Biocompatible properties of surgical mesh using an animal model

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Abstract

Aim: To study the biocompatibility of surgical meshes for use in pelvic reconstructive surgery using an animal model.

Methods: Eight different types of mesh: Atrium, Dexon, Gynemesh, IVS tape, Prolene, SPARC tape, TVT tape and Vypro II, were implanted into the abdominal walls of rats for 3 months’ duration. Explanted meshes were assessed, using light microscopy, for parameters of rejection and incorporation.

Results: Type 1 (Atrium, Gynemesh, Prolene, SPARC and TVT) and type 3 (Vypro II, Dexon and IVS) meshes demonstrated different biocompatible properties. Inflammatory cellular response and fibrosis at the interface of mesh and host tissue was most marked with Vypro II and IVS. All type 1 meshes displayed similar cellular responses despite markedly different mesh architecture.

Conclusions: The inflammatory response and fibrous reaction in the non-absorbable type 3 meshes tested (IVS and Vypro II) was more marked than the type 1 meshes. The increased inflammatory and fibrotic response may be because of the multifilamentous polypropylene components of these meshes. Material and filament composition of mesh is the main factor in determining cellular response.

Key words: animal model, biocompatibility, monofilament, multifilament, surgical mesh.

Introduction

Pelvic organ prolapse is a common and debilitating condition in women. Over 10% of women require pelvic prolapse repair by the age of 80.1 In a more recent survey in South Australia, 46% of women complained of having experienced or were experiencing pelvic floor dysfunction, including prolapse, and up to 25% had a history of surgery for prolapse and pelvic organ dysfunction.2 Numerous surgical techniques have been described for vaginal surgery. Standard vaginal repairs have recurrence rates of up to 40%.3–6 In an attempt to reduce recurrence and increase durability of repairs, various types of artificial meshes have been developed. While initial data on the clinical use of surgical mesh for vaginal prolapse surgery are promising with regard to reduction in recurrence of prolapse, complications such as mesh erosion and infection indicate that improvements are still required.

Types of mesh vary substantially with regard to composition of the fibres, type of weave, pore size, tensile strength, interstices characteristics and flexibility of the material. Based on pore size, the most common synthetic meshes can be classified into four types.7 Type 1 is macroporous mesh with pore size greater than 75 microns; type 2 is microporous with pore size less than 10 microns in at least one of their three dimensions; type 3 is macroporous with multifilamentous or microporous components; and type 4 has submicronic pore sizes. Types 1 and 3 meshes are used in pelvic reconstructive surgery, types 2 and 4 meshes are instead used for prostheses such as vascular grafts.

While much research has been done assessing optimal meshes for abdominal wall surgery, much less is known about the long-term contribution and properties of mesh for vaginal surgery. Ideal mesh properties for pelvic reconstructive surgery should result in minimal infection, minimal inflammatory reaction, adequate fibrosis and avoidance of excessive fibrosis.

The aim of this study was to assess the biocompatibility of eight surgical meshes (used in urological and gynaecological surgery) in an animal model.

Methods and materials

Animal ethics committee approval was obtained from the University of Queensland prior to commencement of the study. Forty male Sprague-Dawley rats at 70 days of age

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were obtained. Eight different types of mesh were prepared in strips of 5 × 1 cm size. The mesh types employed were Atrium (Atrium Medical Corporation, Hudson, NH, USA), Dexon (Davis & Geck, Quebec, Canada), Gynemesh (Ethicon, Somerville, NJ, USA), IVS tape (Tyco Healthcare International, Mansfield, MA, USA), Prolene (Ethicon), SPARC tape (American Medical Systems, Minnetonka, MN, USA), TVT tape (Ethicon) and Vypro II (Ethicon) (see Table 1). These meshes were divided according to mesh type 1–4. The type 1 meshes made of monofilamentous polypropylene included Atrium, Gynemesh, Prolene, SPARC and TVT. Type 3 meshes included Vypro II (combined multifilamentous polypropylene and multifilamentous polyglactin), Dexon (multifilamentous polyglactin) and IVS (multifilamentous polypropylene).

The rats were anaesthetised using xylazine and ketamine administered intraperitoneally. Using an aseptic technique, each rat had a midline abdominal skin incision, and the subcutaneous tissues were separated with dissection. A sterile mesh strip was placed subcutaneously over intact fascia to the right of the midline. The mesh was sutured in place with three interrupted 2-0 Vicryl sutures. A gentamicin solution was washed over the sutured mesh. The skin was closed with skin clips.

The following mesh types and quantities were implanted: Atrium × 4, Dexon × 4, Gynemesh × 5, IVS × 5, Prolene × 4, SPARC × 5, TVT × 5, Vypro II × 5 and 3 controls.

The meshes were explanted (with fascia intact) at 12 weeks. A midline abdominal skin incision was made and the initial dissection repeated. The abdominal wall was harvested at the site of mesh implantation to include the peritoneal surface. Explanted tissue for histopathological examination was placed in 10% formalin. The tissue was subsequently blocked and stained with haematoxylin–eosin. All samples were labelled using an alphanumeric code.

Light microscopy was used by a pathologist, blinded to the mesh types, to assess parameters of rejection and incorporation. Another independent pathologist, also blinded to the mesh types, assessed the sections and graded the parameters qualitatively. Fibrosis and inflammation was evaluated histologically, by estimating the amount of fibroblasts, fibrosis and inflammatory cells, including giant cells and histiocytes present. Interobserver and intraobserver comparisons were undertaken to ensure reproducibility of results.

Table 1 Properties of biomaterials

<table>
<thead>
<tr>
<th>Product name</th>
<th>Material</th>
<th>Mesh type</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrium</td>
<td>Monofilamentous polypropylene</td>
<td>Type 1</td>
<td>Atrium Medical Corporation</td>
</tr>
<tr>
<td>Dexon</td>
<td>Multifilamentous polyglactin</td>
<td>Type 3</td>
<td>Davis &amp; Geck</td>
</tr>
<tr>
<td>Gynemesh</td>
<td>Monofilamentous polypropylene</td>
<td>Type 1</td>
<td>Ethicon</td>
</tr>
<tr>
<td>IVS</td>
<td>Multifilamentous polypropylene</td>
<td>Type 3</td>
<td>Tyco Healthcare</td>
</tr>
<tr>
<td>Prolene</td>
<td>Monofilamentous polypropylene</td>
<td>Type 1</td>
<td>Ethicon</td>
</tr>
<tr>
<td>SPARC</td>
<td>Monofilamentous polypropylene</td>
<td>Type 1</td>
<td>American Medical Systems</td>
</tr>
<tr>
<td>TVT</td>
<td>Monofilamentous polypropylene</td>
<td>Type 3</td>
<td>Ethicon</td>
</tr>
<tr>
<td>Vypro II</td>
<td>Combined multifilamentous polypropylene, and multifilamentous polyglactin</td>
<td>Type 3</td>
<td>Ethicon</td>
</tr>
</tbody>
</table>

Results

There were no major postoperative complications in the rats. None of the meshes eroded through the abdominal wall or fascial sheath. All wound sites healed without signs of infection. Two rats from the Dexon group developed sterile seromas, which did not reaccumulate after aspiration.

All mesh samples were analysed. With histological review, the samples could be divided into five groups by mesh pattern and cellular response:

- Type 1 meshes (Atrium, Gynemesh, Prolene, SPARC and TVT): small tissue fibrosis; minimal giant cells or histiocytes.
- IVS mesh (type 3): moderate fibrotic reaction with mesh perimeter fibrosis present; highest proportion (same as Vypro II) of giant cells and histiocytes.
- Vypro II mesh (type 3): moderate fibrotic reaction; highest proportion (same as IVS) of giant cells and histiocytes.
- Dexon mesh (type 3): fibroblasts surrounding each polyglactin filament; minimal giant cells or histiocytes.
- Control group: no mesh present; minimal fibrosis or inflammatory response.

Type 1 meshes (Atrium, Gynemesh, Prolene, SPARC and TVT) were indistinguishable from each other, despite markedly different mesh architectures.

Inflammatory reaction

There were variations in the inflammatory cellular response to the different meshes, with Vypro II and IVS (type 3 meshes) having the highest proportion of giant cells and histiocytes. Type 1 meshes and Dexon mesh had minimal giant cells or histiocytes. Control tissues had no inflammatory processes present.

Fibrotic reaction

Vypro II mesh and IVS mesh had a more marked fibrotic reaction than the other meshes. Dexon mesh contained fibroblasts surrounding each polyglactin filament giving it a unique appearance. Type 1 meshes had comparatively small quantities of tissue fibrosis present.
**Discussion**

Different meshes vary in types and amounts of basic polymers present. A more detailed comparison of meshes should include assessment of textile properties, mechanical properties (including tensile strength and mobility), as well as histologically proved tissue reactions.

A number of different animal models have been used for full thickness abdominal wall mesh implantation, including dogs, pigs and rats. The rat is a well-documented animal model for the testing of surgical meshes. This study differs from previous rat experiments, as a full thickness abdominal defect was not created. When using surgical mesh in the genital tract, the mesh is laid over a repaired fascia. By avoiding a full thickness defect, the peritoneal surface remains intact and thus intra-abdominal adhesions do not occur. This technique is more relevant to mesh for use in the genital tract.

In our study, histological assessment of explanted mesh tissue has demonstrated differences in tissue reactions between types 1 and 3 meshes.

All type 1 meshes tested were macroporous, non-absorbable and composed of monofilamentous polypropylene. Despite significantly different mesh architecture, no differences were noted in cellular tissue responses. It could be expected that differences would have been evident as these different type 1 meshes have different biomechanical properties. While adjustments to pore size, mesh weight and mesh pattern aim to optimise mesh biocompatibility, our study demonstrated that the material and filament composition of the mesh is the main factor in determining cellular response. While the histological analysis has shown only subtle variations within this group, other parameters such as biomechanical properties require consideration.

The type 3 meshes (Dexon, IVS and Vypro II) each had unique histological patterns. IVS and Vypro II are both macroporous, non-absorbable and composed of multifilamentous polypropylene. Vypro II also has multifilamentous absorbable polyglactin fibres within its structure. Dexon, however, is a totally absorbable polyglactin mesh.

The inflammatory response in the non-absorbable type 3 meshes tested (IVS and Vypro II) was more marked than the non-absorbable type 1 meshes. The marked inflammatory response of giant cells and histiocytes, may be because of the multifilamentous polypropylene components to these meshes. This finding is consistent with other studies comparing monofilamentous and multifilamentous polypropylene mesh.

Comparison of the fibrous reaction in non-absorbable type 1 and non-absorbable type 3 meshes showed a more marked fibrotic response in the non-absorbable type 3 meshes tested. Once again, the multifilamentous polypropylene fibres may promote added fibrosis compared to monofilamentous polypropylene. The more vigorous inflammatory response of the non-absorbable type 3 meshes may also contribute to fibrosis. While adequate fibrosis is anticipated to give good tissue strength, excessive tissue fibrosis may result in reduced tissue flexibility. Biomechanical testing of these tissues will give correlation to histological appearance and tensile strength.

Dexon differs from the other meshes tested as it is composed totally of absorbable multifilamentous polyglactin. After 12 weeks of implantation, the cellular reaction to Dexon mesh was minimal inflammatory response and moderate fibrosis. The strength of the induced scar tissue that forms over polyglactin mesh has been shown to be lost over time as demonstrated with previous abdominal mesh hernia studies. In addition, clinical studies assessing durability of polyglactin mesh used in vaginal repairs demonstrate higher prolapse recurrence rates compared to non-absorbable meshes.

Infection is also known to enhance inflammatory reaction and connective tissue induction. There is a higher rate of infection with multifilaments rather than monofilaments of the same material. A theoretical disadvantage of multifilaments is that their interstices are less than 10 microns and this may allow small bacteria to infiltrate and proliferate. The bacteria may then not be eliminated by macrophages and neutrophils, which may be too large to enter a 10-micron tridimensional pore. There was no significant cellular evidence of infection in all mesh types tested in our study. While the size of macrophages and neutrophils may limit their access to bacteria within small pores, other chemical, vascular and cellular defence mechanisms are active.

Excessive fibrosis may result in reduced tissue flexibility. Abdominal wall studies show that the degree of inflammatory response and fibrosis directly relates to abdominal wall restriction. Flexibility is a significant issue in genital tract surgery. While durability of vaginal prolapse repair surgery is emphasised, function must also be preserved. Reduced flexibility and increased stiffness may result in reduced function. This study did not demonstrate extensive fibrosis in any of the meshes used currently. It is unknown what extent of fibrosis will result in reduced tissue flexibility.

**Conclusion**

This study assessed meshes used for genital tract surgery over an intact fascia on the rat abdominal wall. Types 1 and 3 meshes tested demonstrated different biocompatible properties within the context of this animal model. Inflammatory cellular response and fibrosis at the interface of mesh and host tissue was most marked with Vypro II and IVS meshes (both type 3 meshes). All type 1 meshes displayed similar cellular responses despite markedly different mesh architecture indicating that material and filament composition of the mesh is the main factor in determining cellular response.

This study confirms the utility of type 1 meshes in uro-gynaecological procedures. However, further information such as tensile strength is required to assess optimal mesh qualities.

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References