The Initial Anterior Cruciate Ligament Graft Pre-Tension Force Affects Graft Healing: An Experience with a Small Animal Reconstruction Model

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Introduction: Several technical factors are important to the success of soft-tissue anterior cruciate ligament (ACL) reconstruction. One often-cited variable is the amount of the initial graft pre-tension and its effect on the success of repair at the time of reconstruction. The current literature on the optimal ACL graft pre-tension is controversial however [1]. The limitations of existing preclinical studies include lack of standardization of post-operative ACL graft loads as well as heterogeneity in the types of graft used [2-3]. As a result, conflicting evidence exists regarding the impact of graft pre-tension on healing following soft-tissue ACL reconstruction. There is no current consensus on the optimal amount of graft pre-tension at the time of ligament reconstruction.

Previous studies have demonstrated that tendon healing and maturation of the tendon-bone entheses are sensitive to changes in mechanical environment. It is therefore possible that the amount of initial pre-tensioning may affect graft healing and maturation following soft-tissue ACL reconstruction. The objective of this study is to evaluate the impact of initial ACL graft tension on graft healing using a small reconstruction model where ACL graft load and knee motion can be controlled post-operatively. Our hypothesis is that an excessively tensioned or under-tensioned soft-tissue ACL graft at the time of surgery would lead to decreased ACL healing properties as manifested by inferior ACL biomechanical properties and decreased incorporation at the graft-tunnel interface.

Methods: Male Sprague-Dawley rats (n= 72) underwent unilateral ACL resection followed by reconstruction using a 1.4 mm flexor tendon autograft. The animals were allocated into one of three initial ACL graft pre-tension levels at the time of reconstruction: (1) 0N pre-tension, or (2) 5N pre-tension, or (3) 10N pre-tension. All limbs were flexed to 40 degrees at the time of graft pre-tension (Fig. 1). The operative limbs were then immobilized at 40 degrees using a small joint fixator in order to control and eliminate joint motion and ACL load post-operatively. Outcomes measured included biomechanical, micro-CT, and histologic analyses at 3 and 6 weeks. Comparison was performed using ANOVA. All data are presented as mean ± standard error of the means (SEM). A p-value <0.05 was considered to indicate significant differences. The study was approved by the local Institutional Animal Care and Use Committee.

Results: Our results suggest that under-tensioning (0N) or over-tensioning (10N) ACL grafts at the time of reconstruction resulted in impaired ACL graft healing. The ultimate load-to-failure of the femur-ACL graft-tibia complex was significantly lower for 0N (3 weeks: 3.96 ± 1.83N; 6 weeks: 10.82 ± 1.97N) and 10N (3 weeks: 4.46 ± 2.52N; 6 weeks: 7.35 ± 2.85N) pre-tensioned grafts when compared to 5N (3 weeks: 8.58 ± 2.67N; 6 weeks: 16.56 ± 3.50N) ACL grafts (p<0.05) (Fig. 2). The stiffness of 0N and 10N rat femur-ACL graft-tibia complexes were also significantly lower than 5N pre-tensioned grafts at 3 and 6 weeks (p<0.05). There were also differences in mode of ACL graft failure during biomechanical testing between 5N pre-tensioned grafts and 0N and 10N grafts. While most 5N pre-tensioned ACL grafts failed with an intact graft via graft-tunnel pullout (93.3% graft pullout, 6.3% ACL substance failure), higher numbers of ACL graft intrasubstance ruptures occurred within the 0N (60% ACL substance failure) and 10N (53.8% ACL substance failure) pre-tension groups. Histologically, greater cellularity as well as collagen fiber gapping and disorganization were seen in portions of 0N and 10N grafts at both 3 and 6 weeks (Fig. 3). Finally, micro-CT demonstrated a higher mean bone volume per tissue volume (BV/TV) within the tibial tunnels of 5N pre-tensioned graft at 6 weeks (5N: 0.26 ± 0.7; 0N: 0.18 ± 0.07; 10N: 0.2 ± 0.02).

Discussion: Our controlled laboratory study demonstrates that ACL graft healing is sensitive to initial graft pre-tension at the time of surgery. An excessively tensioned (10N) or under-tensioned (0N) soft-tissue ACL graft resulted in inferior ACL properties as manifested by lower graft load-to-failure and stiffness. The mode of graft failure and histological analyses, however suggest graft substance degeneration as an underlying mechanism of failure rather than failure at the graft-bone tunnel interface. There were more ACL intrasubstance graft failures seen with under-tensioned and excessively tensioned ACL grafts during biomechanical analyses. Furthermore, histological evidence of graft degeneration and collagen disorganization were seen in both under-tensioned and excessively tensioned ACL grafts. One aspect of our study that may limits its clinical applicability is the immobilization of the animals’ knees following reconstruction. Our goal for the present study was to attempt to isolate and evaluate the graft pre-tension as the sole mechanical factor in our experiment. Future studies may evaluate the interplay between knee motion and graft pretension by combining an external fixator along with a mechanized knee motion device to deliver daily controlled knee motion following reconstruction.

Significance: The results of this study have particular relevance since the most common method of ACL reconstruction performed by surgeons today utilizes soft tissue grafts, specifically hamstring autografts. The result of this study suggests that there is likely...
an optimal level of pre-tension for ACL graft healing, therefore, it may have implications on how we execute one of the most common musculoskeletal reconstructive procedures being performed.

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References:

Figure 1. Initial pre-tensioning of ACL graft prior to graft fixation (left). An external fixator is placed to eliminate post-operative ACL load following surgery (right).
Figure 2. ACL graft pre-tension levels and load-to-failures at 3 weeks (left) and 6 weeks (right) following reconstruction.

Figure 3. Histological section of ACL graft within tibial graft tunnel at 6 weeks. Excessively tensioned (10N) ACL graft (left) demonstrated greater cellularity and collagen disorganization with gapping between collagen fibers when compared to 5N pre-tensioned graft (right).

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