Are Magnetic Resonance Imaging Recovery and Laxity Improvement Possible After Anterior Cruciate Ligament Rupture in Nonoperative Treatment?

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Purpose: This study aimed to determine whether anterior cruciate ligament (ACL) features on magnetic resonance imaging (MRI) and knee laxity are improved 2 years after ACL rupture treated nonoperatively and to analyze the relation between changes in scores of ACL features and changes in laxity. Methods: One hundred fifty-four eligible patients were included in a prospective multicenter cohort study with 2-year follow-up. Inclusion criteria were (1) ACL rupture diagnosed by physical examination and MRI, (2) MRI within 6 months after trauma, and (3) age 18 to 45 years. Laxity tests and MRI were performed at baseline and at 2-year follow-up. Fifty of 143 patients, for whom all MRI data was available, were treated nonoperatively and were included for this study. Nine ACL features were scored using MRI: fiber continuity, signal intensity, slope of ACL with respect to the Blumensaat line, distance between the Blumensaat line and the ACL, tension, thickness, clear boundaries, assessment of original insertions, and assessment of the intercondylar notch. A total score was determined by summing scores for each feature. Results: Fiber continuity improved in 30 patients (60%), and the empty intercondylar notch resolved for 22 patients (44%). Improvement in other ACL features ranged from 4% to 28%. Sixteen patients (32%) improved on the Lachman test (change from soft to firm end points [n = 14]; decreased anterior translation [n = 2]), one patient (2%) showed improvement with the KT-1000 arthrometer (MEDmetric, San Diego, CA) and 4 patients (8%) improved on the pivot shift test. Improvement on the Lachman test was moderately negatively associated with the total score of ACL features at follow-up. Analyzing ACL features separately showed that only signal intensity improvement, clear boundaries, and intercondylar notch assessment were positively associated with improvement on the Lachman test. Conclusions: Two years after ACL rupture and nonoperative management, patients experienced partial recovery on MRI, and some knee laxity improvement was present. Improvement of ACL features on MRI correlates moderately with improved laxity. Level of Evidence: Level II, Prospective comparative study.

Anterior cruciate ligament (ACL) rupture is a common sports-related injury, occurring in 5 per 10,000 persons annually.1 An experienced clinician can diagnose ACL rupture by medical history and physical examination.2,3 Magnetic resonance imaging (MRI) is an accurate noninvasive method used to evaluate intra-articular knee injuries and is useful in cases of diagnostic uncertainty or concomitant injury and for research.4 Two systematic reviews report MRI sensitivities of 86% and 94%, and specificities of 95% and 94%, respectively, for diagnosing ACL injuries.5,6 The ACL is an intra-articular ligament with limited healing capacity. Unlike the medial collateral ligament, there is no formation of functional scar tissue or increased histologic blood flow during recovery. It appears that after ACL rupture, a layer of synovial tissue surrounds the ruptured ends; cells in this synovial tissue may retract tissue and limit healing.7-9 This limited healing capacity has been clinically demonstrated as abnormal laxity and high revision rates after initial ACL suturing.10,11 Current treatment options are surgical reconstruction of the ACL or nonoperative treatment with
Rehabilitation. If initial knee instability exists, operative treatment is chosen; otherwise, nonoperative treatment is indicated. However, the decision between operative and nonoperative treatment can be complex and is also influenced by different variables, e.g., the patient’s activity, willingness to modify activities, age, and additional injuries.

In this study, we reviewed nonoperatively treated patients because we were interested in the capability of the ACL to recover after rupture, expressed by changes in laxity seen with physical examination, and the possibility of confirming recovery on MRI of the ACL. Geraets et al. showed that experience in diagnosing ACL rupture is an important factor for performing laxity tests with accuracy. If changes in laxity are related to changes in ACL features on MRI, the latter can support the interpretation of the ACL physical examination.

Radiographic studies of ACL recovery show improvement on MRI. In addition to improved MRI signs, some studies show improved knee stability. However, these latter studies had small sample sizes and reported MRI improvements in aggregate rather than as individual MRI sign improvements. Some researchers have reported no correlation between radiographic ACL recovery and clinical knee stability.

The aim of this study was to determine whether ACL features on MRI and knee laxity are improved 2 years after ACL rupture treated nonoperatively and to analyze the relationship between changes in scores of ACL features and changes in laxity. We hypothesized that ACL features on MRI would improve during follow-up and that changes in scores of ACL features are related to changes in laxity.

**Methods**

Between January 2009 and November 2010, 154 eligible patients were included in the KnKnee osteoArthritis anterior cruciate Ligament Lesion (KNALL) study—a prospective multicenter cohort study with 2 years of follow-up. The patients were recruited from 3 hospitals in the Netherlands: Erasmus MC University Medical Center, Rotterdam; Medical Center Haaglanden, the Hague; and Reinier de Graaf Gasthuis, Delft. Inclusion criteria were (1) ACL rupture diagnosed by physical examination and MRI, (2) MRI within 6 months after trauma, and (3) age 18 to 45 years. Patients who did not speak Dutch, those with previous intra-articular knee trauma or surgery of the involved knee, those with disabling comorbidities, and those with osteoarthritic changes on radiography (Kellgren and Lawrence grade > 0) were excluded.

Baseline and 2-year follow-up MRI data were available for 143 patients. All patients were treated according to the Dutch guideline on ACL injury. Of the 143 patients, 50 patients were treated nonoperatively during the 2-year follow-up period. Two of the 50 patients treated nonoperatively had medial meniscectomies during the 2-year follow-up period. At the time of inclusion, 10 patients had 1+ medial collateral ligament injury and 7 patients had lateral collateral ligament injury (1+, n = 4; ≥2+, n = 3). Patients were treated only with a brace if a collateral ligament injury was present. All patients had physiotherapy according to the Dutch guidelines for physical therapists. Our institution’s Medical Ethics Committee approved the study, and all included patients gave their written informed consent and were evaluated at baseline, at 1 year, and at 2 years.

At baseline, MR images were obtained using MRI scanners with a magnetic field strength of 1.0 (n = 7), 1.5 (n = 37), or 3.0 (n = 6) Tesla. At follow-up, all MR images were acquired on the same type scanner with a magnetic field strength of 1.5 Tesla MRI. Patients’ legs were positioned neutrally. All MRI examinations included a set of routine clinical MRI pulse sequences. To assess ACL features, we used sagittal and coronal density-weighted turbo spin echo (TSE) sequences (slice thickness 3 mm, repetition time (TR)/echo time (TE), 2700/27 ms) and the coronal T2-weighted TSE sequence with fat saturation (slice thickness 3 mm, TR/TE 5030/71 ms).

**Measurements**

An expert panel, consisting of an orthopaedic surgeon experienced in ACL pathologic conditions, an experienced musculoskeletal radiologist, and a physician researcher, defined 9 features by which to assess the ACL on MRI, based on primary MRI signs. Features (Figs 1-7) were scored as normal (0) or abnormal (1), except for fiber continuity, which was scored as intact (0), partially visible (1), or no distinct fibers visible (2):

- Fiber continuity (0 = intact; 1 = partially visible; 2 = no distinct fibers visible)
- Signal intensity (abnormal = high or heterogeneous signal)
- Slope of ACL with respect to the Blumensaat line (abnormal = more horizontal orientation)
- Distance between the Blumensaat line and ACL (abnormal = increased distance)
- Tension (abnormal = bowing)
- Thickness (abnormal = thickening)
- Clear boundaries (abnormal = unclear boundaries)
- Assessment of original insertions (abnormal = ACL tissue outside original insertions)
- Assessment of intercondylar notch (abnormal = empty notch)

A total score was determined by summing scores for these 9 features. A score of 10 was maximally abnormal for all features, whereas a score of 0 was normal for all features.

Before the application of this scoring method we organized training sessions with the expert panel. We
made an atlas of examples of all ACL features with their normal and abnormal scores. Additionally, we scored several knee MRIs and discussed discrepancies in scoring until consensus was reached. A physician researcher blinded to clinical history evaluated all MR images. Baseline and follow-up MR images were assessed contemporaneously; the order of measurements was known. Laxity tests—including the Lachman test, KT-1000 arthrometer (MEDmetric, San Diego, CA) measurements, and the pivot shift test—were performed at baseline and at follow-up. The Lachman test was performed as described by Torg et al.20 to assess tibial translation. Using the International Knee Documentation Committee form, the translation was scored as 0 (−1 to 2 mm), 1+ (>2 to 5 mm), 2+ (>5 to 10 mm), or 3+ (>10 mm), and the end point was scored as soft or firm.21 Instrumented anterior laxity testing of the knee was performed using the KT-1000 arthrometer.22,23 We used absolute maximal measurement values for analysis because some patients had a history of ACL injury in the contralateral knee. Rotational instability was evaluated using the pivot shift test,24 which was scored as normal (0), glide (1+), clunk (2+), or gross (3+) according to the International Knee Documentation Committee.21 The same physician examined all patients at baseline and at follow-up. At baseline, the physician evaluator was aware of the presence of ACL rupture on MRI but unaware of the scores of the ACL features. At follow-up, the physician examined patients without knowledge of MRI findings. Baseline MRI assessments and laxity tests were compared with measurements at 2 years.

**Definition of Improvement and Deterioration**

Improvement of ACL features on MRI was defined as a score changed from 1 to 0 (or from 2 to 1 for fiber continuity). Deterioration was defined as present if a score of an ACL feature on MRI changed from 0 to 1 at 2 years (or from 0 to 2 or 1 to 2 for fiber continuity).

Laxity improvement was determined separately for each test. The Lachman test result was improved at follow-up if the anterior translation changed to 0, by an improvement of 2 or more, or if the end point changed from soft to firm. Laxity deterioration was present if the anterior translation increased to 1+ or greater and the end point did not improve. Pivot shift test improvement at follow-up was defined as a change to 0 or 2-step improvement (e.g., from 3+ to 1+). Pivot shift test deterioration was defined as an increase of 1+ or greater. KT-1000 arthrometer laxity was improved at follow-up if there was a difference of at least 4 mm of the absolute maximal value compared with baseline. An increase of at least 4 mm was defined as laxity deterioration by KT-1000 arthrometer measurements.

**Reliability**

To assess inter-rater reliability of ACL scoring on MRI, an orthopaedic surgeon and a physician researcher, both with experience in ACL injuries, independently scored the same 25 MRIs.

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**Fig 1.** Fiber continuity (arrows: partially visible; no distinct fibers visible). MRI sequence: sagittal proton density weighted turbo spin echo (TSE); slice thickness, 3 mm; repetition time (TR)/time echo (TE), 2700/27 ms.

**Fig 2.** Signal intensity (abnormal = high or heterogeneous signal). MRI sequence: sagittal proton density weighted turbo spin echo (TSE); slice thickness, 3 mm; repetition time (TR)/time echo (TE), 2700/27 ms.
Descriptive statistics were used to analyze baseline characteristics. Mean and standard deviation (SD) were obtained for normally distributed variables. Median and interquartile range (IQR) were obtained for non-normally distributed variables. To assess inter-rater reliability of ACL scores, we determined the prevalence-adjusted bias-adjusted kappa (PABAK), which considers both the prevalence of positive findings and bias of each observer to report positive findings. A kappa value of greater than 0.8 is considered very good, between 0.6 and 0.8 is good, between 0.4 and 0.6 is moderate, and a kappa less than 0.4 indicates fair agreement. Prevalence of abnormal scores for ACL features on MRI at baseline and at 2 years is presented in Table 2. Abnormal scores for ACL features ranged from 66% to 100% at baseline and from 28% to 94% at 2 years. The median total score of ACL features changed from 10 (IQR: 8-10) at baseline to 7 (IQR: 5-9) at the 2-year follow-up.

ACL feature changes over time are presented in Table 3. Fiber continuity improved in 30 patients (60%), and the empty intercondylar notch resolved in 22 patients (44%). Improvement in other features ranged from 4% to 28%. Deterioration of ACL features was evidenced by fiber discontinuity (4%), signal intensity (2%), slope of the ACL with respect to the Blumensaat line (4%), ACL tension (4%), and deterioration of original insertions (4%). Most patients (76%) improved on a minimum of one feature (Table 4).

Improvements were noted for 16 patients (32%) on the Lachman test, for 1 patient (2%) on the KT-1000 arthrometer, and for 4 patients (8%) on the pivot shift test. Improvement on the Lachman test was caused by a change from soft to firm end points in 14 patients; only 2 patients experienced decreased anterior translation. Six patients (12%) showed deterioration on the Lachman test, and 5 patients (10%) experienced an increase in anterior translation of at least 4 mm by KT-1000 arthrometer measurements. The mean maximal
anterior translation, as measured by the KT-1000 arthrometer, increased from 11.3 (SD, 2.1) mm at baseline to 12.1 (SD, 2.9) mm at the 2-year follow-up ($P = .009$). Deterioration of the pivot shift test was present in 15 patients (30%) (Table 5).

The total score of ACL features at the 2-year follow-up was significantly associated with improvement on the Lachman test (odds ratio [OR], 0.8; 95% confidence interval [CI], 0.6 to 0.97; $P = .029$), i.e., the likelihood of improvement on the Lachman test is higher for a lower total score of the ACL features on MRI at 2-year follow-up. Analyzing the ACL features separately showed that improvement of the following ACL features was significantly associated with improvement on the Lachman test: signal intensity (OR, 7.3; 95% CI, 1.2 to 43.0; $P = .012$), clear boundaries (OR, 5.8; 95% CI, 1.5 to 22.7; $P = .012$), and assessment of the intercondylar notch (OR, 4.6; 95% CI, 1.3 to 16.5; $P = .019$). We found no relation between improvements on the following ACL features and Lachman test improvement: fiber continuity, slope of ACL with respect to the Blumensaat line, distance between the Blumensaat line and the ACL, tension, thickness, and assessment of original insertions. The number of improved ACL features was positively associated with improvement on the Lachman test (OR, 1.6; 95% CI, 1.1 to 2.2; $P = .007$); the likelihood of improvement on the Lachman test is higher when more ACL features were improved on MRI at 2 years. Because the percentages of improvement on the pivot shift test and KT-1000 arthrometer were low, we did not analyze their relation to improvement of ACL features.

**Discussion**

Our study results suggest that MRI recovery from ACL rupture is possible in patients treated nonoperatively. In particular, fiber continuity improved over time and the empty intercondylar notch resolved in almost half of the patients after 2 years. However, the other evaluated ACL features showed improvement in only some of the patients. The Lachman test result improved in one third of the patients, which means no translation anymore or $\geq 2+$ decrease of anterior translation or a change from a soft to a firm end point. This clinical improvement showed a moderate negative relation with the total score of the ACL features at follow-up (the higher the total score the more abnormal features) and a moderate positive relation with the number of improved ACL features.

Our MRI recovery results are consistent with those found in previous studies.13-18 To understand the ACL recovery process, it is important to understand what causes improvement in ACL features on MRI. Yoon et al.28 showed that ACL morphologic features on MRI—as assessed by signal intensity, shape, and nonvisualization—correlate well with chronicity of the ACL rupture. In their study, ACL morphologic features, defined as “increased signal intensity and an edematous mass-like shape,” dominated MRI findings until 3 months after rupture, whereas “low signal intensity and a band-like fragmented shape or nonvisualization” was most commonly present in MR images from patients with chronic (>1 year) ACL ruptures. Their finding of “band-like fragmented shapes” in chronic...
ACL ruptures is consistent with our findings of ACL thickening and unclear boundaries. Because our study follow-up was 2 years, all patients had chronic ACL rupture at the time of the second MRI. Observed improvements in fiber continuity and resolution of empty intercondylar notches might be related to scar tissue development. Tsai et al.29 and Vahey et al.30 showed in their studies that MRI is less accurate in diagnosing chronic ACL ruptures. A possible explanation for this low accuracy is the presence of scar tissue, which may complicate an adequate assessment. For knee stability, it is important to know whether the recovered fiber continuity, as demonstrated on MR images, is functional. Our results showed no relation between fiber continuity improvement and Lachman test improvement; this lack of association suggests that ACL fibers contributed nothing to stability. This hypothesis is supported by the high percentage of abnormal tension scores at follow-up. Our results suggest that ACL fibers showing recovery on MRI do not reflect improved laxity and support the findings of Chung et al.13 and Van Dyck et al.18 Our results showed that during follow-up of nonoperatively treated patients, ACL physical examination should be the guidance in further treatment. Assessment of fiber continuity alone on MRI is inadequate. All ACL features together should be taken into account, in particular signal intensity, clear boundaries, and assessment of the intercondylar notch.

We observed improvement on the Lachman test but deterioration over time when measuring the mean maximal anterior translation with the KT-1000 arthrometer. At first, these findings appear contradictory because both tests aim to measure anterior translation. However, additional analyses clarified this discrepancy. Lachman test improvement was caused primarily by a change from soft to firm end points (n = 14), and only 2 patients experienced decreased anterior translation. Change to a firm end point or decrease in anterior translation could result from remnant scar tissue attachment to the posterior cruciate ligament (PCL), the roof of the notch, or the lateral femoral condyle.31 This is also supported in the study of Dejour.

### Table 1. Baseline Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n = 50</th>
</tr>
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<tbody>
<tr>
<td>Age, mean (SD)</td>
<td>29.9 (±7.0)</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>17 (34)</td>
</tr>
<tr>
<td>BMI (kg/m²), median (IQR)</td>
<td>24.3 (22.4-27.1)</td>
</tr>
<tr>
<td>Time from trauma to baseline MRI in mo, median (IQR)</td>
<td>1.1 (0.5-2.4)</td>
</tr>
<tr>
<td>Activity (Tegner score), median (IQR)</td>
<td></td>
</tr>
<tr>
<td>Before trauma</td>
<td>8.0 (7.0-9.0)</td>
</tr>
<tr>
<td>At baseline</td>
<td>3.0 (2.0-4.0)</td>
</tr>
<tr>
<td>Lachman test, n (%)</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>1+</td>
<td>16 (32)</td>
</tr>
<tr>
<td>2+</td>
<td>33 (66)</td>
</tr>
<tr>
<td>3+</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Lachman test; soft end point, n (%)</td>
<td>42 (84)</td>
</tr>
<tr>
<td>Pivot shift test, n (%)</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>22 (44)</td>
</tr>
<tr>
<td>Glide</td>
<td>18 (36)</td>
</tr>
<tr>
<td>Clunk</td>
<td>3 (6)</td>
</tr>
<tr>
<td>Not applicable*</td>
<td>7 (14)</td>
</tr>
<tr>
<td>KT-1000 arthrometer (n = 49)</td>
<td></td>
</tr>
<tr>
<td>Maximal manual in mm, mean (SD)</td>
<td>11.3 (2.1)</td>
</tr>
</tbody>
</table>

BMI, body mass index; IQR, interquartile range; SD, standard deviation.

*Not applicable because of opposing muscle contraction.

Missiing data for one patient because of large leg circumference.

### Table 2. ACL Features on MRI at Baseline and at 2-Year Follow-up (n = 50)

<table>
<thead>
<tr>
<th>ACL Features</th>
<th>T0 Abnormal Score n (%)</th>
<th>T2 Abnormal Score n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber continuity</td>
<td>47 (94)</td>
<td>38 (76)</td>
</tr>
<tr>
<td>Partially visible</td>
<td>8 (16)</td>
<td>23 (46)</td>
</tr>
<tr>
<td>No distinct fibers</td>
<td>39 (78)</td>
<td>13 (30)</td>
</tr>
<tr>
<td>Signal intensity</td>
<td>48 (96)</td>
<td>42 (84)</td>
</tr>
<tr>
<td>Slope</td>
<td>46 (92)</td>
<td>42 (84)</td>
</tr>
<tr>
<td>Distance of Blumersaat to ACL</td>
<td>50 (100)</td>
<td>41 (82)</td>
</tr>
<tr>
<td>Tension</td>
<td>47 (94)</td>
<td>47 (94)</td>
</tr>
<tr>
<td>Thickness of ACL</td>
<td>50 (100)</td>
<td>43 (86)</td>
</tr>
<tr>
<td>Clear boundaries</td>
<td>47 (94)</td>
<td>34 (68)</td>
</tr>
<tr>
<td>Assessment of original insertions</td>
<td>33 (66)</td>
<td>21 (42)</td>
</tr>
<tr>
<td>Assessment of intercondylar notch</td>
<td>36 (72)</td>
<td>14 (28)</td>
</tr>
<tr>
<td>Total score, median (IQR)</td>
<td>10 (8-10)</td>
<td>7 (5-9)</td>
</tr>
</tbody>
</table>

ACL, anterior cruciate ligament; IQR, interquartile range; MRI, magnetic resonance imaging; T0, baseline; T2, two-year follow-up.
In this study, the ACL tear was classified as PCL healing when during arthroscopy the stump of the ACL was found to be healing on the PCL. The clinical evaluation of this group showed less laxity on the Lachman test and pivot shift test compared with the group with complete ACL tears. However, Dejour et al. did not present results of the end point of the Lachman test. Overall, we conclude that little functional recovery, based on laxity tests, occurred among our patients.

Diagnosis of a partial ACL rupture on MRI is difficult, as shown by Van Dyck et al. and Dejour et al. Van Dyck et al. found a low level of accuracy for diagnosing partial ACL tears on MRI compared with arthroscopic confirmation of partial ACL tears. For partial ACL tears, Dejour et al. found no correlation between preoperative MRI findings and the arthroscopic type of ACL tear. However, Dejour et al. showed that partial and complete tears could be distinguished with a combination of clinical examination and instrumented laxity testing with stress radiographs. In our study, we did not make a distinction between partial and complete ACL tears because only 2 patients of the 50 nonoperatively treated patients in our study underwent arthroscopy.

Strengths of this study are its prospective design, use of an adequate sample size, and complete baseline and follow-up MRI and laxity tests for all patients. Furthermore, we analyzed changes in MRI scores and laxity tests to prospectively determine MRI and clinical recovery. Another strength is that we reported the individual ACL features on MRI. This study showed which features improved, which deteriorated, and which did not change over time. This information could be used in clinical practice.

**Limitations**

This study also has some limitations. Because all patients were treated nonoperatively, we did not perform arthroscopic evaluation—the reference standard for diagnosing ACL rupture. Another limitation is that different MRI scanners and magnetic field strengths were used at baseline and at follow-up. However, all MRI examinations included a set of routine clinical MRI pulse sequences of good diagnostic quality, and a recent study showed that the use of a 3.0 Tesla MRI scanner does not significantly improve diagnostic accuracy for ACL ruptures compared with a 1.5 Tesla MRI scanner.

**Conclusions**

Two years after ACL rupture and nonoperative management, patients experienced partial recovery on MRI and some knee laxity improvement. Improvement of ACL features on MRI correlates moderately with improved laxity.

**References**


