AN EXPERIMENTAL METHOD FOR MECHANICAL ANALYSIS OF THE INTERSPINOUS AND SUPRASPINOUS LIGAMENTS

Brian Beaubien[1], Joan Bechtold[1], William Lew[1], Pascal Swider[2]
[1]Midwest Orthopaedic Research Foundation, Minneapolis, MN
[2]Laboratory of Biomechanics, Toulouse, France
e-mail:bbeaubien@morfn.org; web: www.morfn.org

INTRODUCTION

Differences in the interspinous ligaments (ISLs) and supraspinous ligaments (SSLs) have been observed in patients with kyphotic and scoliotic spines. These differences are to be evaluated mechanically, but the appropriate test method is unclear. Specifically, a protocol to compare the combined and individual viscoelastic contributions of the ISL and SSL needs to be developed. The objective of this study was to select a rigorous but interpretable model and experimental method to use in comparing clinically obtained tissues. Sample data from porcine ligaments were evaluated using this method.

METHODS

The quasi-linear viscoelasticity (QLV) model was chosen to model the stress-relaxation behavior of the ligaments. This method assumes separable time-dependent relaxation and strain-dependent elastic functions. The relaxation function was the focus of this study, and was represented by a three-element Maxwell model (Eq.1):

Eq. 1 $$G(t) = [G_1\, e^{\beta_1 t} + G_2 e^{\beta_2 t} + G_2 e^{\beta_3 t} + G_\infty]$$

Relaxation time constants (β_i) were fixed at 10ms, 100ms, and 1s, respectively, in order to provide an accurate but more constrained curve fit, and to facilitate physical interpretation. Furthermore, because G(t) is normalized to the instantaneous strain, G(0) was constrained to be 1.

Models were fit to sample relaxation data acquired from porcine bone-ligament-bone ISL-SSL constructs (N=4). These constructs were preconditioned and subjected to a “step input” of 25% strain and allowed to relax for 1000s. Ligaments were returned to zero strain and tested again after separation of the ISL and SSL with a scalpel blade (without disruption of the ligament-bone interface), and after removal of the SSL (n=2) or ISL (n=2). The remaining ligament was tested to failure at 0.1 mm/s, and the failure stresses and strains were calculated. Two additional bone-ligament-bone constructs were evaluated histologically to observe the ISL and SSL fiber orientation. The mean and standard deviation were calculated for each relaxation variable.

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RESULTS AND DISCUSSION

The relaxation function fit the data well (Table 1). Separating the ligaments reduced the maximum and equilibrium stress of the bone-ligament-bone complex by 31% and 19%, respectively. Removing the SSL further reduced the instantaneous and equilibrium stress of the ISL to approximately 90% and 89% of the respective sectioned states. With the ISL removed, the mean instantaneous and equilibrium stresses of the SSL alone were 25% and 15% of the sectioned sate stresses, respectively. The ISL’s failed at a mean 1122kPa and 72% strain, and SSL’s failed at a mean 1720kPa and 42% strain. Histology revealed ISL fibers parallel to the spinous processes, SSL fibers perpendicular to the processes, and many fibers spanning the two ligaments.

	G_∞	G_1	G_2	G_3	R^2
Specimen 1	0.643	0.152	0.112	0.107	0.997
Specimen 2	0.651	0.123	0.086	0.129	0.997
Specimen 3	0.698	0.111	0.095	0.094	0.996
Specimen 4	0.666	0.105	0.095	0.118	0.998
Mean	0.664	0.123	0.097	0.112	
St. Dev.	0.024	0.021	0.011	0.015	

Table 1- Reduced relaxation function coefficients and residual values

CONCLUSIONS

The three-element relaxation function provided a close and relatively repeatable fit to stress-relaxation data to ISL-SSL construct. The stress in the intact ligaments decreased greatly when the ISL and SSL were separated. This decrease may be attributed to cutting the fibers that were seen to span the two ligaments. The stresses in the SSL alone during the relaxation experiment appeared to be lower than those for the ISL, but the failure load for the SSL appeared to be higher. This discrepancy may exist because the SSL spans several spinal levels *in vivo*, and its unloaded length may therefore differ from that of the ISL in single-level constructs.

The QLV model employed as described here will be used to test clinically obtained tissue. The ISL and SSL can be sectioned to determine the properties of the two ligaments individually, but care should be taken in considering the interaction of these non-discrete ligaments. A larger study is needed to statistically describe the findings in this study.

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