THE RATE OF VISCOELASTIC RECOVERY IS FASTER THAN THE RATE OF CREEP

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INTRODUCTION:

The recovery of load-induced lengthening is a fundamental behavior relevant to joint function, albeit one that has not been explored. It is relevant to athletes who often "stretch" ligamentous restraints before exercise, and to surgeons who stretch ligament grafts before and during insertion. In these examples, the temporal aspect of normal loading causes viscoelastic adaptation (i.e. ligament lengthening), which should be explored further.

Ligaments behave in a time-dependent manner and have a nonlinear stress-strain response. Studies have shown that deformation over time from constant load (creep) progresses more slowly than the decrease in load from constant stretch (stress relaxation) (Thornton 1997, Provenzano 2001). Recent experiments reveal that the rate of creep and stress relaxation are dependent on the stress and strain levels, respectively (Provenzano 2001, Hingorani 2003). This phenomenon is not accurately described by a separable QLV theory and, therefore, a more general formulation is necessary (Hingorani 2003, Lakes 1999, Provenzano 2001). The above suggests that time dependent recovery from loading will be different than the time dependent behavior during loading, although experimental evidence is lacking. The purpose of this study was then to determine the rates of recovery and creep.

METHODS:

This study was approved by the Institutional Animal Use and Care Committee and meets the National Institute of Health guidelines for animal welfare. Medial collateral ligaments (MCLs) were exposed and extraneous tissue was carefully dissected from adult male Sprague-Dawley rats (385 $\pm$ 18g). MCLs, including intact femoral and tibial bone sections (FMT complex) were excised for ex vivo testing. The FMT complex was then mounted into a custom designed bath, and optical markers were placed on the MCL insertion sites. Specimens were tested in creep and recovery in the following manner. After a preload of 0.10 N was applied, a step load of 7.35 N was added, and the MCL was allowed to creep. After 100 seconds, the 7.35 N was released, and the ligament was allowed to recover for 1000 seconds with the preload remaining on the ligament. Tests were video taped, digitized, and analyzed to measure strain during creep and the subsequent recovery. Creep and recovery data versus time were fit with a power law. The exponent of the power law represents the rate of creep and the rate of recovery. The absolute values of the exponents were compared. Statistical analysis was performed using Student's paired t-Test with $\alpha = 0.05$ and a significance level of $p = 0.05$.

RESULTS:

Figure 1 shows a representative pair of creep and recovery tests, respectively. For each pair of tests, the rate of creep was slower than the rate of recovery. Figure 2 shows the average rates for creep and recovery. The rate of creep is significantly slower than the rate of recovery ($p = 0.04$).

DISCUSION:

This study shows that the rate of recovery is faster than the rate of creep. This difference would appear to be of physiologic benefit, biased towards maintaining ligaments in their "normal" resting length. From a physiological standpoint, these data suggest that MCLs are slower to stretch out and faster to recover their "normal" lengths.

Results of this study are in contrast to the assumption that the rates of creep and recovery are equal, which is commonly used when modeling the viscoelastic properties of ligaments. Therefore, the different rates should be taken into consideration in future models. These results also have important experimental implications for sequential test protocols. More studies must be performed to better understand the mechanisms behind this phenomenon.

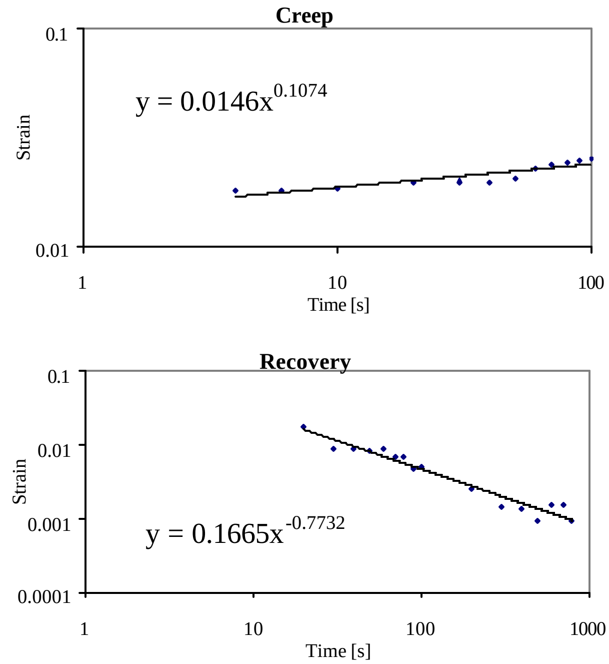

Figure 1. Example of a pair of creep (top) and recovery (bottom) tests. The rate of creep was slower than the rate of recovery for every pair of tests.

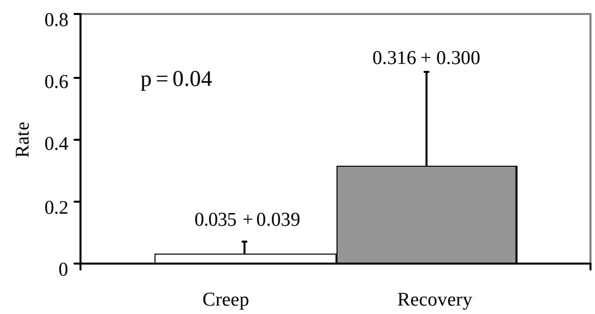

Figure 2. Average rate of creep and recovery. The rate of creep is significantly slower than the rate of recovery ($p = 0.04$).

REFERENCES:

Hingorani RV, Provenzano PP, Lakes R, Escarcega A, Vanderby R Jr. *Ann Biomed Eng*. Accepted 2003.

Lakes RS, Vanderby R Jr. *J Biomech Eng*. 121(6):612-5, 1999.

Provenzano P, Lakes R, Keenan T, Vanderby R Jr. *Ann Biomed Eng*. 29:908-914, 2001.

Thornton GM, Oliynyk A, Frank CB, Shrive NG. *J Orthop Res*. 15(5):652-6, 1997.

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