Enhancement of Mechanical Strength from Preconditioning Varies in Ligaments and Tendons

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Introduction: Ligaments and tendons are frequently injured soft tissue structures in sports activities. A common procedure to prevent athletes from ligament and tendon injuries is warming-up and stretching prior to activities. This preconditioning recommended by most clinicians is believed to reduce the risk of injuries [1, 2]. A recent study further suggested that the preconditioning with cyclic stretching might temporarily enhance the patella tendon on mechanical strength [3]. However, it is unclear that the same enhancement exists for other ligament or tendon structures.

The purpose of this study was to investigate structural dependent effect of preconditioning on the mechanical strength of ligaments and tendons. We hypothesized that preconditioning had different enhancements on the mechanical strength depending on the specific of ligaments and tendons.

Materials and Methods: 26 anterior cruciate ligaments (ACLs), 22 medial collateral ligaments (MCLs), 20 patella tendons (PTs), and 18 Achilles tendons (ATs) from euthanized Sprague-Dawley rats were used. The specimens were wrapped in moistened gauze (0.9% normal saline), sealed in plastic Petri dishes and stored at -20°C until testing. Before testing, the specimens were allowed to thaw at room temperature for 6 hours.

Testing was performed with a universal testing machine (TestResources Inc., Shakopee, MN) at room temperature and specimens were kept moist with 0.9% normal saline during the entire test sequence. For ACL and MCL testing, the femur and tibia were potted into a plastic tube with fixation of bone cement. The plastic tubes were placed into grip of test device. For PT testing, the tibia was potted into a plastic tube with bone cement. The patella was placed directly into upper grip and the tube with tibia was placed into lower grip of test device. For AT testing, the calcaneus was placed directly into upper grip of test device. The AT was aligned with load axis of the actuator. Load and displacement were continuously recorded at a sampling rate of 50 Hz during testing by a computer attached to the materials testing system. The ultimate failure load was calculated from the peak of the load-displacement curve. The strength was calculated as the load to failure divided by the cross-sectional area of each ligament and tendon.

Specimens were tested and randomly divided into control and preconditioning group. The specimens in control group were used for immediate failure loading without preconditioning. In preconditioning group, then 150 sinusoid cyclic stretching at 0.5Hz (300 seconds) were performed. The cyclic sinusoid oscillation profile was applied under displacement control mode, with amplitude of 0.05-0.15mm (1-2% cyclic strain) depending on the specimen to maintain longitudinal loading from 0.5 to 1.5 N. The specimens were consecutively loaded to ultimate failure in the same manner as the control with an axial load at a speed of 0.05mm/s.

A two-way analysis of variance (ANOVA) with post hoc Tukey test was performed in control and preconditioning groups of MCL, ACL, PT, and AT to detect preconditioning effects, variations in ligaments and tendons, and interaction. All differences were considered significant at a probability level of 95% (p<0.05).

Results: Two-way ANOVA revealed significant differences in ultimate failure load and mechanical strength with preconditioning (p<0.001 and p<0.001, respectively), with regard to the specific of ligaments and tendons (p<0.001 and p<0.001, respectively), and significant interaction (p<0.001 and p=0.001, respectively). The ultimate failure loads of PT and AT were significantly different between control group and preconditioning group (p<0.001 and p<0.001, respectively) (Fig. 1). The mechanical strengths of MCL, PT, and AT were significantly increased in preconditioning group (p=0.04, p=0.006, and p=0.002, respectively) (Fig. 2). There were no significant differences among the mechanical strengths of MCL, PT, and AT in preconditioning group.

Preconditioning did not affect the strength of ACL. In control groups, there were no significant differences among the mechanical strengths of each ligament and tendon. In preconditioning groups, however, the strength of ACL was significantly smaller than those of other ligaments and tendons (all p<0.001) (Fig. 2).

There were significant differences in stiffness and elastic modulus depending on ligaments and tendons (p<0.001 and p=0.001, respectively), however, no significant differences were found within preconditioning. There was no significant interaction between preconditioning and the specific of ligaments and tendons.

Discussion: This study investigated structural dependent effect of preconditioning on the mechanical strength of ligaments and tendons. Preconditioning significantly increased the mechanical strengths of MCL, PT, and AT. However, it did not affect that of ACL. The difference in mechanical strength of AT was the most significant (p=0.002), followed by PT (p=0.006), and MCL (p=0.04). The results suggested that different preconditioning strategy may be needed for different ligament and tendon structures in order to gain maximal protection during sports activities.