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MICROSTRUCTURAL AND MICROMECHANICAL STUDIES OF SURGICAL MESH MATERIALS

Hypothesis / aims of study

Surgical mesh designs have differing mesh dimension and tightness of weaves which may influence the clinical outcome in terms of tissue incorporation, risk of mesh exposure, and possibly rate of infection (1,2). The goal of this study was to examine the microstructural and mechanical properties of two surgical meshes currently used for vaginal prolapse repair.

Study design, materials and methods

The properties of two different types of FDA approved meshes, Uphold™ (Boston Scientific Corporation) and Marlex (C. R. Bard, Inc), were tested for chemical, mechanical, and surface microstructure comparison. These two commonly used meshes are made of polypropylene (PP) but differ in weave and knit structure. Polymer chemical composition was verified by Fourier transform infrared spectrometry (FTIR), and RAMAN spectroscopy. Micromechanical properties were tested on mechanical force measurement instruments adapted to hold meshes for tension and bending measurements. Electron micrographs for surfaces were obtained and characterized before and after stressing and cryofreezing under various conditions.

IR SPECTRA: Samples from the two meshes were analyzed by surface reflection spectroscopy of selected microscopic areas by FTIR using a Nicolet 6700 instrument scanning from 700 to 4000 cm^{-1}, and by RAMAN with a Thermo Scientific DXR RAMAN Microscope scanning from 510 to 3500 cm^{-1}.

MECHANICAL TESTS: Samples of PP sheet and the two meshes were tested on an MTS Systems Corporation Insight 2 electromechanical stress instrument to reach the failure limit. Separate stress tests were done from two orthogonal directions in relation to the waft and weave of the meshes. Three repetitions of each test were carried out.

ELECTRON MICROGRAPHS: The surfaces of the meshes and the PP sheet were examined by scanning electron microscopy (Hitachi S-5000) before and after stress tests, and before and after freezing in liquid nitrogen under dry conditions and after soaking for *15* minutes in water, followed by surface drying.

Results

Spectral results averaged over three scans in each case were compared to library spectra; peak and intensity matches for library PP spectra were from 85% to 95%. Spectra were also compared with a sample of commercial PP sheet with similar results (Figures 1. and 2.). The infrared spectra did not vary significantly before and after stress application. Slight differences were found when comparing unstressed or elastic stressed PP to samples that had been stressed until plastic deformation resulted. Both meshes have a square knit pattern with approximately 8 openings per cm. The Uphold has a tighter, more compressed fiber structure resulting in pores of approximately 0.5 mm diameter, compared with pore diameter of 0.025 mm or less for the more loosely knitted (and more complex porosity) of the Marlex fabric. The electron micrographs (Figure 3.) revealed a slight surface striation pattern on the Uphold fiber surfaces that was not observed on the Marlex. The cross-over points for fibers in the Uphold appeared to have been fused as though the fabric had been compression rolled. The striation pattern was enhanced after freezing. Examples of the elastic limit and stress versus strain slope for the two meshes are shown in Figure 4. The two meshes had roughly the same average stress-strain slope (Young's modulus) in initial loading (0-3 N with 100% deformation), but showed significant differences in strain patterns. Mechanical tests on PP sheet showed elastic deformation of 2.5% up to a load of 33 Newtons (N) , followed by plastic deformation at approximately 30N until failure at 650% deformation. In contrast the meshes had more complex deformation yield patterns in response to much smaller forces, up to 3 N to 6 N. The Marlex samples, with a complex, loose knit, gave a roughly linear 100% expansion in response to loading up to 3 N, at which load resistance dropped to 1 N. Thereafter the mesh expanded roughly linearly with loading up to 5 N until failure at 425% extension. The complex knit resulted in a series of drops in loading resistance over the approximately linear expansion curve, which may correspond to slippage and tightening of the knit. The initially tighter grid of the Uphold mesh had an almost smooth linear expansion of 80% with application of loading up to 2.5 N, followed by a quasi-plastic deformation (roughly flat load curve varying from 2-3 N) with further loading up to failure at 200% extension.

Interpretation of results

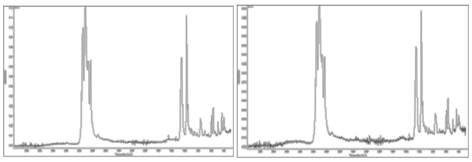
Human structural tissues are very complex materials with multiple layers, heterogeneous composition, and hierarchical sub-structural organization. A working hypothesis is that surgical meshes and scaffold materials should match the tissues that they support and replace in their dynamical mechanical properties (response to stress loadings and deformation). For meshes with the same polymer composition, the organization of the fiber structure (knit and weave, etc.) results in subtle but significant differences in stress-strain and failure behaviour under loads. By thoroughly and precisely characterizing this response for two surgical meshes in current use, we are building a base of data to be used in comparison with measurements on human tissue and in relation to clinical surgical outcomes.

Concluding message

The two meshes studied did not differ in polymer composition but did show significantly different mechanical and microstructural qualities, which may impact their clinical performance. Further studies with comparative biomechanical and polymer stress measurements are planned to assess the most determinant properties of currently available meshes (1) in relation to clinical outcomes.

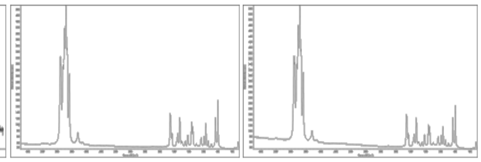
FIGURES (for Mesh 1 = Marlex and Mesh 2 = Uphold)

Figure 1. FTIR Spectra



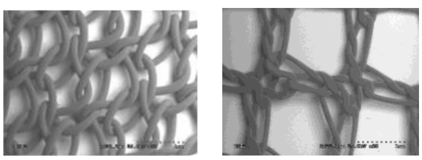
Mesh 1 Mesh 2

Figure 2. RAMAN Spectra



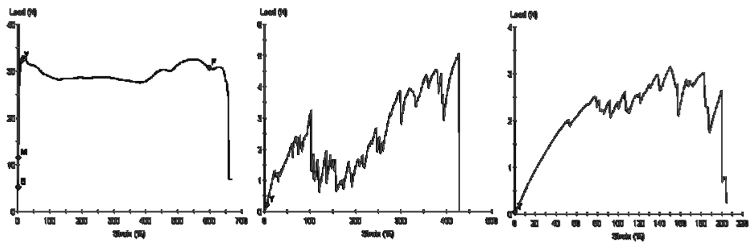
Mesh 1 Mesh 2

Figure 3. Micrographs X30



Mesh 1 Mesh 2

Figure 4. Stress Tests



PP sheet Mesh 1 Mesh 2

References

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2. Gilchrist AS, Gupta A, Eberhart RC, Zimmern PE. Do biomechanical properties of anterior vaginal wall prolapse tissue predict outcome of surgical repair? J Urol 2010; 183: 1069-73.

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