Anterior and Rotational Knee Laxity Does Not Affect Patient-Reported Knee Function 2 Years After Anterior Cruciate Ligament Reconstruction

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Background: While a primary goal of anterior cruciate ligament (ACL) reconstruction is to reduce pathologically increased anterior and rotational knee laxity, the relationship between knee laxity after ACL reconstruction and patient-reported knee function remains unclear.

Hypothesis: There would be no significant correlation between the degree of residual anterior and rotational knee laxity and patient-reported outcomes (PROs) 2 years after primary ACL reconstruction.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: From a prospective multicenter nested cohort of patients, 433 patients younger than 36 years of age injured in sports with no history of concomitant ligament surgery, revision ACL surgery, or surgery of the contralateral knee were identified and evaluated at a minimum 2 years after primary ACL reconstruction. Each patient underwent Lachman and pivot-shift evaluation as well as a KT-1000 arthrometer assessment along with Knee injury and Osteoarthritis Outcome Score and subjective International Knee Documentation Committee (IKDC) scores. A proportional odds logistic regression model was used to predict each 2-year PRO score, controlling for preoperative score, age, sex, body mass index, smoking, Marx activity score, education, subsequent surgery, meniscal and cartilage status, graft type, and range of motion asymmetry. Measures of knee laxity were independently added to each model to determine correlation with PROs.

Results: Side-to-side manual Lachman differences were IKDC A in 246 (57%) patients, IKDC B in 183 (42%) patients, and IKDC C in 4 (<1%) patients. Pivot-shift was classified as IKDC A in 209 (48%) patients, IKDC B in 183 (42%) patients, and IKDC C in 11 (2.5%) patients. The mean side-to-side KT-1000 difference was 2.0 ± 2.6 mm. No significant correlations were noted between pivot-shift or anterior tibial translation as assessed by Lachman or KT-1000 and any PRO. All predicted differences in PROs based on IKDC A versus B pivot-shift and anterior tibial translation were less than 4 points.

Conclusion: Neither the presence of IKDC A versus B pivot-shift nor increased anterior tibial translation of up to 6 mm is associated with clinically relevant decreases in PROs 2 years after ACL reconstruction.

Keywords: ACL reconstruction; knee laxity; patient-reported outcomes
the KT-1000 arthrometer is classified as IKDC A (−1- to 2-mm difference), IKDC B (3- to 5-mm or −3- to −1-mm difference), IKDC C (6- to 10-mm or less than −3-mm difference), or IKDC D (greater than 10-mm difference).5

In addition to knee laxity, patient-reported outcomes (PROs) are frequently utilized to assess results of ACL reconstruction. The IKDC subjective score7 and Knee injury and Osteoarthritis Outcome Score (KOOS)17 are validated PRO tools often used in the ACL-injured population. The IKDC subjective score is a single score, while the KOOS includes 5 distinct subscales (Pain, function in Activities of Daily Living [ADL], knee Symptoms, Sports and Recreation function, and knee-related Quality of Life [QOL]).

The relationship between degree of knee laxity after ACL reconstruction and patient-reported knee function is not completely clear. Previous work has generally noted poor correlation between residual anterior laxity after ACL reconstruction and PROs,6,7,9,15,20 but none of these studies control for other factors known to influence PROs after ACL reconstruction.21 The relationship between residual rotational knee laxity and PROs after ACL reconstruction may be more significant10 but has been studied less frequently.

The goal of this study was to evaluate the relationship between the degree of knee laxity (instrumented and physical examination) and PROs (IKDC and KOOS) in a prospective nested cohort of young patients a minimum of 2 years after primary ACL reconstruction. The hypothesis tested was that there would be no significant correlation between the degree of anterior or rotational knee laxity and PROs.

METHODS

Patients

From a prospective multicenter cohort of patients who underwent primary ACL reconstruction between 2005 and 2012, a subset of patients (nested cohort) younger than 33 years of age at the time of surgery (younger than 36 years of age at follow-up) who were injured in sports with no history of concomitant ligament surgery, subsequent ipsilateral revision ACL surgery, or surgery of the contralateral knee were identified at a minimum 2 years after their ACL reconstruction. From this cohort of 869 eligible patients, 433 patients were recruited to return to their enrolling center between 2 and 3 years after surgery (Figure 1). Reconstruction was performed by 1 of 6 experienced surgeons at 4 institutions. Each institution’s institutional review board approved the study.

Baseline Data Collection

All participants completed questionnaires at enrollment and at the 2-year follow-up to capture patient variables and PROs including the KOOS,17 IKDC subjective score,8 and Marx activity score.13 Surgeon-completed questionnaires at the time of surgery documented physical examination, arthroscopic findings, and surgical technique that included graft type and meniscal and cartilage pathology and treatment.

Figure 1. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) diagram. ACL, anterior cruciate ligament.

869 Subjects Eligible

- 51 Secondary exclusion: Death, pregnancy, out of the country, previous ipsilateral intra-articular surgery, double bundle technique, patella fracture, partial ACL reconstruction technique, all-epiphyseal technique, meniscus transplant, intra-articular infection, synovial proliferative disorder

818 Subjects Eligible

- 16 Randomly eliminated
- 106 Not reached in eligible window
- 53 Not reached before study closure

643 Invited to participate

- 200 Refused
- 10 Tore ACL graft or contralateral ACL after agreeing to participate

433 Subjects participated

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Meniscal status was classified as normal, stable meniscal tear without treatment, meniscal repair, or partial meniscectomy. Articular cartilage status was dichotomized according to the modified Outerbridge scale as normal/grade 1 or grade 2, 3, or 4.12,16

Follow-up Data Collection

All 433 patients underwent a physical examination by 1 of 9 independent examiners that included Lachman and pivot-shift evaluation as well as a KT-1000 assessment of anterior knee laxity and measurement of knee range of motion with a goniometer. Examiners were board-certified orthopaedic surgeons for the Lachman, anterior drawer, and pivot-shift evaluation and certified physical therapists for the range of motion measurements and KT-1000 arthrometer testing. The examiners were blinded as to which was the operative knee through the use of a knee sleeve during the examination. Patients also completed PRO assessments with KOOS and IKDC subjective scores. Any subsequent ipsilateral knee surgery other than revision ACL reconstruction (which was a study exclusion criterion) was noted.

Statistics

The relationship between laxity measures (KT-1000, Lachman, and pivot-shift) and PROs at 2 years postoperatively was assessed by utilizing multiple regression modeling. For each of the 5 KOOS subcales (Symptoms, Pain, ADL, Sports and Recreation, and QOL) and the subjective IKDC scores at 2 years, a model was built that included the baseline score; age; sex; body mass index; education level; smoking status (never, quit, current); Marx activity scale; graft type (autograft bone–patellar tendon–bone, autograft hamstring, allograft, hybrid autograft + allograft); medial and lateral meniscal treatment (normal, stable untreated tear, repair, resection); articular cartilage grade in the patellofemoral, medial, and lateral compartments (normal/grade 1; grade 2, 3, or 4); subsequent surgery (yes/no); side-to-side knee extension difference measured at the 2-year examination (degrees); and age by education interaction. Attempted linear regression on the PRO scores resulted in a violation of the normality of residuals; therefore, proportional odds logistic regression was used.

For each outcome, side-to-side differences in KT-1000, Lachman, and pivot-shift measures were individually added to the baseline model due to the anticipated collinearity between them. Odds ratios, 95% CIs, and P values were obtained for each physical examination measure. To compensate for multiple comparisons, P values less than .002 were considered statistically significant.

To quantify the magnitude of the relationship between each physical examination measure on PRO score (as opposed to the odds ratio), the linear predictors from the proportional odds models were transformed back to the scale of the PRO. For a given outcome score, each unique value observed in the sample was multiplied by the predicted probability that the patient’s score equaled that value, which produced a weighted average. These transformed scores were evaluated by cross-validation.

For each model, 10-fold cross-validation was carried out to obtain out-of-sample predictions for every patient. This methodology randomly splits the data into 10 nonoverlapping sets and then for each of the 10 sets, fits a model on 9 of the 10 sets, fits a model on 9 of the 10 sets and gets predicted values on the set that was left out. This method was repeated for all 10 partitions, so each patient got a prediction based on a model that it was not used to create. Scatterplots were then made of the observed KT-1000 value versus cross-validated predicted PRO scores, and box plots were made of the predicted scores for each Lachman and pivot-shift value.

RESULTS

The 433 study participants included 210 males (48.5%) and 223 females (51.5%) with a mean age at follow-up of 22.7 ± 4.9.
4.9 years (range, 15-35 years). Meniscal and cartilage status at the time of ACL reconstruction and other patient data are reported in Table 1. ACL reconstruction with hamstring autograft was performed in 149 patients (34.4%), patellar tendon autograft in 262 patients (60.5%), allograft in 9 patients (2.1%), and hybrid allograft in 13 patients (3.0%). Fifty-four patients (12.5%) underwent additional surgery on the index knee before follow-up.

Side-to-side manual Lachman differences were IKDC A (0-2 mm) in 246 (57%) patients, IKDC B (3-5 mm) in 183 (42%) patients, and IKDC C (6-10 mm) in 4 (1%) patients. Pivot-shift was classified as IKDC A in 209 (48%) patients, IKDC B in 183 (42%) patients, IKDC C in 11 (2.5%) patients, and could not be obtained due to guarding in 30 (7%) patients. The mean side-to-side KT-1000 difference was 2.0 ± 2.6 mm. The side-to-side KT-1000 difference was classified as IKDC A (–1 to 2 mm) in 178 (41.1%) patients, IKDC B (2 to 6 mm or –3 to –1 mm) in 214 (49.4%) patients, IKDC C (6 to 10 mm or < –3 mm) in 37 (8.5%) patients, and IKDC D (>10 mm) in 2 (0.5%) patients. The mean side-to-side knee extension difference was 0.7° ± 2.6°.

The mean, unadjusted KOOS subscale and IKDC subjective scores were generally similar based on postoperative knee laxity as assessed by physical examination (Tables 2-4), with the exception of the KOOS QOL subscale for IKDC C classified patients on the Lachman, which was notably lower. However, there were an insufficient number of patients with IKDC laxity (particularly Lachman) to perform a meaningful analysis of these patients. Evaluation of those patients with IKDC anterior laxity as assessed by KT-1000 demonstrated no clinically relevant differences (Table 4). Distributions of the instrumented side-to-side anterior laxity measurements are shown in Figure 2.

When patient characteristics and surgical variables were controlled for in the proportional odds logistic regression models, the presence of an IKDC B pivot-shift did not correlate with significantly increased odds of having lower PRO scores relative to patients with IKDC A pivot-shift. Similarly, increased anterior tibial translation with Lachman or KT-1000 arthrometer testing did not correlate with significantly increased odds of lower PRO scores.

Predicted PRO scores based on anterior tibial translation assessed with KT-1000 (Figure 3) and Lachman testing (Figure 4) and rotational laxity as assessed with the pivot-shift (Figure 5) were calculated. All predicted differences in score based on IKDC A versus B pivot-shift and anterior tibial translation were less than 4 points (not clinically significant as the clinically relevant difference in these PRO scores is 10).22

DISCUSSION

The most important findings of this study are that when controlling for patient and surgical factors, mildly increased

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Lachman Examination at 2-Year Follow-Upa</th>
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<tr>
<td>Side-to-Side Lachman</td>
<td>0-2 mm (IKDC A), n = 246</td>
</tr>
<tr>
<td>IKDC subjective</td>
<td>88.3 ± 10.8</td>
</tr>
<tr>
<td>KOOS Symptoms</td>
<td>87.8 ± 10.6</td>
</tr>
<tr>
<td>KOOS Pain</td>
<td>93.3 ± 8.5</td>
</tr>
<tr>
<td>KOOS ADL</td>
<td>97.7 ± 5.4</td>
</tr>
<tr>
<td>KOOS Sports/Rec</td>
<td>86.2 ± 15.0</td>
</tr>
<tr>
<td>KOOS QOL</td>
<td>78.7 ± 16.4</td>
</tr>
</tbody>
</table>

| Values are presented as score ± SD. ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, Quality of Life; Rec, Recreation. |

<table>
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<tr>
<th>Table 3</th>
<th>Pivot-Shift Examination at 2-Year Follow-Upa</th>
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<tr>
<td>Pivot-Shift Grade</td>
<td>None (IKDC A), n = 209</td>
</tr>
<tr>
<td>IKDC subjective</td>
<td>88.1 ± 10.4</td>
</tr>
<tr>
<td>KOOS Symptoms</td>
<td>87.9 ± 10.4</td>
</tr>
<tr>
<td>KOOS Pain</td>
<td>93.3 ± 7.9</td>
</tr>
<tr>
<td>KOOS ADL</td>
<td>97.6 ± 4.9</td>
</tr>
<tr>
<td>KOOS Sports/Rec</td>
<td>86.4 ± 15.0</td>
</tr>
<tr>
<td>KOOS QOL</td>
<td>79.0 ± 17.4</td>
</tr>
</tbody>
</table>

| Values are presented as score ± SD. 30 patients did not have pivot shift test due to guarding. ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QOL, Quality of Life; Rec, Recreation. |
anterior (KT-1000) or rotational laxity (IKDC B vs IKDC A) is not associated with clinically relevant decreases in PRO scores in young, active patients 2 years after ACL reconstruction.

These findings are consistent with prior literature that has routinely failed to identify any clinically relevant or statistically significant correlations between PRO scores and moderately increased anterior knee laxity. In the late 1990s and early 2000s, Hrubesch et al,6 Hyder et al,7 Muneta et al,15 Sernert et al,20 and Kocher et al10 published series of 44, 62, 97, 527, and 202 patients, respectively, that identified no correlation between residual anterior knee laxity and PROs after ACL reconstruction. Muneta et al15 did identify several objective findings that did correlate with PROs, most notably failure to regain full knee extension and persistent quadricep weakness relative to the contralateral side. None of these studies specifically controlled for other patient and surgical factors in their analyses.

The influence of greater degrees of anterior knee laxity in outcome scores is less clear. In 2002 Sernert et al19 noted poorer Lysholm scores in patients with residual anterior laxity greater than 6 mm on Lachman examination. In the current series, the ability to address this question is limited given that only 4 patients had an IKDC C Lachman and none had an IKDC D Lachman. A larger number of patients (n = 37) did demonstrate IKDC grade C anterior laxity when utilizing KT-1000 testing. These patients did not demonstrate clinically relevant differences in PROs compared with the IKDC A and B groups (Table 4), and no statistically significant differences between side-to-side KT-1000 measurements and PROs were noted in the proportional odds logistic regression model. Many authors have defined the presence of a side-to-side difference in anterior translation of greater than 6 mm (IKDC C or D) as indicative of graft failure.18 The longer-term effects of persistent anterior laxity of this magnitude remain unknown, although it is likely that the resultant increased articular cartilage loads would increase the risk of osteoarthritis with time.1,3,4

Fewer published studies evaluate the correlation between postoperative pivot-shift and PROs of ACL reconstruction. In a 2004 retrospective study, Kocher et al10 noted a correlation between postoperative pivot-shift and Lysholm score. Patients with a pivot glide (IKDC B) demonstrated lower scores than those with no pivot-shift (IKDC A), while those with a clunk (IKDC C) demonstrated poorer scores than the other 2 groups. It should be noted that this series also included relatively few patients (13 of 202, 6.4%) with an IKDC grade C pivot-shift. In the current series (in contrast), no differences in any PRO scores were noted based on IKDC pivot-shift grade B versus A. The number of patients with IKDC grade C pivot-shifts was too low for meaningful conclusions. The reason for the different findings in these characteristically similar cohorts is not completely clear but may be related to controlling for confounding variables.

There are limitations in this study. First, the patient population included in the study is not representative of all patients undergoing ACL reconstructions. While the patient characteristics and activity level are typical for ACL tears, this group only reflects those patients who had not suffered a subsequent ipsilateral or contralateral ACL reconstruction in the first 2 years postoperatively. We therefore cannot comment as to any relationship...
between increased postoperative knee laxity and risk of reinjury or contralateral injury. In addition, we only performed on-site evaluation in approximately one-half of the patients who met inclusion criteria. This limitation is mitigated by the fact that the remaining patients who did not come back did provide information regarding repeat surgery and PROs. No significant differences between this group and the patients who underwent on-site evaluation were noted in regard to patient characteristics or PROs, suggesting that the patients included in the study were representative of the entire eligible group. Further, the length of follow-up in the study was only 2 years. While important, these relatively short-term outcome data do not allow for analysis of any effect of postoperative laxity on the subsequent development of posttraumatic osteoarthritis or long-term declines in knee function or increases in pain. In a 2009 study, Möller et al\textsuperscript{14} compared PROs of 2 groups of patients at 11.5 years after ACL reconstruction based on whether their anterior laxity at 2 years postoperatively was less than 3 mm (35 patients) or greater than 3 mm (23 patients). They noted no difference between the groups, although it was not clear how many (if any) patients in the high-laxity group exhibited laxity greater than 6 mm. These data indicate that relatively small degrees of increased anterior laxity do not lead to clinically important declines in function up to 10 years postoperatively. While the presence of a high-grade pivot-shift postoperatively has been associated with an increased risk of the development of osteoarthritis 5 to 9 years after ACL reconstruction,\textsuperscript{9} no data are available regarding the effect of a persistent low-grade pivot-shift on long-term outcomes of ACL reconstruction.\textsuperscript{11} Finally, given that different examiners performed the independent evaluations at each institution, we were not able to definitively assess interrater reliability of the physical examination tests among different examiners. Although the IKDC classification system was utilized by all raters, the Lachman and pivot-shift grading represent subjective assessments by the examiners rather than quantitative measures.

This study's strengths are in its large numbers (N = 433), prospective nested cohort study design, and multivariable analysis that controls for potential confounding.
factors associated with or hypothesized to affect IKDC and/or KOOS, such as increased anterior laxity including age, sex, graft type, and extension loss.

CONCLUSION

Neither the presence of IKDC A versus B pivot-shift nor increased anterior tibial translation of up to 6 mm compared with the contralateral side is correlated with clinically relevant decreases in IKDC and KOOS 2 years after primary ACL reconstruction.

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Figure 4. Predicted Lachman results. ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; PRO, patient-reported outcome.
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REFERENCES


Figure 5. Rotational laxity as assessed with the pivot-shift. ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; PRO, patient-reported outcome.


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