EFFECT OF CYCLIC STRETCHING ON THE TENSILE PROPERTIES OF PATELLAR TENDON AND MEDIAL COLLATERAL LIGAMENT

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INTRODUCTION:
Athletes typically perform warm-up and stretching exercises to prepare for more strenuous exercise. However, the effect of stretch alone on the prevention of injury is still controversial in clinical and basic science evidence [1].

Increased tensile stress and elastic modulus might represent a mechanism to resist tendon damage when the tendon is loaded. In 1995 Simonsen documented that Achilles tendon properties may respond to the number of cycles of muscle loading during training [2]. It implied that the repeated muscle contraction associated with tendon stretching may play a role in increased tensile stress of the tendon.

The objective of this study was to determine the influence of stretching before exercise on the structural and mechanical tensile properties of tendon and ligament. We hypothesized that an increase in ultimate tensile stress and elastic modulus would occur during sinusoidal cyclic loading stretch in patellar tendon and medial collateral ligament. Therefore, it would indicate that stretching did exert a protective effect on tendon and ligament.

METHODOLOGY:
Ten pairs of medial collateral ligaments (MCLs) and patellar tendons (PTs) from euthanized Sprague-Dawley rats were used in this study. Ten MCL and PT specimens were loaded to failure after sinusoidal cyclic stretching. The contralateral specimens were used for immediate tensile testing without cyclic stretching. A universal testing machine (TestResources Inc. Shakopee, MN) was used. Actual load and deformation were collected on a controller (TestResources Inc.). The femur-MCL-tibia complex was tested with the knee in 70° of flexion. The PT was aligned with the load axis of the actuator and the tendon was fully extended to achieve straight line test. Specimens were preloaded for 0.8-1 N, and then subjected to sinusoidal strain oscillation profiles under the displacement control mode, with an amplitude of 0.04 mm to maintain longitudinal loading from 0.5 to -0.5 N at 0.5 Hz during 300 sinusoid cycles. This amplitude was chosen based on pilot testing to determine the optimal oscillating strain that could be consistently applied without damage to the specimen.

Paired t-tests were used to compare all test parameters between noncyclic and cyclic loading of the MCLs and the PTs respectively. The confidence interval was set at 95% and the parameter for the comparison was P = 0.05.

RESULTS:
Ultimate failure load was significantly different between the non-cyclic and cyclic groups in both MCL and PT (P = 0.0165 and 0.003, respectively). Absorbed energy was significantly increased after cyclic stretching in MCLs (P = 0.0031) but with borderline significance in PTs (P = 0.0595). Table 1 & 2 show the ultimate stress was significantly increased between the non-cyclic and cyclic groups in both MCLs and PTs (P = 0.0026 and 0.0002, respectively). Ultimate strain was significantly increased after cyclic stretching in MCLs (P = 0.0003) and in PTs (P = 0.0325). Elastic modulus in the cyclic group improved significantly in both MCLs and PTs (P = 0.0057 and 0.0017, respectively).

Although tensile stress and modulus increased in magnitude after the cyclic stretching test, there were comparably different amounts between the two types of specimens. The larger amount of increased stress and modulus was observed for PTs (stress: 40.64±9.47 MPa vs 62.29±10.61 MPa; modulus: 369.27±75.19 MPa vs 573.49±93.78 MPa) than for MCLs (stress: 41.77±8.89 MPa vs 51.33±10.84 MPa; modulus: 278.91±44.64 MPa vs 314.31±43.2 MPa).

DISCUSSION:
This study characterized the structural and mechanical properties of PT and MCL in rat under sinusoidal oscillation cyclic stretching. The tensile stress, strain and elastic modulus of PT and MCL increased significantly after cyclic stretching. The increase of tensile stress and elastic modulus after cyclic stretching were higher for PT than for MCL.

There was a significant increase in tensile stress and modulus of PT and MCL with applied cyclic stretching (Fig. 1). This suggests that cyclic stretching causes microstructural change, reorganization or gradual recruitment of a microstructural feature. The viscoelastic property of tendon and ligament under uniaxial tensile loading have been attributed to inherent viscoelasticity of the collagen fibers, the extracellular matrix, interfibrillar crosslinking, intermolecular crosslinking, and fluid content. However, the exact sources of ligament viscoelasticity under different loading conditions remain controversial [3].

The increase in stress and modulus of PT after cyclic stretching was greater than that for the MCL because of different amounts of fiber recruitment. The material properties of ligament and tendon exhibit a directional dependence in response to applied load [3]. Patellar tendons consist mainly of parallel oriented fibers, while the MCL is a flattened fibrous structure made up of a superficial and a deep layer with oblique oriented alignment. These obliquely running fiber bundles cannot perform the same uniform recruitment patterns as the patellar tendon during uniaxial cyclic stretching. Thus the increase of stress and modulus after cyclic stretching would be not greater in MCL than in PT. This evidence gives a new perspective on the importance of ligament axis relative to stretching axis during stretching exercise to obtain advantages for soft tissue strengthening.

In summary, sinusoidal cyclic stretching contributes to increased tensile stress and modulus of the tendon and ligament. The increased tensile stress and modulus after cyclic stretching have increased ability to resist damage during sport activity. Tendon and ligament have a unique and complex running alignment which is likely critical to a recruitment of the fibers bundled within them as the joint moves during stretching exercises. Therefore, we propose that correct stretching techniques performed prior to strenuous exercise may be more important than previously thought.

REFERENCES:

AFFILIATED INSTITUTIONS FOR CO-AUTHORS:
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<td>Ultimate strain (%)</td>
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<td>Elastic modulus (MPa)</td>
<td>369.27±75.19</td>
<td>573.49±93.78</td>
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Table 1. MCL complex: mechanical properties

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<th>Non-cyclic</th>
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<tr>
<td>Ultimate stress (MPa)</td>
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<td>Elastic modulus (MPa)</td>
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Table 2. PT complex: mechanical properties

![Fig. 1 Stress-strain curve of MCL. The ultimate stress, ultimate strain and absorption energy increased after cyclic stretching.](image-url)