NON-LINEAR ELASTIC BEHAVIOR OF SMALL INTESTINAL SUBMUCOSA

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INTRODUCTION

Small intestinal submucosa (SIS) has been used as a bioactive scaffold for repair of soft tissue injuries. For load bearing and tissue engineering applications, knowledge of the material properties of the implanted scaffold is essential. The properties of SIS have been characterized by linear elastic constant[1]. However, most soft tissues exhibit non-linear elastic behavior. The goal of this study was to characterize the non-linear elastic behavior of SIS laminates.

METHODS

Five 20-layer SIS samples were cut into a dog bone shape with the gage length of 60 mm, cross sectional width of 25 mm, and 40 mm tabs. While dry, a speckle pattern was painted on the samples using an airbrush to facilitate the strain measurement using a digital speckle displacement measurement technique (Fig. 1).

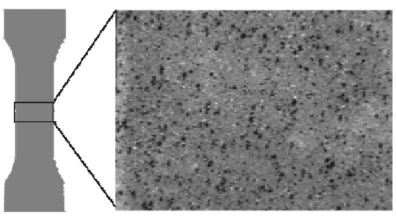


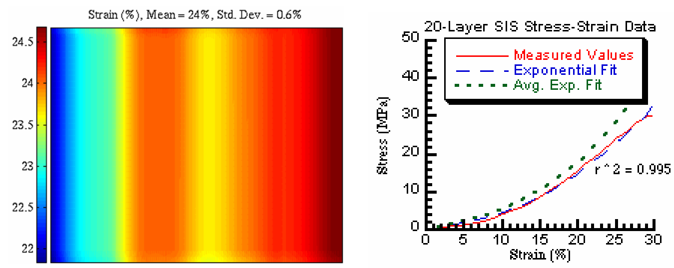
Figure 1. Dog-bone specimen shown with location of strain correlation.

The dry mass of each specimens was measured after which they were soaked in deionized water for two hours for full hydration prior to testing. The hydrated samples were weighed and the new dimensions were measured. They were then placed into cryogenic tissue grips on a material testing machine (Instron 8821, Instron, Canton, MA). A uniaxial tensile test was performed at a strain rate of 100%/s to specimen failure. During the test, video images were taken using a black and white CCD video camera (Sony XCD-X710, Sony Corporation, Tokyo, Japan) at 30 frames per second. A two-dimensional strain field was computed from the images using Vic-2D (Correlated Solutions, West Columbia, SC) optical displacement measurement software. Due to the strains uniformity in each (Fig. 2a) image the average strain values were used to generate stress-strain curves. The out-of-plane strain was calculated by assuming incompressible behavior. The force, stress, and strain at failure were also recorded.

A nonlinear constitutive model was constructed using an exponential strain energy function of the form:

$$W = C(e^{b_1(I_1-3)+b_2(I_2-3)} - 1) \qquad (1)$$

where W is the strain energy , C, b_1, and b_2 are constants, and I_1 *and* I_2 are the invariants of the right Cauchy Green deformation tensor.



(a) (b)

Figure 2. (a) A typical strain field demonstrating uniformity with a size of 25 mm by 10 mm. (b) Stress-strain behavior of laminated SIS. The dashed line is the fit of the data shown by the solid line. The dotted line is the model prediction using the mean coefficients from five specimens.

RESULTS AND DISCUSSION

The hydrated samples had an 80% change in cross-sectional area and an increase of mass of over 100%. Based on the hydrated cross-sectional area the average ultimate tensile strength was 30.5±2 MPa. The constants C, b_1, and b_2 in the nonlinear material model (Eqn. 1) had values of 3.268±1.4 MPa, 0.076±0.84, and 1.045±0.25 (mean ± std. dev.), respectively (Fig. 2b).

Variations of this model have been used to characterize the biaxial mechanical data of SIS [2], pressure properties in a rabbit aorta [3], and blastula wall stiffness[4]. Although this non-linear neo-Hookean exponential constitutive model agreed with the experimental data, other models can also be applied to this data to assess which model best describes the material behavior.

CONCLUSIONS

An exponential neo-Hookean constitutive model was found to correlate well with the measured stress-strain behavior of layered laminated SIS. This constitutive model can be applied to further research of SIS soft-tissue composites to predict the strength of the construct as a load bearing scaffold.

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