The Relation between Ultrashort Echo Time (UTE) T2* **Imaging and Knee Laxity: Cohort Study**

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INTRODUCTION:

Identifying reliable, non-invasive biomarkers for ACL graft maturation and mechanical strength is crucial for managing graft healing post-ACL reconstruction (ACLR). In this context, UTE-T2* is a novel MRI sequence for capturing detailed images of tissues such as tendons and ligaments, which were difficult to image using traditional T2 sequences. This sequence is useful for examining the structural properties of graft tissues during ligamentization post-ACLR. UTE-T2* imaging quantifies the tissues' T2* relaxation times by analyzing the decay of MR signal intensity over a series of images at different short echo times. The decay signal is more complex than previously thought, highlighting the limitations of the traditional mono-exponential decay fit (i.e., T2m*). Instead, a bi-exponential decay analysis is advocated, with short (T2s*) and long (T2l*) phases representing bound and free water, respectively. Bound water, associated with collagen organization, contributes to the graft’s structural integrity and mechanical properties. By analyzing these different phases, improved understanding can be gained into the graft ligamentization process and the role of treatments in enhancing it.

However, there is a lack of understanding about how UTE-T2* correlates with knee stability and functional clinical outcomes. Laxity is a widespread clinical assessment for monitoring joint stability, evaluating surgical outcomes, guiding rehabilitation, and predicting graft failure risk. Exploring the laxity-UTE-T2* relationship, especially using bi-exponential decay analyses, is critical. Therefore, bridging clinical and research imaging gaps in this way is vital for evidence-based practice, refining care, and assessing treatment efficacy.

This study will correlate UTE-T2* outcomes and laxity post-ACLR over time (6 and 12 mos.) and test the impact of mono- vs. bi-exponential decay fits on these relationships. It was hypothesized that T2s* will correlate with laxity.

METHODS:

31 subjects with unilateral ACLR (14 males and 17 females; 18 ± 3.7 years; body mass index [BMI] of 24.06 ± 4.7 kg/m^2) were included in this IRB-approved study. Knee laxities and UTE-T2* images were acquired at 6 and 12 months post-ACLR. Laxity was objectively measured using an automated arthrometer. The knee was flexed at 20˚ and subjected to a 200 N anterior drawer force. Using a UTE-T2* sequence, 3T MR images were collected from the ACLR knee (9 UTEs: 2.3-18.3 ms with 2 ms increments).

The graft was manually segmented from the MR images and decay coefficients (T2m*, T2s*, and T2l*) were calculated by fitting the mono- and bi-exponential fits to these data points using a least squares approach. Decay coefficients were reported as the median T2* value of the voxels.

The laxity and decay coefficients were BMI normalized, and their correlations were assessed using Pearson’s correlation ($\alpha = 0.05$).

RESULTS: At six months, laxity measures showed a moderate correlation with T2s* ($R = 0.285$, $p = 0.025$) and no significant correlations with T2m* ($R = 0.233$, $p = 0.068$) and T2l* ($R = 0.166$, $p = 0.197$). By twelve months, significant correlations were detected for both T2s* ($R = 0.669$, $p < 0.001$) and T2l* ($R = 0.354$, $p = 0.034$) as well as T2m* ($R = 0.532$, $p < 0.001$).

DISCUSSION AND CONCLUSION:

T2s* had the strongest correlation to knee laxity than other measures at both time points, supporting the study hypothesis. These findings align with prior clinical and basic science studies showing that reduced T2s* strongly correlates with the tissue's bound water content—a reflection of its collagen organization. Reducing T2s* has been linked to improved ACL mechanical properties, which can contribute to decreased knee laxity, as supported by the current findings. These results suggest that UTE-T2*imaging, especially the T2s*component, could serve as a valuable tool in monitoring graft healing and assessing the success of ACL reconstruction surgeries.

The different correlation between T2s* coefficients and knee laxity at 6 and 12 months may be associated with differing stages of ligamentization. Studies have shown variability in the timing of the proliferation stage, but there is consensus that by 12 months post-ACLR, the graft has transitioned to a mature state. This maturation process may explain the low correlation between T2* coefficients and knee laxity at 6 months, as the graft is undergoing significant biological changes. At 12 months, the graft has generally reached a more stable and mature stage, leading to more consistent correlations with knee laxity across all T2* values. The ability of T2s* to reveal a linear relationship between imaging and knee laxity, even during the mid-to-late maturation stages, underscores its potential utility in monitoring graft healing.

T2l* displayed no correlation with laxity at 6 months and only a weak correlation at 12 months. This aligns with the understanding that T2l* relates to the graft's free water content, which minimally affects knee laxity. The observed correlation at 12 months suggests an intrinsic link between graft maturation and its influence on regulating water content, which is an area of future exploration. The mono-exponential approach, characterizing decay as an ambiguous mix of

T2s* and T2l* traits, showed T2m* correlating with laxity, albeit with coefficients between T2s* and T2l* at both time points. However, this analysis fails to clearly differentiate between bound and free water content, limiting mechanistic insights into its role in graft maturation post-ACLR.

UTE-T2* imaging, especially the T2s* component, correlates with knee laxity—a crucial clinical measure for assessing knee function. This suggests its potential as a valuable and clinically relevant biomarker for evaluating graft maturation.

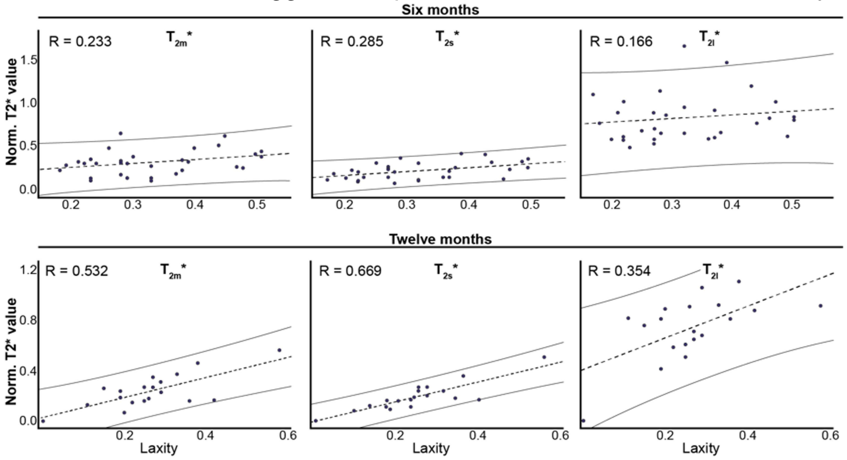

Figure 1. Scatter plots of BMI-normalized laxity and T_2* coefficients for 95% confidence intervals