Mechanical Properties of Semitendinosus Tendon Recover with Time Post Transsection for ACL Reconstruction

Stephen M. Suydam, MSc, Daniel H. Cortes, Ph.D., Thomas S. Buchanan, Ph.D.
University of Delaware, Newark, DE, USA.


Introduction: Anterior cruciate ligament (ACL) tears result in reduced stability of the knee joint and ACL reconstruction has been adopted as a method of stability restoration[1,2]. Greater than 50% of all ACL tears result in knee osteoarthritis within 10 years of the incident and is thought to be caused by several factors including joint instability. A semitendinosus (ST) tendon autograft has been demonstrated as an effective procedure for restoring knee stability and has a reduced prevalence of osteoarthritis following reconstruction compared to other autograft techniques[3]. Though the ST autograft has been shown to be a reliable surgical technique, hamstring weakness in deep knee flexion and internal rotation still exists as well as an increased external tibial rotation during running[4,5]. The manifestation of these weaknesses may lead to altered kinematics and condylar loading locations, which have been associated with osteoarthritis progression[6,7]. These remaining weaknesses are associated with the function of the ST muscle and the restoration of this muscle group would aid in reducing those musculoskeletal changes. Previous studies have shown, via imaging techniques such as MRI and ultrasound, there is evidence of the regrowth and reorganization of the ST tendon, though no studies have shown whether the regrown tendon returns to its previous functional capabilities[8]. Therefore, it is the purpose of this study to show that mechanical properties, i.e., the shear modulus of elasticity of the tendon (μ), recover with time post ACL reconstruction with a ST tendon autograft.

Methods: Eight subjects who sustained an ACL rupture were recruited to participate in this study. Each patient, following an ACL tear, received a ST tendon autograft and was 6-24 months post-op. Regrowth of the ST tendon was confirmed via b-mode ultrasound. Shear modulus of the ST tendons was ascertained through continuous shear wave elastography (cSWE). cSWE is a technique which utilizes external shear waves traveling along a medium and tracks their speed through high frame rate ultrasound, which is then translated to shear modulus[8]. Each subject lay prone on a plinth with their knee at a 45 degree flexion angle. The ST tendon was palpated and verified as the correct hamstring tendon via B-mode ultrasound and a mark was placed on the skin's surface to identify the tendons location. The high frame rate ultrasound probe was placed transversely along the tendon and an actuator capable of generating sinusoidal shear waves was also placed along the tendon, proximal to the ultrasound probe (Figure 1). The actuator generated a sine wave at a single frequency while the ultrasound collected raw RF data. The frequency was increased and the process was repeated 6 times with the frequency ranging from 200-600hz. The average wave propagation velocity was determined within the tendon from the raw RF data using a custom Matlab code for each of the frequencies. The shear modulus was determined through the optimization of a Voigt model using the frequencies and velocities determined from the 6 RF data sets[8]. A Pearson's correlation was used to determine the correlation between time post-surgery (in months) and percent difference of shear modulus between the involved and uninvolved tendons.
**Results:** A positive correlation between time post-op and shear modulus exists ($r = 0.77$, $p = 0.023$) (Figure 2). This demonstrates not only tendon regrowth, but also recovery of its functional mechanical properties.

**Discussion:** The elastic modulus (E) of the tendon indicates the ability for force generated by the muscle to be transmitted across the joint. The greater the elastic modulus, the more energy is transferred through the tendon during a contraction to produce motion. The shear modulus has a linear correlation to the elastic modulus, as shown by Zhang and colleagues, and therefore an increase of $\mu$ is be related to an increase in E[9]. Given the architecture of the ST muscle and the insertion location of the ST tendon, the ST muscle generates its peak force at a greater flexion angle than the other hamstring muscles, reducing deep knee flexion weakness, and the ST contributes to the internal rotation of the tibia due to its more medial tendon insertion[10]. The recovery of the shear modulus is a measure showing the ability for the ST muscle to regain its functionality and contribute to internal rotation and deep knee flexion strength, as it did before the transection. The restoration of this function has the potential to restore lost strength to the knee and prevent kinematic and loading alterations of the joint. The altered loading of the knee caused by these deficits could be leading to osteoarthritis. By following the regrowth of the tendon and the restoration of the mechanical properties, a rehabilitation regimen could be developed to strengthen the once again functional ST muscle. The return to bilateral symmetry of the ST may lead to a reduction in osteoarthritis following ACL reconstruction.

**Significance:** This work demonstrates that, following the transection of the semitendinosus tendon for use in an ACL autograft, the tendon regrows and the functional, mechanical properties of the tendon recover with time. The reconstitution of the semitendinosus tendon allows for the restoration of semitendinosus muscle function and a possible reduction in the strength deficits associated with this graft type.
Figure 2. Correlation between the time post-op and the difference between the involved and uninvolved semitendinosus tendon shear modulus. Note Pearson’s r=0.77, which indicates the tendon is recovering its mechanical properties as it regrows over time.