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Research paper

Long-term anisotropic mechanical response of surgical meshes used to repair abdominal wall defects

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ABSTRACT

Routine hernia repair surgery involves the implant of synthetic mesh. However, this type of procedure may give rise to pain and bowel incarceration and strangulation, causing considerable patient disability. The purpose of this study was to compare the long-term behaviour of three commercial meshes used to repair the partially herniated abdomen in New Zealand White rabbits: the heavyweight (HW) mesh, *Surgipro*® and lightweight (LW) mesh, *Optilene*®, both made of polypropylene (PP), and a mediumweight (MW) mesh, *Infinit*®, made of polytetrafluoroethylene (PTFE). The implanted meshes were mechanical and histological assessed at 14, 90 and 180 days post-implant. This behaviour was compared to the anisotropic mechanical behaviour of the unrepaired abdominal wall in control non-operated rabbits.

Both uniaxial mechanical tests conducted in craneo-caudal and perpendicular directions and histological findings revealed substantial collagen growth over the repaired hernial defects causing stiffness in the repair zone, and thus a change in the original properties of the meshes. The mechanical behaviour of the healthy tissue in the craneo-caudal direction was not reproduced by any of the implanted meshes after 14 days or 90 days of implant, whereas in the perpendicular direction, SUR and OPT achieved similar behaviour. From a mechanical standpoint, the anisotropic PP-lightweight meshes may be considered a good choice in the long run, which correlates with the structure of the regenerated tissue.

1. Introduction

Hernia repair is a common surgical procedure when an abdominal wall defect exists. Mechanically speaking, the abdominal hernia is an opening in the abdominal wall layer that makes it impossible for the wall to maintain intra-abdominal pressure. Since the introduction of Lichtenstein's tension-free mesh procedure (Lichtenstein and Shulman, 1986; Lichtenstein et al., 1989), the classic suture techniques have gradually given way to the use of a biomaterial for

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the surgical repair of an abdominal wall hernia, which is a practically standard practice today. Prosthetic mesh was first used for ventral hernia repair in the 1960s, when Usher (Usher, 1959; Usher et al., 1960; Usher, 1970) described the advantages of knitted polypropylene (PP) mesh for the repair of anterior abdominal wall hernias. Since then several studies have shown that closing hernial defects with mesh leads to a lower recurrence rate (Morris-Stiff and Hughes, 1998; Luijenkijk et al., 2000).

There are a variety of meshes made of different materials available to the surgeon when contemplating hernia repair. Currently, PP and expanded polytetrafluoroethylene (ePTFE) meshes are the most commonly employed, although their physical characteristics differ considerably (Bellón et al., 1996). These traditional biomaterials have been gradually modified over the years including modifications to pore size and the spatial arrangement or diameter of their filaments. According to the German school, density is the main feature that serves to classify a mesh into heavyweight (HW) or lightweight (LW) (Klinge, 2007) such that the classic HW meshes have a density above 80 g/m^2 and the LW meshes below 50 g/m^2. A third type or mediumweight (MW) mesh has a density between 50 and 80 g/m^2 (Cobb et al., 2006). When used to repair a tissue defect, PP and ePTFE confer clinical strength to the repair site (Simmermacher et al., 1994; Holzman et al., 1997) but they also elicit an intense inflammatory tissue response (Brown et al., 1985; Law and Ellis, 1988; Saiz et al., 1996; Morris-Stiff and Hughes, 1998). PP shows excellent host tissue incorporation and is relatively inexpensive (Bellón et al., 1998) but unfortunately induces adhesion formation to underlying viscera (Law and Ellis, 1988; Bleichrodt et al., 1993; Saiz et al., 1996; Bellón et al., 1999; LeBlanc et al., 2000; Dinsmore et al., 2000; LeBlanc et al., 2002; Van't et al., 2003). These adhesions may eventually result in bowel erosion, fistulization or obstruction (Simmermacher et al., 1994; Szymanski et al., 2000). In contrast, ePTFE meshes provoke minimal inflammation and adhesion formation (Law and Ellis, 1988; Buján et al., 1997; Bellón et al., 1999; Johnson et al., 2004) and also seem to show some resistance to infection (Brown et al., 1985).

Good clinical results in abdominal hernia surgery are known to strongly depend on a perfect match between the mechanical properties of the abdominal wall and those of the biomaterial used for repair in the long term (Conze and Klinge, 1999). Thus, once the mesh has adapted to the host tissue, the behaviour of the implant site (tissue and mesh) should reproduce the behaviour of healthy tissue. The abdominal wall works as a dynamic system that can withstand sudden pressure changes (coughing, vomiting, etc.) or sustained pressures (obesity, pregnancy, etc.) (Cobb et al., 2005; Song et al., 2006). After the surgical mesh is implanted, the wound repair process causes the mesh to shrink and this is reflected by a reduction in mesh size. However, following mesh shrinkage the implanted material should still show some distensibility to allow movement of the abdominal wall (Klinge et al., 2002; Junge et al., 2001). This determines a need for knowledge of the long term mechanical behaviour of the different biomaterials.

To address the concerns of Bleichrodt et al. (1993) regarding poor host tissue ingrowth into ePTFE implants compromising the strength of clinical repair, LeBlanc et al. (2002) compared the strength achieved by three different implanted meshes; a PP mesh and two ePTFE meshes (a dual-surface mesh DLM and a modified surface mesh DLMC). Having already established that considerable tissue ingrowth occurs within 7–14 days of implant (LeBlanc et al., 1998), LeBlanc et al. (2002) examined the early stage of host tissue ingrowth (3 days). These authors observed that modified forms of ePTFE mesh could achieve abdominal wall repairs that were as strong or stronger than with the use of PP through early host tissue incorporation, while still avoiding adhesions (LeBlanc et al., 1998, 2002). Johnson et al. (2004) compared Sepramesh (SM) and Dualmesh (DM) in terms of strength of tissue incorporation (SOI), mesh shrinkage and adhesiogenesis at 30 days and 5 months post implant. These authors concluded that the SOI achieved by DM increases over time such that at 5 months it becomes comparable to that achieved by SM. Though DM undergoes more mesh shrinkage, similar adhesions are induced by the two materials. In a similar comparison of SM and Parietex composite mesh (PCM) in terms of SOI, adhesion formation and mesh shrinkage at 1 and 5 months, Judge et al. (2007) reported a substantially better SOI for PCM that improved over time, compared to a decline in SOI observed for SM. PCM was also better at avoiding adhesions but underwent considerably more shrinkage.

The functional, morphological and histological properties of HW versus LW PP meshes have also been addressed by several authors. Thus, Bellón et al. (2009) concluded that the lower amount of foreign material implanted when a LW rather than a HW was used resulted in better abdominal wall compliance. Cobb et al. (2006) also reported that physiological abdominal wall compliance could be achieved in the long term after LW mesh implantation used for hernia repair. In a histological study, Pascual et al. (2008) examined the early host tissue incorporation of several LW and HW meshes and observed that the larger pore LW meshes induced the genetic overexpression of collagen types I and III, more collagen type III deposition, its faster conversion to collagen I and that these features conferred these LW meshes greater tensile strengths 14 days after implant.

In the present study, we examine the *in vitro* passive mechanical behaviour of healthy and partially herniated repaired muscle tissue from the short to the long term in the New Zealand White rabbit. As far we are aware, this is the first investigation of this type to include a 6-month time point. First, we characterized the healthy abdominal muscle tissue in terms of its anisotropy and stiffness at 14, 90 and 180 days. Next, we mechanically characterized the partially herniated repaired muscle tissue, and also determined mesh shrinkage at the different post-implant times and the effects of mesh material, pore size, the spatial arrangement of filaments, etc. This was followed by a histological study in which the tissue incorporation process was monitored over time. Finally, in an effort to explain current clinical results, we also determined mechanical correspondence between the intact abdominal muscle and muscle repaired using the three different meshes.

2. Materials and methods

2.1. Experimental data

Experimental tests were conducted on New Zealand White rabbits, an animal model frequently used for the study of