Original Article With Video Illustration

The Diagnostic Value of Clinical Tests, Magnetic Resonance Imaging, and Instrumented Laxity in the Differentiation of Complete Versus Partial Anterior Cruciate Ligament Tears

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Purpose: To evaluate the question of whether different arthroscopically confirmed anterior cruciate ligament (ACL) injury patterns have distinctive preoperative findings on clinical examination, instrumented laxity, and magnetic resonance imaging (MRI). **Methods:** Three hundred consecutive ACL-deficient patients with isolated ACL tears were evaluated with the Lachman test (LT), the pivot-shift test (PST), stress radiographs using the Telos Stress Device (Metax, Hungen, Germany), and MRI. After arthroscopic confirmation of the ACL injury, we grouped patients into 4 different ACL tear types (complete, partial anteromedial [AM] bundle intact, posterolateral [PL] bundle intact, and posterior cruciate ligament [PCL] healing), and partial tears were further evaluated for mechanical integrity and functionality of the remaining fibers. **Results:** PST grades of +2 and +3 were consistent with complete ACL tears (86%; $P < .00001$), whereas PST grades of 0 or +1 were strongly related to partial tears (76%; $P < .00001$). Instrumented laxity results showed a significant difference in side-to-side difference (SSD) of anterior tibial translation in complete tears (9.1 ± 3.4 mm) versus partial tears (5.2 ± 2.9 mm; $P < .0001$). Most PL-intact cases were "functional" (67%), with lower instrumented laxity values (SSD, 4.3 ± 2.3 mm) than the "nonfunctional" cases (SSD, 6.7 ± 2.9 mm; $P < .001$). The contrary was not observed for AM-intact cases (17% functional). Partial ACL tears with functional remaining fibers had PST grades of 0 or +1 and less than a 4 mm SSD in stress radiographs (sensitivity, 0.76; specificity, 0.90). Partial ACL tears with nonfunctional fibers had positive PST results and an SSD of anterior tibial displacement from 4 to 9 mm (sensitivity, 0.56; specificity, 0.92). Positive PST results and an SSD greater than 9 mm was recorded in complete ACL tears (sensitivity, 0.88; specificity, 0.96). MRI analysis revealed overlapping results between complete and partial tears. **Conclusions:** Preoperative evaluation of different ACL tear types showed differences between complete and partial ACL tears with functional fibers in clinical examination and instrumented laxity tests. The combination of clinical tests and stress radiographs produced threshold values that distinguished complete from partial ACL tears, which may help the surgeon in the early identification of the presence of remaining functional fibers. **Level of Evidence:** Level III, case-control study.

Partial anterior cruciate ligament (ACL) tears are difficult to diagnose and treat.[1] The original skepticism about the existence or the prevalence of partial ACL tears by some authors has been replaced by detailed reports on the diagnosis of and the different available treatment options for incomplete ACL tears.[1-3] The preoperative clinical diagnosis of such injuries poses difficulties even in the hands of experienced surgeons.[4] The importance of grading clinical laxity tests has been recorded and the proper interpretation of mainly the pivot-shift test (PST) could support the diagnosis of such tears.[1,5,6] However, clinical examination is examiner dependent, and the inability to produce consistent and comparable results even with the usual tests raises the need to use objective instrumented laxity methods and to quantify the amount of laxity, especially for research purposes, postoperative follow-up, and comparing the efficacy of surgical procedures.[4,7]

The additional use of instruments to measure knee laxity in cases of partial ACL tears is not new,[8-12] but the efficacy of these devices in the differential diagnosis

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of complete versus incomplete ACL tears has been questioned, especially in patients without severe damage to the ligament.[1] Furthermore, the use of imaging equipment, such as magnetic resonance imaging (MRI), seems to be insufficient to describe the exact pattern of an ACL injury when used alone,[13] mainly because of the many patterns of partial tears and the frequent similarity of partial tears to complete tears or even to mucoid degeneration of the ACL.[14-16] Both instrumented laxity and MRI need to be used in combination with proper clinical evaluation to possibly acquire a greater diagnostic value.

The importance of preoperative diagnosis of partial ACL tears results from data that support the beneficial preservation of the ACL remnant, given the importance of both bundles and their synergistic effect in knee stability.[1-3] The remaining fibers provide additional mechanical stability for the graft (especially in the immediate postoperative period),[17] the vascularity of the reconstructed graft is enhanced by the remaining fibers and vessels,[18] the preservation of neural mechanoreceptors in the remnants of the ACL benefit the proprioceptive function of the graft,[19] and preserving the intact ACL fibers provides more precise tunnel positioning.[5] Some authors believe that in cases of partial ACL tears with functional remaining fibers, ligament augmentation results in increased stability, lower instrumented laxity results, better proprioception, and reduced knee stiffness than do single- or double-bundle reconstruction.[5,20] Therefore, the preoperative diagnosis or the suspicion of such incomplete ruptures in which the remaining fibers are mechanically solid, and therefore functional, could affect the type of treatment (conservative *v* surgical), the steps of the surgery (choice of graft, diagnostic arthroscopy before graft harvesting), and the technical aspects of the operation, such as the extent of debridement of the notch, the proper tunnel placement, the drill guides, and the size of the graft.[1,3,5]

In the search for such a diagnostic approach to the type of ACL tear, we designed a study to correlate the preoperative clinical tests, laxity measurements from stress radiographs, and MRI findings with the arthroscopic evaluation. The purpose of the study was to investigate if different arthroscopically confirmed ACL injury patterns have distinctive preoperative findings in clinical tests, stress radiographs, and MRI results. We tested the hypothesis that complete and partial ACL tears demonstrate different patterns in clinical testing combined with instrumented laxity tests. The purpose of the study was not to compare the results of preserving or not preserving the ligament remnants or to compare ACL augmentation and reconstruction, so presentation of the postoperative results are not described. This study intends to show only the possible different preoperative behavior and performance of various types of ACL tears in clinical examination, MRI, and instrumented laxity and does not suggest any therapeutic or surgical planning.

Methods

This is a prospective study in which all consecutive cases of adult patients scheduled for primary ACL reconstruction during a 6-month period were included. Inclusion and exclusion criteria are listed in Table 1. At the time of office consultation, all patients were tested clinically with the Lachman test (LT) and the pivot-shift test (PST). Two surgeons tested each patient and we observed interobserver agreement throughout the study period. LT evaluation was performed in a standard fashion with the knee flexed at 20°, and for the purposes of the study we scaled the positive results to 2 discriminable groups: +1 for less than 5 mm of anterior tibial translation with a firm endpoint and +2 for greater than 5 mm of anterior tibial translation or with no firm endpoint. The PST was performed with the application of anteriorly directed force to the tibia from full extension to flexion with the leg in internal rotation, as described by Dejour et al.[21] The results were recorded according to International Knee Documentation Committee criteria as equal (0), glide (+1), clunk (+2), or severe (+3).[4]

Preoperative objective evaluation included bilateral stress radiography with the Telos Stress Device (Metax, Hungen, Germany) using 15 kg. The Telos protocol involved absolute numerical measurement of anterior tibial translation of the injured knee and the side-to-side difference (SSD) from the noninjured side with a test similar to LT under fluoroscopy. The patient was positioned in the lateral decubitus position on the side to be evaluated. A pressure plate was placed posteriorly at the midcalf level, with one counter bearing placed at the level of the ankle joint and the other approximately 5 cm above the patella. The patient was then instructed to relax the muscles, and the knee was flexed to 20°.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Instability in daily or sport activities High-level sport athletes with ACL deficiency (systematic ACL reconstruction)	Concomitant ligamentous injuries
ACL laxity by clinical examination (positive Lachman test and/or pivot-shift result)	Concomitant cartilaginous injuries (ICRS grade II or higher)
Unilateral injury	Contralateral knee injury Previous ipsilateral or contralateral knee operation Knee osteoarthritis

ICRS, International Cartilage Repair Society.

The stress was increased steadily and radiographs were taken after application of anteriorly directed forces of 15 kg. The anterior tibial translation was calculated from the radiographs (1 × 1 magnification) by measuring the displacement of the medial compartment from the distance of a line parallel to the posterior tibial shaft cortex and tangent to the posterior contour of the medial tibial condyle (medial anterior tibial translation [MATT]) to the posterior aspect of the medial femoral condyle (Fig 1). Both knees were tested and the SSD was recorded.

Standard MRI on a 1.5 T magnet was performed preoperatively in all cases. Dual turbo spin echo or fast spin echo T1-weighted sagittal views were selected. Most of the patients had an MRI using the French national protocol required for the diagnosis of a knee pathologic process and not a protocol specific to ACL injury. Axial views in the ACL plane that would probably be more informative about the type of ACL injury correspond to a specific prescription that is not reimbursed by the French national insurance policy. The same orthopaedic surgeons who performed the clinical examination and the surgery studied the MRI findings and classified ACL morphologic processes according to 3 different patterns based on previously published data[13]: (1) complete absence or severe distortion of ACL fibers with respect to the Blumensaat line or the presence of a wavy contour of the ligament; (2) hyperintense signal within the ACL substance, fibers disorganized but with the presence of any visible straight lines from the femoral to the tibial insertion of the ACL, or clear fiber disruption in the anteromedial (AM) or posterolateral (PL) bundle; and (3) ACL fibers falling on the posterior cruciate ligament (PCL) mass in continuity from tibial to femoral insertion.[3]

Time from injury to operation was recorded in all cases. In every case, ACL surgery was performed within a maximum of 30 days from the time of office consultation. Arthroscopic evaluation of the ACL rupture included confirmation of the tear by direct vision and palpation with a probe. When the ACL was totally absent, the tear was classified as complete (Fig 2). When there was an isolated rupture of the AM bundle and the integrity of the PL bundle was verified visually and with the use of a probe in the "figure-of-4" position,[22] the tear was classified as PL intact (Fig 3). In the case of an isolated PL bundle rupture, the tear was classified as AM intact (Fig 4), and when the ligamentous stump of the ACL was found to be healing on the PCL, the tear was classified as PCL healing (Fig 5).[23,24] In the case of a partial tear, further dynamic evaluation of the mechanical integrity of the remaining fibers was performed by palpation with a probe. The remaining

Fig 1. Telos stress lateral radiograph. The MATT was measured from the lateral radiographs by calculating the distance of a tangent line to the posterior contour of the medial tibial condyle drawn parallel to the posterior tibial cortex and the posterior aspect of the medial femoral condyle.

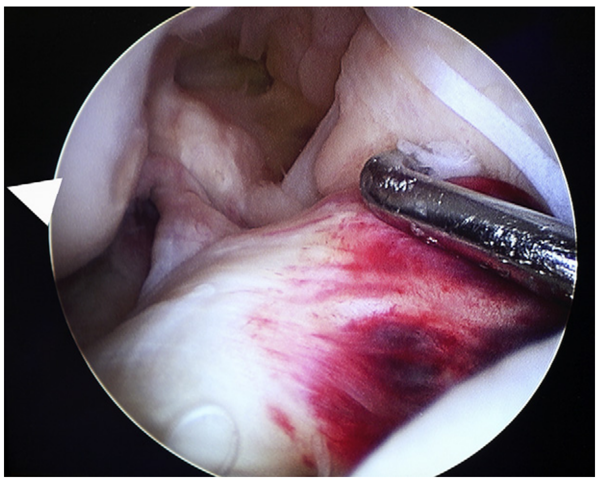

Fig 2. Arthroscopic view of a complete ACL tear, in which all ligament attachments have disappeared from the femoral notch (left knee, view from anterolateral portal).

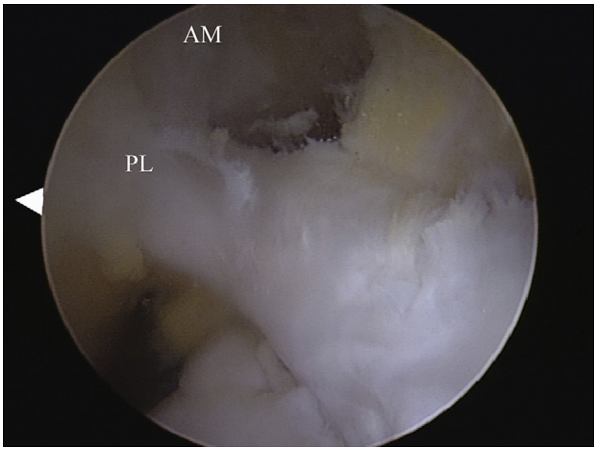

Fig 3. Arthroscopic view of a partial PL-intact tear (left knee, view from anterolateral portal). (AM, anteromedial; PL, posterolateral.)

fibers were classified as functional or nonfunctional, depending on the presence of mechanically solid fibers or the ability of the examiner to further stretch them, respectively. If the remaining fibers resisted further stretching, they were classified as functional (Figs 3 and 6E, and Video 1 [available from arthroscopyjournal.org]). If the remaining fibers were lax and the examiner could stretch them significantly further, they were classified as nonfunctional (Video 1). Meniscal status was also examined arthroscopically, and meniscal injuries were classified into 2 groups: requiring surgical intervention (meniscectomy or suturing) or not.

Statistical Analysis

The χ^2 test was used for comparison of 2 qualitative variables. The Spearman correlation test and the Pearson test were used for comparison of 2 quantitative variables. Results from qualitative versus quantitative variables were compared using the Mann-Whitney and Kruskal-Wallis tests. Level of statistical significance was set as P less than .05.

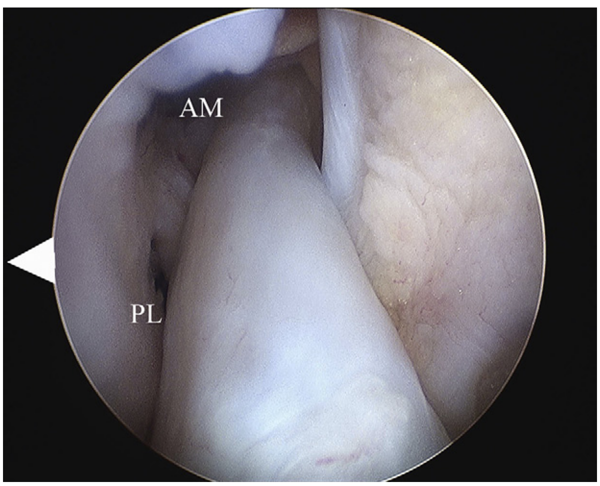

Fig 4. Arthroscopic view of a partial AM-intact tear (left knee, view from anterolateral portal). (AM, anteromedial; PL, posterolateral.)

Results

Three hundred patients (mean age, 29.5 ± 11.3 years; female to male ratio, 0.47) were included in the study during the period from January to June 2007 (Table 2). The results from the arthroscopic evaluation of the ACL injury pattern for the whole study population follow: 177 patients (59%) had complete ACL tears and 123 patients (41%) had partial ACL tears. Sixty-six (22%) patients had PL-intact tears, 21 (7%) patients had AM-intact tears, and 36 (12%) patients had PCL-healing type of injuries. Mean time from injury to operation was 26 months for complete tears, 6.5 months for PL-intact tears, 5 months for AM-intact tears, and 19 months for PCL-healing tears.

The results of clinical examination according to injury pattern are shown in Table 3. There was a statistically significant difference for severe clinical laxity—i.e., LT grade +2 (99%) and PST grades +2 and +3 (86.4%) in complete tears versus all types of partial tears (32.6% and 23.6%, respectively; $P < .00001$ for both values). PST grade 0 or +1 was recorded in 13.5% of complete tears versus 76.4% of all partial tears ($P < .0001$). Clinical tests among partial tear subgroups showed nonsignificant differences when compared with each other.

Instrumented laxity results from the Telos Stress Device are shown in Table 4. We observed a significant difference in the mean SSD of MATT (9.1 ± 3.4 mm) in complete tears versus a mean SSD of MATT (5.2 ± 2.9 mm) in all types of partial tears ($P < .0001$). The difference in the SSD of anterior tibial translation among partial tears according to their anatomic injury pattern (PL intact *v* AM intact) was not significantly different (Table 4). The quality of the remaining fibers in the partial tear groups was 67% functional for the PL-intact group ($P < .00001$ when compared with nonfunctional), with a mean SSD of MATT of 4.3 ± 2.3 mm, and 33% nonfunctional (mean SSD of MATT, 6.7 ± 2.9 mm; $P < .0001$) when compared with the functional PL-intact group. For the 2 remaining partial tear subgroups, we recorded in total only 17% of the cases as having functional remaining fibers (mean SSD of MATT, 4.5 mm) and 83% as being nonfunctional ($P < .0001$), with a mean SSD of MATT of 6.7 mm ($P < .0001$). We calculated the mean SSD of anterior tibial translation for all arthroscopically confirmed functional partial tears versus all nonfunctional partial tears, regardless of the anatomic injury pattern (Table 4). Median SSD of MATT was 9 mm in complete tears, 6 mm in all nonfunctional partial tears, and 4 mm in functional partial tears ($P < .00001$). The combination of clinical examination (i.e., PST) with instrumented laxity testing in the

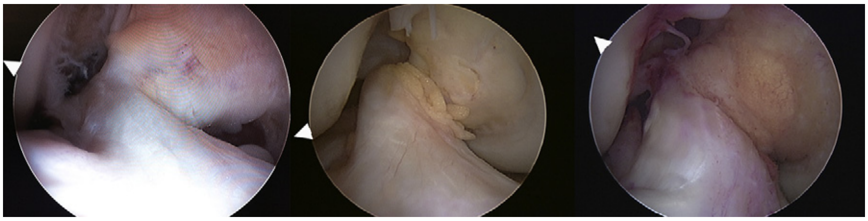

Fig 5. Arthroscopic views of different cases of the PCL-healing type of partial tear. The femoral attachments have clearly disappeared from the notch, but the ligamentous stump "heals" on the PCL (all cases left knee, view from anterolateral portal).

identification of different types of ACL tears had the following results: PST grade 0 or +1 and less than 4 mm SSD had a sensitivity of 0.76 and a specificity of 0.90 in the preoperative identification of partial ACL tears with functional remaining fibers. Positive PST results and an SSD of anterior tibial displacement from 4 to 9 mm had a sensitivity of 0.56 and a specificity of 0.92 for partial ACL tears with nonfunctional fibers. Positive PST results with an SSD greater than 9 mm had a sensitivity of 0.88 and a specificity of 0.96 in cases of complete ACL tears.

The data from the MRI analysis for each type of ACL rupture are presented in Table 5. There was not any statistically significant correlation between MRI findings and the arthroscopically confirmed type of ACL injury, except for the case of absence or severe distortion of ACL fibers with arthroscopically confirmed complete ACL tears (96%; $P < .0001$).

The study of concomitant meniscal lesions in all cases was related to the type of ACL rupture (Table 6). There was a higher number of meniscal lesions requiring surgical treatment in complete tears (50%) than in partial tears (32%; $P < .013$).

Discussion

The most important findings of this study are the different instrumented laxity and clinical testing results between arthroscopically confirmed complete and partial ACL tears. Complete tears had significantly higher anterior tibial translation and also had greater laxity with the LT and PST results when compared with all types of partial tears. In the latter, the functionality of the remaining fibers was also determined. The different types of partial ACL tears did not show significant differences according to the anatomic injury

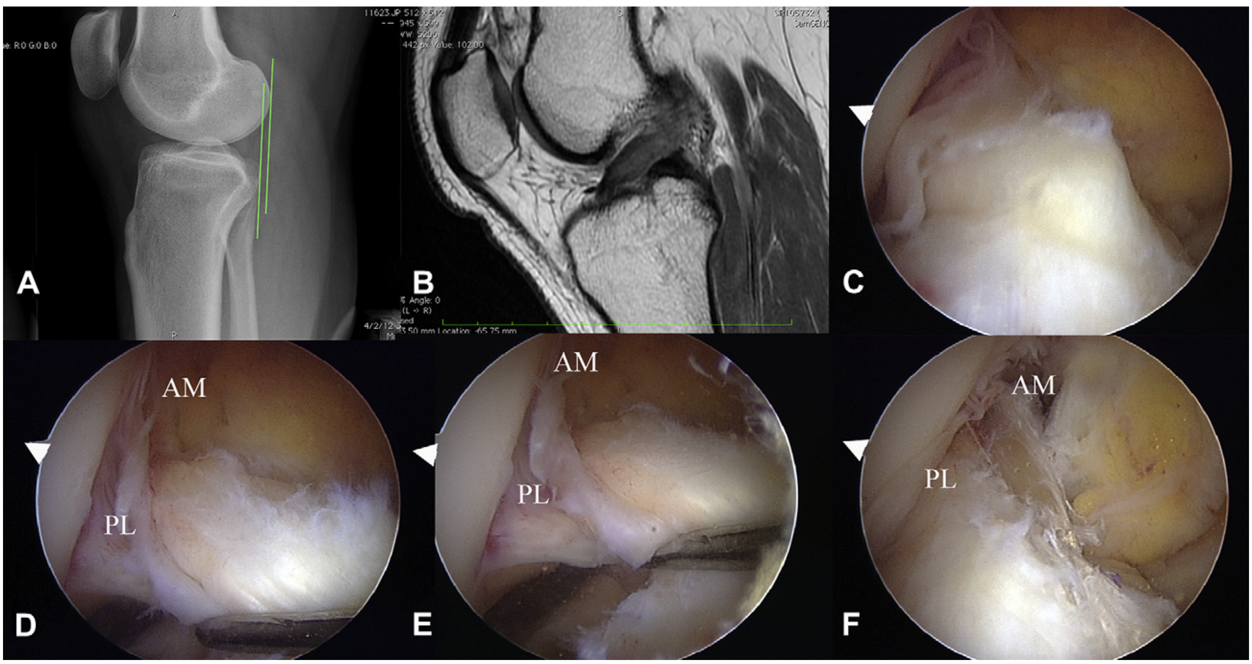

Fig 6. Example of a PL-intact case with functional remnant. (A) A minor side-to-side difference of 2 mm of anterior tibial translation by Telos stress radiography is recorded. (B) MRI findings show the presence of remaining fibers but without identifying the type of injury pattern. (C) Arthroscopy shows remaining fibers without being able to identify the injury type. (D) Evaluation of the integrity of the remaining fibers by stretching the fibers with the probe. (E) Certain partial tears require special maneuvers to confirm the mechanical integrity of the fibers in the figure-of-4 position; in this case the remaining fibers are solid and resist further stretching (i.e., functional). (F) AM bundle augmentation (left knee, view from anterolateral portal). (AM, anteromedial; PL, posterolateral.)

Table 2. Patient Demographics of Patients With Isolated Unilateral ACL Injury

Patient Demographics	
No.	300
Age (yr)	29.5 ± 11.3
Female to male ratio	0.47
Complete ACL tear—mean time from injury to surgery	177 (59%)—26 mo
All types of partial ACL tears	123 (41%)
Partial AM bundle intact—mean time from injury to surgery	21 (7%)—5 mo
Partial PL bundle intact—mean time from injury to surgery	66 (22%)—6.5 mo
Partial PCL healing—mean time from injury to surgery	36 (12%)—19 mo

AM, anteromedial; PL, posterolateral.

pattern (PL or AM bundle) in clinical tests, instrumented laxity test, or MRI findings when compared with each other, but regardless of the anatomic injury pattern, they had different instrumented laxity results according to the functionality of the remaining fibers.

In an effort to diagnose incomplete ACL tears and identify the presence of intact fibers before arthroscopy, this study was designed using available diagnostic tools that can be applied in daily practice. The importance of clinical examination in the diagnostic approach to the ACL-deficient knee needs no further emphasis by us. However, clinical tests are difficult to quantify; results often overlap among examiners, are very dependent on the examiner, and suffer from a degree of intratester liability.[25] The PST seems to be the most reliable testing maneuver in the identification of PL bundle tears according to Petersen and Zantop.[14] This is supported by other authors who recorded increased positive PST results in cases of PL ruptures, whereas the anterior drawer test and the LT may give 0 or +1 results.[5,26] In contrast, there are scarce data confirming that the less frequent AM bundle tears result in greater laxity on the LT and minor laxity or even negative results on the PST.[5] However, Petersen and Zantop[14] indicated that a clinical study validating the PST and the LT in isolated PL and AM bundle ruptures has not been performed. Our results show that great laxity on the PST (+2 and +3) was the most consistent clinical finding in identifying complete ACL tears (86.4%) versus partial tears (23.6%; $P < .0001$), yet it was not efficient to distinguish between the different types of partial ACL tears (30.3% in PL-intact tears and 19% in AM-intact tears; P = not significant). This finding is in compliance with the findings of DeFranco and Bach,[1] who identified a positive PST result as the mainstay of diagnosis of ACL deficiency and the need for surgery.[1] The LT was of similar diagnostic value because we recorded severe laxity (LT +2) in 99% of complete tears versus 32.6% ($P < .001$) in all types of partial ACL tears, and the different subgroups of partial ACL tears showed severe Lachman laxity (LT +2) in 33.3% of AM tears versus 25.7% of PL tears ($P < .01$ compared with LT +1). This is also caused by the higher prevalence of functional PL-intact cases than functional AM-intact cases.

Conversely, instrumented methods of measuring knee laxity provide a useful numerical grading of anteroposterior laxity but are equally dependent on the patient (muscle guarding), require additional equipment and radiation exposure for the patient, provide static rather than dynamic results, and ultimately use the same intratester error, especially when not used in combination with clinical examination.[25,27] Posterolateral bundle ruptures resulted in significantly lower KT-1000 (MEDmetric, San Diego, CA) results (1- to 3-mm difference) than did complete tears according to Siebold and Fu,[5] whereas AM tears had an SSD between 2 and 4 mm.

AM bundle ruptures had similarly smaller instrumented laxity results (5.3 ± 2.6 mm) when compared with complete ruptures (6.0 ± 2.4 mm) in a study by Adachi et al.[28] In another study of a small number of patients, the authors used a modification of the KT-1000 to scale knee laxity in partial tears and found increased laxity in complete versus partial ACL tears but without distinguishing the injury pattern.[11] In the present study anterior tibial translation was calculated with stress radiographs (15 kg), and our results are in compliance with these data; we recorded a statistically significant difference between the SSD of anterior tibial translation in complete tears (mean SSD of MATT,

Table 3. Correlation of Clinical Examination Results and ACL Injury Pattern

	Clinical Examination of Knee Laxity					
	Lachman Test		Pivot-Shift Test			
ACL Injury Pattern	+1 (<5 mm anterior tibial translation)	+2 (>5 mm anterior tibial translation)	0	+1	+2	+3
Complete tear	1% (n = 2)	99%* (n = 175)	2% (n = 3)	12% (n = 21)	48%† (n = 86)	38%† (n = 67)
AM intact	67% (n = 14)	33% (n = 7)	37% (n = 8)	42% (n = 9)	5% (n = 1)	16% (n = 3)
PL intact	75% (n = 49)	25% (n = 17)	23% (n = 15)	47% (n = 31)	28% (n = 18)	2% (n = 2)
PCL healing	56% (n = 20)	44% (n = 16)	20% (n = 7)	66% (n = 24)	14% (n = 5)	0% (n = 0)

AM, anteromedial; PL, posterolateral.
*$P < .00001$ when compared with Lachman test grade +1.
†$P < .00001$ when compared with pivot-shift test grades 0 and +1.

Table 4. Correlation Between Arthroscopic ACL Injury Pattern and Preoperative Results of Side-to-Side Difference of Anterior Tibial Translation Seen by Telos Stress Radiography

ACL Injury Pattern	Mean Side-to-Side Difference of Anterior Tibial Translation (Median Value)
	MATT
Complete tear	9.1 ± 3.4 mm*,† (9 mm)
All partial tears	5.2 ± 2.9 mm‡ (5 mm)
AM intact	5.2 ± 3.6 mm§,NS (5 mm)
PL intact	5.1 ± 2.8 mm¶,NS (5 mm)
PCL healing	7.0 ± 2.5 mmNS (7 mm)
All partial tears with functional remnant	4.4 ± 2.4 mm*,** (4 mm)
All partial tears with nonfunctional remnant	7.0 ± 2.5 mm*,†† (6 mm)

AM, anteromedial; MATT, medial anterior tibial translation; PL, posterolateral.

*$P < .00001$ when compared with partial tears.

†Interquartile range (IQR) 25%-75% = 7.0-11.0 mm.

‡IQR = 3.2-7.0 mm.

§IQR = 3.7-8.0 mm.

¶IQR = 3.0-7.0 mm.

**IQR = 3.0-6.0 mm.

††IQR = 2.0-6.0 mm.

NSNot significant when compared with other partial tear groups.

9.1 mm) versus all cases of partial tears (mean SSD of MATT, 5.2 mm; $P < .0001$). The different types of partial tears constituted a nonsignificant difference in instrumented laxity results according to the anatomic pattern of the tear (AM *v* PL bundle) but presented a significant difference in the SSD according to the functional status of the remaining fibers, regardless of which bundle was injured (Table 4). The PCL-healing group had results smaller than the complete tear group and greater than the AM or PL tear groups but without a significant value, probably showing the degree of pseudostability the stump of the ACL provides when it has healed on the PCL. This is also supported by Bach and Warren,[23] who described a similar ACL tear that is attached or healing on the PCL through scar tissue, leaving a normal-appearing strut of tissue that may be confused as either a complete or partial ACL tear. Instrumented laxity can be a useful adjunct in the assessment and the quantification of anteroposterior knee laxity and can confirm a complete ACL tear or can raise a strong suspicion for the presence of functional remaining fibers, but it is not sensitive enough to identify which bundle is injured.

The use of MRI in the diagnosis of partial ACL tears has focused on finding specific imaging patterns according to the type of rupture.[1,3,14] In a recent study by Van Dyck et al.,[13] the authors did a retrospective study of the MRI images from 51 patients with arthroscopic confirmation of partial ACL tears. They concluded that MRI has a low level of accuracy in the identification of such injuries, mainly because of the significant overlap of the imaging findings between partial tears and complete tears and mucoid degeneration of the ACL and the presence of the initial post-traumatic hematoma. Whenever a partial ACL tear was diagnosed, identification of which bundle was torn was not possible.[13] In our study population, MRI findings showed significant overlap among the different injury types; they were mostly classified as absence or severe distortion of ACL fibers for all types of ACL tears, with a nonsignificant difference between complete tears (96%) and all types of partial tears (73%; P = not significant). In the partial tears, it was generally not possible to locate tears in the AM or PL bundle of the ligament, and there was no correlation between the preoperative MRI findings and the arthroscopic type of ACL tear. The only significant pattern was recorded between the absence or severe distortion of ACL fibers and complete ACL tears (96%; $P < .0001$).

The arthroscopic confirmation of a remaining ACL bundle in partial tears, as well as the examination of the functional properties this bundle may have, has been documented by other authors who have also tested the mechanical integrity and functionality of the remaining fibers.[3,5,14,16] It is probably equally or more important to evaluate the mechanical integrity and functionality of any remaining ligament fibers than to identify which exact bundle has been injured. Siebold and Fu[5] recorded isolated AM or PL bundle tears that sometimes were accompanied by a functional remaining bundle, whereas in other cases there was an elongation of the remaining bundle. Similarly, Zantop et al.[29] not only examined the arthroscopic view of the injury pattern but also tested the functionality of the remaining ligament fibers; they classified them as sufficient versus insufficient.[29] The examination of the functionality of the remaining bundle is difficult to perform and is dependent on the examiner because the remaining fibers may be lax in one knee position and tight in a different position, or they may require special maneuvers to be visualized (Fig 6C and E, and Video 1).[3,14] A usual method to assess the functionality, and thus the benefit from the preservation of the remaining fibers, is

Table 5. Correlation Between Preoperative MRI Findings and Arthroscopically Confirmed ACL Injury Patterns

ACL Injury Pattern	Preoperative MRI Findings		
	Absence or Severe Distortion of ACL Fibers	Presence of Any Visible Fibers	Fibers Falling on PCL
Complete tear	96% (n = 170)	1%* (n = 2)	3%* (n = 5)
AM intact	52% (n = 11)	43% (n = 9)	5% (n = 1)
PL intact	85% (n = 56)	3% (n = 2)	13% (n = 8)
PCL healing	70% (n = 25)	11% (n = 4)	19% (n = 7)

AM, anteromedial; MRI, magnetic resonance imaging; PL, posterolateral.

*$P < .00001$ when compared with absence or severe distortion of ACL fibers.

Table 6. Results of Meniscal Pathologic Process According to ACL Injury Patterns

ACL Injury Pattern	Concomitant Meniscal Pathologic Process: Requiring Surgical Intervention: Partial Meniscectomy	Requiring Surgical Intervention: Meniscal Sutures	No Lesions/Lesions Requiring No Further Treatment
Complete tear	31%* (n = 55)	19%* (n = 33)	50% (n = 89)
AM intact	25% (n = 5)	9% (n = 2)	66% (n = 14)
PL intact	17% (n = 11)	24% (n = 16)	59% (n = 39)
PCL healing	6% (n = 2)	16% (n = 6)	78% (n = 28)

AM, anteromedial; PL, posterolateral.

*$P < .00001$ when compared with all types of incomplete ACL tears.

palpation with a probe and the effort to further attenuate or elongate the fibers.[3,5,14,30] Testing the functionality of the remaining fibers by palpation with a probe was also performed in our study. We recorded a statistically significant difference between the occurrence of a functional remnant in the PL-intact group (67%) and the occurrence of functional remaining fibers in the AM-intact and PCL-healing groups (17%; $P < .0001$). In our patient population, when a partial ACL tear was confirmed arthroscopically, it was predominantly an AM bundle tear and in the majority of these cases, the remaining PL bundle had a functional remnant (median SSD of MATT, 4 mm) (Fig 6), whereas in the less frequent cases of PL bundle tears, the remaining fibers were mostly elongated and nonfunctional (median SSD of MATT, 6 mm). From the study of our results, we recorded a threshold value of 9 mm of SSD of MATT in complete tears and, regardless of the injury pattern of the partial tear, threshold values of 4 and 6 mm median SSD for the functional and nonfunctional partial tears, respectively. With these threshold values, we tested the sensitivity and specificity of the combination of preoperative clinical examination and instrumented laxity: Partial ACL tears with functional remaining fibers were graded 0 or +1 on the PST and less than 4 mm SSD in stress radiographs (sensitivity, 0.76; specificity, 0.90); conversely, complete ACL tears produced positive PST results and an SSD greater than 9 mm (sensitivity, 0.88; specificity, 0.96).

Concomitant meniscal injuries that required some sort of further surgical treatment (i.e., partial meniscectomy or meniscal sutures) at the time of ACL reconstruction were significantly higher in our patients with complete ACL tears (50%) than in the patients with all types of partial tears (32%; $P < .001$). This finding has also been supported by other authors and may be explained by the possible higher forces necessary for a complete ACL rupture.[1,3] We also recorded longer times from injury to operation in the complete tear group than in the groups with all other types of partial tears. This result has also been published previously and a possible explanation is that an initially undiagnosed partial ACL tear with milder symptoms of instability left untreated allowed the patient to eventually return to sport activities and resulted in progression to a symptomatic complete ACL tear with secondary injuries to the meniscus.[1,3]

There are different diagnostic tools available in our armamentarium for the identification of a partial ACL tear with possibly functional remaining fibers. Although the diagnosis of a partial versus a complete ACL tear can be made with greater accuracy during arthroscopy, the decision to perform surgery or not and the type of operation can be affected by combining the preoperative results of clinical tests and instrumented laxity. Severe PST laxity (+2 or +3) was consistent with complete ACL tears, whereas PST grades of 0 or +1 were strongly related to partial tears. Instrumented laxity testing with stress radiographs produced increasing results in a scaled fashion from all types of partial tears to complete tears but without identifying the anatomic injury pattern in partial tears. A partial ACL tear with functional remaining fibers had less than 4 mm of SSD of anterior tibial translation, and 0 or +1 pivot-shift. An SSD of anterior tibial displacement from 4 to 9 mm with positive PST results was consistent with partial tears with nonfunctional remaining fibers. An SSD greater than 9 mm in instrumented laxity testing and a positive PST result were recorded in complete ACL tears.

Limitations

Limitations of this study include possible intratester error for clinical examination tests, which, as previously mentioned, depends on the surgeon's training and experience and the technique performed. The interexaminer variability that is usually recorded in the grading of the PST and the LT was balanced by distinguishing a positive LT result in 2 patients and by grouping severe PST laxity (+2 and +3). There were no exclusion criteria regarding the time from injury to examination so that the study population would be confined to chronic or subacute cases. This was so that all isolated ACL tears would be included regardless of the time from injury and to record the period from injury to surgery. This limitation was balanced by including only isolated ACL tears confirmed by clinical examination, MRI, and arthroscopy. Another limitation is that the examiners for imaging and arthroscopy were not blinded to the results of clinical examination, and a power analysis of the results was not performed. Last, the application of stress radiographs requires additional equipment and trained personnel as well as radiation exposure for the patient.

Conclusions

Preoperative evaluation of different types of ACL tears showed differences between complete and partial ACL tears with functional remaining fibers in clinical examination and instrumented laxity tests. The combination of clinical tests and stress radiographs produced threshold values that distinguished complete from partial ACL tears, which may help the surgeon in the early identification of the presence of remaining functional fibers.

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