MRI Derived Parameters Of Volume And Signal Intensity Predict Clinical, Functional And Patient-oriented Outcome Measures Following ACL Reconstruction

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Introduction: Knee arthrometry, hop testing, and patient oriented outcome questionnaires have been useful for many clinical studies as a standardized way to evaluate overall patient knee outcome following ACL treatment;[1] however, these evaluation techniques are knee specific measures of joint and patient health but may lack the sensitivity to determine the biomechanical properties of the graft. A more specific measure of graft integrity would therefore be a useful compliment to the already existing set of treatment evaluation tools. The purpose of this study is to determine if the magnetic resonance (MR) image-derived parameters of graft volume and signal intensity (SI), which have been used to predict the biomechanical (i.e., structural properties) of the graft in animal models, correlate with commonly used clinical (anteroposterior (AP) knee laxity), functional (1-leg hop) and patient-oriented outcome measures (KOOS)[2] in patients 3- and 5-years after ACL reconstruction.

Methods: A subset of participants enrolled in an ongoing Institutional Review Board (IRB) approved study, investigating the effects of initial graft tension on long-term outcome of ACL reconstruction with autograft, was used for this analysis.[1] Patients received either a high-tension or low-tension graft following an isolated unilateral ACL injury as previously described.[1] The primary study results at 3-year follow-up found no significant differences in the clinical, functional and patient-oriented outcome measures between the high- and low-tension treatment groups.[1] Subsequently, all patients with complete traditional outcomes and MR scans were pooled for this analysis. The resulting study group (10 men, 13 women) had a mean age of 22.8 ± 9 years at time of surgery. Seventeen patients received bone-patellar tendon-bone autograft obtained from the central third of the ipsilateral patellar tendon and 6 received a 4-stranded autograft created from the semitendinosus and gracilis tendons. Ten received a low-tension graft and 13 received a high-tension graft.

Clinical (AP knee laxity), functional (1-legged hop test) and patient-oriented (KOOS) outcomes were used to assess overall patient knee function and patient outcome at 3- and 5-year follow-up and to establish the relationships with the MR parameters of graft healing.[1] MR images were collected at each follow-up. A 3-D T1-weighted FLASH sequence (TR/TE/FA, 20/7.6/12°; FOV, 160 mm; matrix 512X512, slice thickness/gap, 1.5mm/0; avg 1; bandwidth, 130) was used to
image each patient’s operative knee. Both the volume and median SI of the healing graft were
determined from these images[3] and were used as predictors in a multiple regression linear model to
predict the traditional outcome measures. Scans with confounding metal artifact due to magnetic
susceptibility effects in proximity to the graft were omitted from analysis. At 3-year follow-up, 23
patients had complete traditional outcomes and MRI scans not confounded by metal artifact. The same
group of patients used for 3-year follow-up was followed for two more years and used for the 5-year
follow-up. Of the 3-year follow-up patients, 15 patients had complete traditional outcomes and MRI
scans not confounded by metal artifact at the time of the 5-year follow up.

**Results:** Graft volume combined with median SI in a multiple linear regression model predicted 1-legged
hop test at both the 3-year and 5-year follow-up visits (\(R^2=.40, p=.008\) and \(R^2=.62, p=.003\), respectively).
Similar results were found for AP knee laxity (\(R^2=.47, p=.031\)) and the KOOS quality of life (\(R^2=.49, p=.012\)),
sport/function (\(R^2=.37, p=.048\)), pain (\(R^2=.46, p=.017\)) and symptoms (\(R^2=.45, p=.021\)) sub-
scores at 5-year follow up.

**Discussion:** In general, for traditional outcomes at 5-year follow-up, larger grafts with lower median SI
values were associated with better knee performance and surgical outcome. At 5-year follow-up,
patients with higher APlaxity% scores (i.e., more surgical knee laxity than the contra-lateral control)
tended to have grafts with smaller volume and higher median SI (Figure 1). For the functional outcome
at 5-year follow-up, patients with higher hop% (higher percent score reflects better knee function),
tended to have larger grafts with lower median SI (Figure 2). Similarly, for the KOOS-spt, KOOS-pain,
KOOS-qol, and KOOS-sym sub-scores at 5-year follow-up, patients with larger graft volumes and lower SI
had higher sub-scores (higher scores indicate better knee function). Previous research has shown larger
graft or ligament volume[3]-[5] and lower graft or ligament SI[3], [6] are correlated to higher strength or
biomechanical properties. These results show that MR parameters that relate to graft biomechanical
performance are also predictive of overall patient knee health and ACL reconstruction surgical
outcomes.

This study is limited by the use of the SI variable, which can vary depending on scanner hardware and
MRI acquisition parameters.[7] To address this concern we used the same MR imaging parameters and
manufacturer (Seimens, 3T trio) throughout the study. Furthermore, we normalized the graft SI values
to that of cortical bone within each image to minimize concerns of variability between scan sessions.[3]

**Significance:** The MR parameters (volume and median SI) used to predict ex vivo biomechanical
properties of the graft in an animal model have the ability to predict clinical or in vivo outcome
measures in patients at 3 and 5-year follow-up. Results from this study may enhance clinical evaluation
of graft health by relating the MR parameters of volume and median SI to traditional outcome measures
and could potentially aid researchers in determining the appropriate timing for athletes to return to
sport.

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<th>Prediction equations are a function of graft volume and SI. Similar results found KOOS sub-scores</th>
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Figure 1: The patient graft prediction plane for knee AP laxity% as a function of graft volume and median SI at 5-year follow-up. The grafts with the higher volume and lower SI tended to have lower AP laxity% scores.
Figure 2: The patient prediction planes for hop score as a function of graft volume and median SI at A) 3-year follow-up and B) 5-year follow-up. The grafts with the higher volume and lower SI tended to have higher hop scores.
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