

# Temporal Changes in ACL Graft Structure and Composition and Knee Laxity Assessed via Quantitative MRI and a Novel Multiplanar Arthrometer

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**Introduction:** Anterior cruciate ligament (ACL) injuries are prevalent among young athletes, with ACL reconstruction (ACLR) commonly performed to restore knee stability [1]. ACLR failure is high (~18%) especially among young patients participating in high demand cutting and pivoting sports [2]. Although mechanisms for graft failure are multifaceted and complex [3], persistent knee laxity is a key factor related to reinjury, and early osteoarthritis [4-6]. Therefore, restoration of both uniplanar (i.e., Lachman exam) and multiplanar (i.e., Pivot shift exam) knee stability, which depend on a mechanically competent ACL graft construct, are critical indicators of successful ACLR [7]. ACL graft competency can be noninvasively assessed using the quantitative magnetic resonance imaging (qMRI) technique of T2\* mapping to characterize changes in graft structure and composition that occur via biological remodeling [9-11], providing a critical tool to identify patients who may be prone to graft failure in the case when biological remodeling of the graft fails to produce adequate mechanical stability of the knee. To this end, we are conducting a prospective study to link biological remodeling of the ACL graft (obtained using ultra short T2\* qMRI) with objective and quantitative uniplanar and multiplanar assessments of clinical knee stability (obtained using a novel multiplanar arthrometer). In this interim analysis of data from the preoperative, and 6Wk, 6Mo, and 1Yr timepoints, we asked how: 1) uniplanar and multiplanar knee laxity change over time; 2) graft structure and composition via qMRI change over time; 3) knee laxity relates to structure and composition of the ACL graft; and, 4) uniplanar and multiplanar laxity relates to structure and composition of the intact ACL in the uninjured, contralateral knee.

**Methods:** With IRB approval and informed consent, ten subjects have been enrolled (age: 23±5, 4 M/6F, BMI: 23.8±3.1), with a targeted enrollment of 20 subjects. All subjects had sustained non-contact, unilateral rupture of their ACL while participating in cutting and pivoting sports. Graft materials were hamstring (n=1), patellar tendon (n=8), or quadriceps tendon (n=1). Study visit time points are: pre-operative, and 6Wk, 6Mo, 1Y, and 2Yr postoperatively. **Imaging:** qMRI of the contralateral knee (pre-operative visit) and reconstructed knee (6Wk, 6Mo, and 1Yr at the time of this interim analysis) was performed on a clinical 3T system using an ultra-short echo imaging (UTE) acquisition to derive native or graft ACL T2\* values: TE/TR: 0.03 to 25 ms (ATE=2.5ms) / 256.6ms, voxel size 0.31x0.31x1.5mm<sup>3</sup>, BW:±62.5 kHz. The ACL was manually segmented and T2\* was calculated on a voxel-by-voxel basis. **Joint Laxity:** A novel multiplanar knee arthrometer was utilized at 6Mo and 1Yr post-operatively [12]. The examiner performed a Lachman exam and a simulated pivot shift exam with their leg at 30° of flexion. To perform the Lachman, the examiner applied forces of 135 N anteriorly and 50 N posteriorly for five cycles. The outcome of this exam was anterior laxity (measured from 0 to 135 N of anterior load). Second, the examiner performed a simulated clinical pivot shift exam. The examiner first applied a valgus moment of 8. Then, while holding the valgus moment constant, the examiner applied five cycles of anterior-posterior (AP) forces from 10 N posterior to 75 N anterior to the lateral handle of the arthrometer to subluxate and reduce the lateral tibial compartment. The outcome measure was AP translation of the lateral tibial compartment (from 0 to 75 N anterior). **Statistical Analyses:** (1) Anterior laxity, and lateral compartment translation were compared at 6Mo and 1Yr post-operatively using an unpaired t-test; (2) UTE T2\* values were compared at 6Wk, 6Mo, and 1Yr post-operatively using an un-paired t-test. (3) and (4) Joint laxity was related to the corresponding T2\* outcome for the uninjured limb at pre-op and the reconstructed limb at 6Mo post-op using simple linear regression. Statistical significance was taken as p < 0.05.

**Results:** Data collection for this study is ongoing; data has been collected for 10 patients pre-operatively, 10 at 6Wk, 7 at 6Mo, and 4 at 1Yr. No statistical differences of the laxity outcomes (anterior or simulated pivot) were currently detected among the timepoints (Fig. 1) (p≥0.1). The T2\* relaxation values significantly increased, 4.3±1.7 ms on average, from 6Wk to 1Yr (p=0.02), but not from 6Wk to 6Mo (p=0.05, Fig. 2). T2\* values of the native ACL were positively related to anterior laxity of the uninjured contralateral limb (p=0.01, β=3.0±0.9, Fig. 3 Left), but not with lateral compartment translation. Finally, a negative relationship between anterior laxity and T2\* in the reconstructed knee at 6Mo post-op did not achieve statistical significance (p=0.12, β=-1.3±0.7, Fig. 3, Right).

**Discussion:** A key strength of this study is relating objective arthrometric assessments of uniplanar laxity (i.e., Lachman exam) and multiplanar knee stability (i.e., pivot shift exam) with noninvasive, objective measures of graft structure and composition via qMRI. At this interim timepoint, we observed that joint laxity values did not increase from 6Mo to 1Yr for any test, but that T2\* values in the reconstructed limb increased between 6Wk and 1Yr, as has been previously described [9]. We identified a positive relationship between T2\* in the contralateral uninjured knee and anterior knee laxity in agreement with a previous finding [14]. Elevated T2\* is associated with decreased collagen organization and the presence of more mobile water; thus, elevated knee laxity may also be associated with a structurally weaker ACL. In contrast to the native ACL, a potential negative relationship between anterior laxity and graft T2\* was observed, which could suggest differences in structure and composition of the graft compared to the native ACL. This relationship may be attributable to ligamentization [15] and changes of collagen fibril organization and local water content. It could also be attributable to graft volume [13, 16]. Enrollment is on-going towards increasing the statistical power of our analyses. Data collection includes assessments of post-operative strength and neuromuscular control to power a larger study relating graft structure and function to biomechanics of the joint and whole-body scales.

**Clinical Relevance:** Clinically, integrating qMRI with objective arthrometric assessments could enhance early detection of suboptimal graft healing to guide return-to-sport decisions. This work demonstrates that T2\* relaxation times are associated with joint laxity measurements, potentially identifying patients at risk for persistent knee laxity and graft failure via non-invasive imaging.

**References:** [1] Wojtys J Athl Train 2010 [2] Maletis AJSM 2016 [3] Mancino BJO 2024 [4] Jonsson Acta Orthop Scand 2004 [5] Leitz CORR 2005 [6] Kocher AJSM 2004 [7] Magnussen AJSM 2016 [8] Wada JOR 2025 [9] Chu OJSM 2019 [10] Warth AJSM 2020 [11] Jerban JOR 2022 [12] Imhauser J Biomech 2024 [13] Bedi KSSTA 2010 [14] Wang OJSM 2021 [15] Yau AJSM 2023 [16] Biercevicz AJSM 2014

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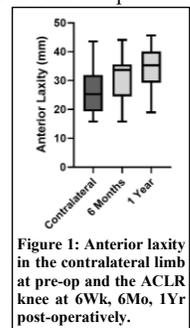


Figure 1: Anterior laxity in the contralateral limb at pre-op and the ACLR knee at 6Wk, 6Mo, 1Yr post-operatively.

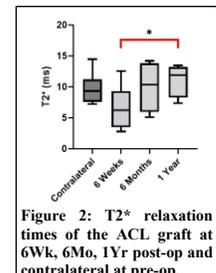


Figure 2: T2\* relaxation times of the ACL graft at 6Wk, 6Mo, 1Yr post-op and contralateral at pre-op.

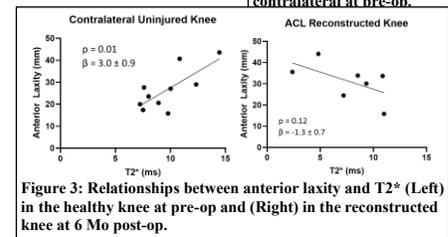


Figure 3: Relationships between anterior laxity and T2\* (Left) in the healthy knee at pre-op and (Right) in the reconstructed knee at 6 Mo post-op.