STRESS RELAXATION OF CANINE FLEXOR TENDONS

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INTRODUCTION

Viscoelastic materials, such as tendons and ligaments, exhibit mechanical behavior that is dependent on time and load-history. Viscoelasticity in tendon has been studied to a lesser extent than in ligament. Much of the previous tendon data is difficult to interpret because of the various experimental techniques used, such as gripping the bony insertions vs. the tendon itself or using grip-to-grip vs. local strains [1,2]. The development of accurate material models requires data that are obtained with a minimum of experimental artifact. Therefore, our aim was to investigate the viscoelasticity of tendon and evaluate the gripping artifact associated with our experimental method.

METHODS

Twenty-five flexor digitorum superficialis (FDS) tendons were harvested from the hind paws of seven mature, male, mongrel dogs (24–30 kg) and frozen until tested. At testing, tendons were thawed and clamped directly, leaving a grip-to-grip gage length of ~20 mm. Cross-sectional area was estimated from optical analysis of images captured during rotation of the tendon in a custom device. Optical markers were placed on the surfaces of the tendons and monitored throughout the test to determine the local strain. Tendons were tested in saline at 37ºC, and preconditioned 11X to 30 MPa at 10 mm/min. Data from the 11th cycle of preconditioning was used to determine elastic modulus (data not reported here). Tendons were then rested for 40 min, preloaded to 0.25 N, and immediately ramped to 1.45 mm (stresses ≥ 30 MPa), at a rate of 100mm/sec, and held for 1200 sec. A stress relaxation ratio was computed from the ratio of final to peak load. A stress relaxation rate was defined as the slope of the log(stress)-log(time) curve between 3-100 sec [3]. Gripping artifact was evaluated by comparing grip-to-grip and local strains.

RESULTS

Viscoelastic testing data is shown in Table 1. Mean relaxation ratio and rate are similar to values previously reported for tendon and ligament [1-3]. Note that the mean local step strain of 4.1% was considerably less than the calculated grip-to-grip step strain of 7.25 % (based on a 1.45 mm step and 20 mm gage length). Further, local step strains varied widely among the specimens (~3-7 %), despite starting with similar gage lengths and applying the same step displacements to all samples. To investigate local strain measurements further, we extrapolated the local strain at 1.45 mm displacement from the test used to determine elastic modulus that had been run on the same specimens just prior to viscoelastic testing. The high correlation between the local strains at 1.45 mm displacement determined from the two different tests (Figure 1), suggests variation in the viscoelastic local strain is not related to measurement error or loading rate. Further, no correlation was found between viscoelastic local strain and specimen cross-sectional area.

Parameter	Mean ± St. Dev.	Range
Relaxation Ratio	0.692 ± 0.042	0.553 to 0.759
Relaxation Rate	-0.025 ± 0.005	-0.035 to -0.015
Local step strain	0.041 ± 0.009	0.030 to 0.067
XSA (mm^2)	3.21 ± 0.40	2.54 to 4.31

Table 1. Viscoelastic testing data from canine flexor tendons (n=25)

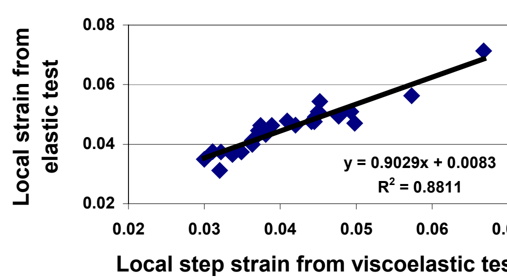

Figure 1. Local (Optical) Strain at 7.25% Grip-to-Grip Strain (1.45 mm displacement)

DISCUSSION

The canine flexor tendons in this study relaxed similarly, though somewhat less and at a slower rate, than bone-tendon-bone samples reported previously [1, 2]. We speculate that these differences are due to a greater, and perhaps faster, relaxation at the bone-tendon interface than in pure tendon. The result that local strains were considerably less than grip-to-grip strains underscores the importance of making local strain measurements in order to avoid gripping-artifacts. Finally, the wide variation in local step strain, despite application of the same grip-to-grip step strain, could not be explained by measurement error, loading rate, or specimen cross-sectional area. Further investigation of these results, including assessing non-linear material behavior, is ongoing.

REFERENCES

1. Atkinson, T.S., Ewers, B.J., and Haut, R.C., 1999, "The tensile and stress relaxation responses of human patellar tendon varies with specimen cross-sectional area," Journal of Biomechanics, Vol. 32, pp. 907-914.
2. Graf, B.K., Vanderby, R. Jr., Ulm, M.J., Rogalski, R.P., and Thielke, R.J., 1994, "Effect of preconditioning on the viscoelastic response of primate patellar tendon," Arthroscopy, Vol. 10, pp. 90-96.
3. Provenzano, P., Lakes, R., Keenan, T., Vanderby, R. Jr., "Nonlinear ligament viscoelasticity," Annals of Biomedical Engineering, Vol. 29, pp. 908-914.