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Research paper

# Characterizing the ex vivo mechanical properties of synthetic polypropylene surgical mesh

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ABSTRACT

The use of synthetic polypropylene mesh for hernia surgical repair and the correction of female pelvic organ prolapse have been controversial due to increasing post-operative complications, including mesh erosion, chronic pain, infection, and support failure. These morbidities may be related to a mismatch of mechanical properties between soft tissues and the mesh. The aim of this study was to gain a better understanding of the biomechanical behavior of Prolene polypropylene mesh (Ethicon, Sommerville, NJ, USA), which is widely used for a variety of surgical repair procedures.

The stiffness and permanent deformation of Prolene mesh were compared in different directions by performing uniaxial tensile failure tests, cyclic and creep tests at simulated physiological loads in the coursewise (0°), walewise (90°) and the diagonal (45°) directions.

Failure tests suggest that the mechanical properties of the mesh is anisotropic; with response at 0° being the most compliant while 90° was the stiffest. Irreversible deformation and viscoelastic behavior were observed in both cyclic and creep tests.

The anisotropic property may be relevant to the placement of mesh in surgery to maximize long term mesh performance. The considerable permanent deformation may be associated with an increased risk of post-operative support failure.


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## 1. Introduction

Synthetic meshes, typically constructed of knitted filaments of extruded polymers, are commonly used in tension-free hernia and pelvic organ prolapse repair to reinforce weakened tissue and facilitate the incorporation of fibro-collagenous tissue into the porous mesh (Junge et al., 2002; Baessler and Maher, 2006). With some evidence of reduction in hernia recurrence and postoperative pain compared to conventional suture repair, mesh application has become widely accepted with over one million meshes implanted per year world-wide (Brown and Finch, 2010; Schumpelick and Nyhus, 2004). Nevertheless, hernia repair with the use of mesh comes with its own risks. Two-thirds of hernia recurrences occur after three years of mesh implant, and prolapse recurrences following mesh reinforcement is not uncommon (Altman et al., 2011; Schumpelick and Nyhus, 2004). Despite a shift towards lightweight mesh composed of monofilament fibers weaved into a macroporous structure (USFDA, 2011; Amid, 1997), there is still increasing evidence of post-operative complications including infection, hernia and prolapse recurrences, chronic pain, and support failure associated with the mesh implants (Brown and Finch, 2010; Leber et al., 1998; Bellón, 2009). These morbidities are thought to be related to the structural and mechanical properties of the mesh (Leber et al., 1998; Feola, 2011).

With the increasing popularity of mesh use, a wide variety of synthetic meshes are now commercially available, making the selection of the most appropriate mesh difficult. Previous research has focused on distinguishing the morphological and mechanical differences between meshes. Some of the common morphological terms used for comparison include the type of polymer, mesh weight, pore size, and knit structure (Brown and Finch, 2010; Klinge et al., 2002; Krause et al., 2008; Jones et al., 2009). It was found that light-weight mesh with large pore size facilitates tissue infiltration and induces less pronounced foreign body reaction, hence reducing infection and adhesion risks (Brown and Finch, 2010; Bellón, 2009; Klinge et al., 2002; Hernández-Gascón et al., 2011).

The mechanical properties of hernia and urogynaecologic meshes were also investigated, primarily on the static uniaxial tensile failure strength, which is far from being physiologically relevant (Velayudhan et al., 2009; Dietz et al., 2003). A limited number of studies investigated mesh anisotropy, where random orientation of mesh during implantation has been suggested as a main reason for inconsistent surgical outcomes (Anurov et al., 2012; Anurov et al., 2009; Saberski et al., 2011). Hysteresis and permanent deformation were also examined for commonly used surgical meshes, as these are associated with increased risk of mesh support failure (Jones et al., 2009; Hernández-Gascón et al., 2011; Velayudhan et al., 2009; Shepherd et al., 2012; Klinge et al., 1998). Raw mesh is typically subjected to loading shortly after implantation, responding with various degrees of elastic and permanent strain and significantly affecting the ability of the mesh to support surrounding tissues. Furthermore, because of individual differences in long term tissue infiltration of mesh, it is difficult to reliably quantify the mechanical characteristics of combined tissue mesh. Therefore there is a need to understand the long term effects and time-dependent mechanical properties of mesh prior to tissue infiltration in order to facilitate better mesh design (Schumpelick and Nyhus, 2004; Shek et al., 2012). However, the existing tensile failure test is insufficient to provide information on the time-dependent mechanical properties of mesh.

In this study, we aimed to gain a better understanding of the mechanical properties of a commonly used polypropylene mesh, the Prolene mesh (Ethicon, Sommersville, NJ, USA), with a particular focus on the mesh anisotropy and the time-dependent viscoelasticity of the mesh under relevant physiological loading conditions. This was achieved by performing uniaxial tensile failure tests, cyclic, and creep tests on the Prolene mesh in three different directions. By simulating relevant physiological loads in these tests, we provide insight into mesh behavior under large amplitude intra-abdominal pressure changes as well as the viscoelastic properties of the mesh under sustained static loading conditions.

## 2. Materials and methods

### 2.1. Sample preparation

Sterile samples of Prolene polypropylene mesh were cut in coursewise (0°), walewise (90°) and the diagonal (45°) directions (Fig. 1). Eight samples were tested in each direction. Samples were cut using a Trotec Speedy 300 laser cutter to avoid weave distortion and to achieve consistency. "Dog-bone" geometry was used to avoid stress localization near the clamp regions (Fig. 2). Each sample was sandwiched between two 25 mm × 90 mm acrylic plates with epoxy glue at each attachment region. A 25 mm × 50 mm acrylic plate was fixed to each of the attachment regions of the sample with a bolt to allow attachment to the clamps of an Instron™ 5800, which was used for uniaxial tensile testing (Fig. 3).

### 2.2. Mechanical testing

Three types of mechanical tests were performed to examine the mechanical properties of the mesh.

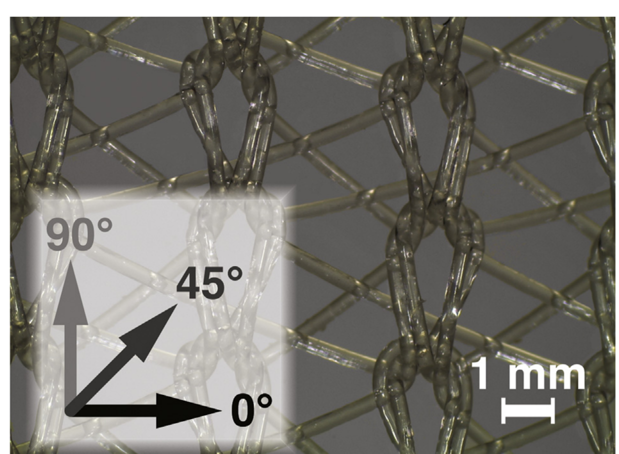


**Fig. 1 – Prolene mesh directions: coursewise (0°), walewise (90°) and diagonal (45°).**