Biaxial Creep Behavior of the Apical Vaginal Support in Gilts

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Abstract. Despite the essential role of the uterosacral ligaments in female pelvic organ support, more work remains to be done to characterize their viscoelastic mechanical behavior. In this study, digital image correlation and optical coherence tomography were used to take high accuracy measurements of uterosacral ligament tissue deformation in 3 dimensions during creep, including axial strain mapping in 2 dimensions and average through-thickness change. The resulting stress-strain curves showed that the tissue specimens deformed insignificantly more in the ligaments' perpendicular loading directions than in their main *in vivo* loading directions. The optical coherence tomography data showed that the specimens got measurably thinner over the course of creep, challenging the incompressibility assumption that is often made in the mechanical analysis of soft tissues.

Introduction

Pelvic organ prolapse, characterized by the descent of the pelvic organs into the vagina, is estimated to affect up to 50% of the U.S. adult female population, often resulting in serious physical and psychological symptoms [1,2]. The uterosacral ligaments (USLs) are the most important support structures for the apical vagina and uterus and are often targeted as supportive anchors for prolapsed pelvic organs in reconstructive surgeries. Despite their mechanical importance in the body and their use as native surgical mechanical supports, the USLs remain understudied from a mechanistic perspective. In particular, the viscoelastic mechanical properties of the USLs must be elucidated in order to understand the etiologies of pelvic floor disorders as well as the outcomes of their surgical correction. The objective of this study is to characterize the three-dimensional deformations of the USLs under creep loading.

Materials and Methods

USLs were excised from 5 healthy gilts (virgin swine) immediately post sacrifice. Since the USLs *in vivo* are membrane-like in nature, the main loading axes were defined in the direction from the distal attachment at the cervix to the proximal attachment at the sacrum (the main *in vivo* loading direction) and the direction perpendicular to it (the perpendicular direction). Specimens of 1.5 cm by 1.5 cm were isolated, suspended with hooks, and loaded into a custom-built biaxial testing apparatus equipped with two 50 g-capacity load cells. Specimens were immersed in PBS and preloaded to 5 mN along the main *in vivo* loading direction and the direction perpendicular to it. They were then preconditioned between 0.01 N and an upper value ranging from 1 to 2 N depending on the thickness of the individual specimens at a rate of 10 µm/sec for 10 cycles. Following preconditioning, specimens were loaded to their upper load and held for 40 min. During this time, images were taken at a rate of 1 Hz for strain mapping using digital image correlation (Vic-3D, 8, Correlated Solutions, SC). Optical coherence tomography (OCT) was used to collect through-thickness images at discrete time points throughout the tests.

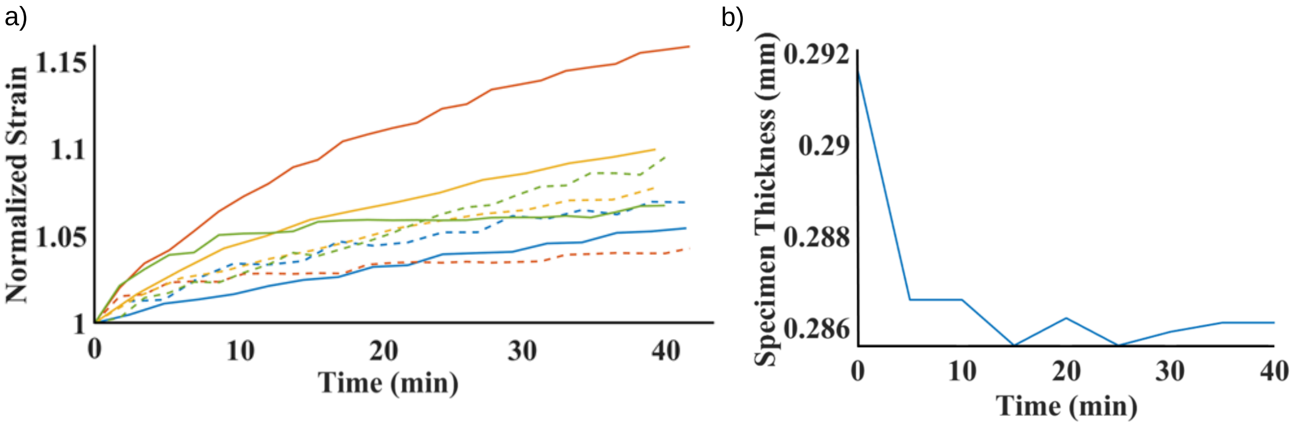

Fig. 1 (a) Strain over time in the main *in vivo* loading (solid lines) and the perpendicular directions (dotted lines) during creep for 4 representative specimens from n=10 total. (b) Change in tissue thickness over the course of creep, showing a thickness change of 1.8% (about 5.5 µm).

Results and Discussion

While the maximum normalized creep strains were not significantly different between the two loading axes due to high variance between specimens, the specimens were found to strain slightly more in the perpendicular loading direction with an average maximum strain of 0.090 vs. a maximum strain of 0.084 for the main in vivo loading direction. The OCT images showed that the specimens were substantially flatter and measurably thinner by the end of the tests.

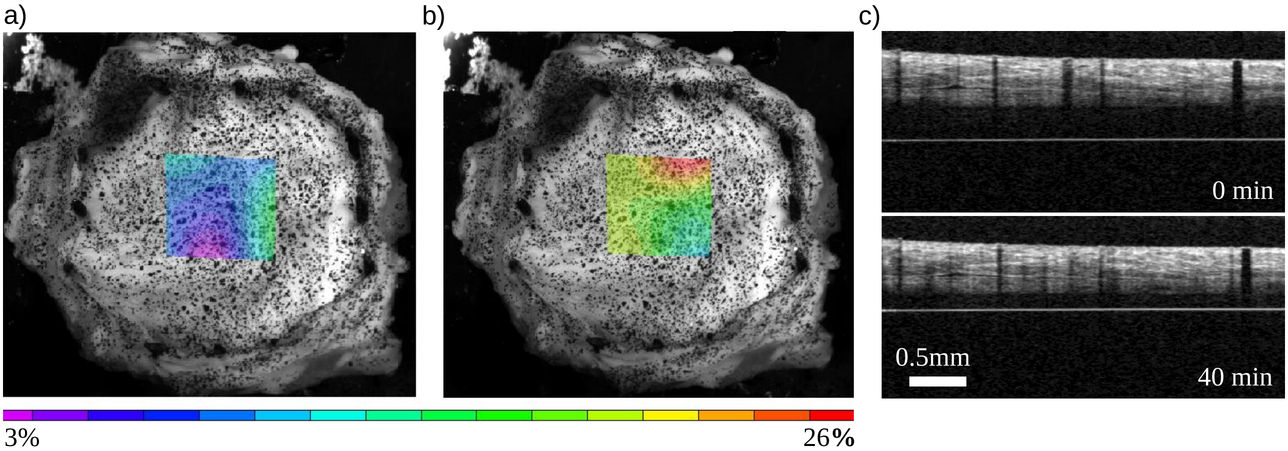

Fig. 2 (a) Axial Lagrangian strain map for a single specimen in the main *in vivo* loading direction of gilt uterosacral ligaments during creep testing. (b) Axial Lagrangian strain map for the same gilt USL specimen in the perpendicular loading direction. (c) Cross-sections of a gilt USL specimen 0 minutes (top) and 40 minutes (bottom) into creep, showing a change in thickness of 1.8% over the course of the test.

Conclusion

Creep testing showed high variance and some potential anisotropy in the viscoelastic behavior of the USLs. The OCT images showed that the specimens changed thickness a small but measurable amount, which challenges the incompressibility assumption that is often made when modeling and testing soft tissues. Collectively, these data could allow us to better understand the in vivo behavior of the USLs and ultimately inform surgeries for prolapse correction which use the USLs to restore pelvic organ support.

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References

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