30 °C. The dried PP mesh samples were activated with oxygen plasma cleaning machine (PDC-M, Intensity is 40 W, Oxygen flow is 800 mL/min) for 30 s. Then, the PP meshes were extracted with CH_2Cl_2 and dried under vacuum again. After this procedure, the PP mesh was denoted as PP-OH mesh.

A 500 mL round flask containing 350 mL solution of maleic anhydride (10.0 g) in dry acetone was purged with nitrogen for 20 min to remove any oxygen. The PP-OH meshes were immersed in the flask under a constant oil bath temperature (60 °C) for 2 h. BPO (5.0 g) as the initiator was added to the acetone solution. 2 h later, 2% pyridine solution was added into the flask, during this period the oil bath temperature descended to 50 °C and reaction continued for 1 h. The PP meshes were taken out and dried under vacuum at 30 °C for 6 h.

Those dried PP meshes were subsequently put into a 500 mL round flask containing 350 mL dry acetone, and phosphorus pentachloride (PCl_5) (5.0 g) and polyvinyl alcohol (PVA) (10.0 g) were put into the round flask and reacted with the PP meshes at room temperature for 3 h. The whole reaction was protected with nitrogen. Then, meshese were cleaned with CH_2Cl_2 two times and dried at 60 °C. Finally, these obtained PP meshese from this stage were denoted as PP-g-PVA meshes. The reaction mechanism was demonstrated in Scheme 1.

XPS (Thermo ESCALAB 250, USA) was used to determine the surface composition of the PP meshes. Operation setting: the monochromatic Al Kα X-ray source, 1486.6 eV; the anode X-ray source, 15 KV and 8.9 mA. Survey spectra were acquired from 0 to 1200 eV binding energy (BE), the pass energy is 160 eV, the step size is 1.0 eV, and the dwell time is 50 ms. For high-resolution spectra, a typical average of 12 scans was used, the pass energy is 17.9 eV, the energy step is 0.1 eV, and the dwell time is 1.2 s. The operating pressure of the spectrometer was ~10^{-9} mbar. All data were collected and analysed using software provided by the manufacturer.

2.3. Animals and groups

White New Zealand rabbits (2.5 ± 0.5 kg) were supplied by the Experimental Animal Center of Southeast University. All the rabbits were received a complete diet of rabbit feed ad libidum throughout the entire study and acclimatized at a relative condition (temperature: 25 °C, nature light and dark, humidity: 70%) at least for one week before experiment, which was performed according to the “Principles of Laboratory Animal Care” (NIH publication #85-23, revised 1985). These animals were randomly divided into three groups (each n = 6).

2.4. Surgical procedure

White New Zealand rabbits were anesthetized through ear vein with the amobarbital. The abdomen was shaved and disinfected with 0.5% Povidone-iodine, and made an 8 cm long median incision. Full-thickness square defects (3.0 cm × 3.0 cm) at both sides of abdominal wall were created, only the rabbit skin left as the remainder. In order to compare with themselves, PP-g-PVA mesh and native PP mesh were employed randomly to repair two sides of abdominal wall defects. Mesh borders were laid between peritoneum and muscle and fixed with 8 interrupted Vicryl 4-0 sutures. Fig. 1 showed a hernia model and one repaired with mesh. The muscle layer and skin incisions were then closed each with a continued Vicryl 4-0 suture. Postoperatively, all animals were housed in individual cages with water provided continuously and feed stopping supplying for 6 h.