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ORIGINAL ARTICLE

The role of the anterolateral ligament in knee's biomechanics: a case–control retrospective study

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Abstract

Purpose The aim of this study was to assess the functional and clinical results of patients who underwent ACL reconstruction surgery and were divided into subpopulations related to ACL-associated lesions and focused on ALL-associated lesion.

Methods Our retrospective analysis included 62 patients who underwent standard ACL reconstruction surgery in our hospital from 2014 to 2016. The mean follow-up period was 21 months (range 11–35). We divided the sample into two subpopulations due to the presence or absence of ALL tear at the preoperative MRI. In 42 patients out of 62 (68%), ALL lesion was evident. We evaluated in both subpopulations the ACL failure rate, the functional outcomes rated with IKDC, KOOS, Lysholm scores and the clinical assessment of anteroposterior and rotatory instability with the Lachman test and pivot-shift test.

Results The overall re-injury rate in our cohort of patients was 4.8% with a smaller but not a significant difference between the two groups. A statistically significant difference was observed for the three functional scores, favoring the isolated ACL-lesion group ($p < 0.05$). Similarly, a better Lachman score was observed in the isolated ACL-lesion group, without statistical significance ($p = 0.77$); overall, the rate of positive test was lower in the isolated ACL-lesion group. We observed a significant difference of residual rotatory instability (positive pivot-shift test) in the two subpopulations ($p = 0.036$), and 9% of patients in the ACL + ALL lesion group showed residual jerk or subluxation.

Conclusion The additional ALL reconstruction/repair surgery should always be considered in patients with evident ALL tear at the preoperative MRI.

Keyword Knee · MRI · ALL · ACL

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Introduction

Anterior cruciate ligament (ACL) tears are among the most common knee injuries, and ACL reconstruction has evolved considerably over the past 30 years. Although ACL reconstructions provide satisfactory clinical results nowadays, regardless of the type of graft, tunnel drilling technique and graft fixation system, the residual rotatory instability is still a matter of concern among surgeons. Different degrees of ACL tear combined with damage to other intra- and extra-articular structures of the knee result in different patho-laxities [10, 18]. A detailed understanding of which structures of the knee joint act as secondary restraints to the ACL and how their lesions correlate to clinical tests is necessary to formulate the proper diagnosis.

The anatomy of the lateral knee has been widely studied, but the relationship between these structures and their respective functions, especially during active motion of the knee, have not been completely clarified [15, 28].

Recent studies showed that ACL reconstruction is often successful in repairing anterior stability, while rotational instability often persists over time [2, 3, 7–9, 12, 21].

The lack of rotational control was thought to contribute to secondary meniscal or cartilaginous problems, and this led surgeons to reconsider the ACL anatomy and biomechanics.

The pivot-shift test is the most specific test for knee rotational instability, and it is the only physical examination test that correlates with the subjective feeling of instability [23].

The neo-ACL failure rate within 5 years after surgery is about 7% (6% in the first 3 years), and it grows up until 17% in the 15 years after surgery. Counter-lateral ACL injury after ACL reconstruction is about 9% after 5 years (6% in the first 3 years) and about 26% 15 years after surgery. Comprehensive ACL injury rate within 5 years after surgery is among 16% (13% after 3 years) and 32% after 15 years. Patient anthropometric criteria, kind of graft (hamstrings or bone-patellar tendon-bone) and femoral or tibial fixation technique did not affect re-injury rate and functional outcomes in the current literature. On the other hand, unrepaired secondary stabilizers have been noted as a reason for reconstruction failure [11]. These data could suggest that knee biomechanic and proprioceptive disorders persist after ACL reconstruction surgery and that these disorders may occur in meniscal tears, cartilage lesions and neo-ACL re-rupture. Furthermore, ALL achieved more relevance, in the current literature, to knee rotational stability. According to Inderhaug, in a knee with combined ACL and ALL injuries, the modified Lemaire tenodesis combined with ACL reconstruction restored normal laxities at all angles of flexion for graft fixation (0°, 30°, or 60°), with 20 N of tension. Therefore, the combined ACL and ALL procedures restored intact knee kinematics when tensioned in full extension [19].

Our hypothesis is that patients with the isolated ACL perform much better after isolated ACL reconstruction than patients with the ACL + ALL-associated lesion.

Materials and methods

Study aims:

- To assess the prevalence of recognizable ALL on standard knee 1.5-Tesla MRI preoperative imaging
- To assess the prevalence of ALL lesion associated with the ACL lesion
- To evaluate the neo-ACL re-rupture rate and the clinical and functional outcomes of two groups of patients. The first group of patients had a MRI evidence of ACL + ALL ruptures; the second one had isolated ACL rupture.

In our clinic, 266 patients underwent ACL reconstruction from January 2014 to January 2016. Our retrospective analysis included the 62 patients who carried out the follow-up period and provided complete preoperative MRI imaging documentation at the final follow-up medical examination. Exclusion criteria were associated ligament lesions (MCL, LCL, PCL $n = 37$), associated ipsilateral lower limb fractures ($n = 18$), associated systemic rheumatic diseases ($n = 14$), patient age under 15 years old ($n = 35$) and over 50 years old ($n = 38$), associated knee osteoarthritis (Kellgren and Lawrence grade > 2) or cartilage lesions (grade III or superior with Outerbridge classification) recognizable on MRI images ($n = 18$), not recognizable ALL on preoperative MRI imaging ($n = 3$), inveterate ACL lesion ($n = 41$). We consider that, 8 months after injury, other factors might affect the stability of the knee and the peripheral restrains, and we consider it like a bias for the study.

Fifty-three out of 62 patients were male (85%). Mean patient's age was 29 years old (SD 9, range 15–50). The injured knee's side was left in 24 (39%). No patient practices sport at a professional level. All performed sports including pivoting and twisting knee movements. In all cases, surgery was performed between 4 and 8 months from the injury.

All knee surgeries were performed by two senior knee and sport medicine surgeons with the assistance of resident doctors. The surgical technique was arthroscopic ACL reconstruction with a single-bundle quadruplicated hamstrings graft with a trans-tibial tunnel drilling technique. The fixation system was a cross-pinning fixation for the femoral side (RigidFix, DePuy, Johnson & Johnson) and interference screw for tibial side (BiointraFix, Depuy, Johnson & Johnson).

We reviewed the MRI 1.5-Tesla performed before surgery for all patients. MRI examinations came from different radiological services, but all were performed with a 1.5-Tesla MRI machine with the standard setting to evaluate ACL and menisci with at least one coronal T2-weighted scan with fat suppression or a PD scan (Fig. 1).

A clinical follow-up was planned at about 24 months; it was performed by the same orthopedic surgeon. Follow-up assessments included measurements of functional outcomes and knee stability.

The functional outcomes evaluation included knee international scoring systems "2000 IKDC subjective knee evaluation form," "KOOS" (Knee injury and Osteoarthritis Outcome Score) and "Lysholm score." The knee stability was assessed with Lachman test for the anteroposterior tibial translation and the pivot-shift test for the rotational instability. The pivot-shift test score was 0 (no translation difference between the two knees), 1 (a "glide" of the lateral tibial plateau-increased lateral compartment translation), 2 (a "jerk," "jump" of the lateral tibial plateau with a slight anterior subluxation, with the gross subluxation reduction during the test) and 3 (a gross subluxation of the anterolateral tibial plateau with

Fig.1 In the first frame a knee in MRI with an intact ALL, in the second and third a proximal and distal ALL lesion, respectively

Table 1 Group 1: ALL lesion; Group 2: Not ALL lesion

	Lachman				Pivot-shift			
	3+	2+	1+	0	3+	2+	1+	0
Group 1	2	1	9	30	1	3	12	26
Group 2	0	0	3	17	0	0	1	19
Total	2	1	12	47	1	3	13	45

impingement of the posterior aspect of the lateral tibial plateau against the femoral condyle) [26].

Statistical analysis

Data were analyzed with Stata 13.1 (StataCorp, College Station, TX, USA). A two-sided *p* value was considered statistically significant.

Continuous variables were reported as mean and standard deviation and categorical variables as counts and percent. They were compared at baseline between the ACL and LLA + ACL groups with the Student's *t* test and the Fisher's exact test, respectively. General linear or logistic models were fitted to estimate differences in the outcomes at 2 years; Huber–White robust standard errors were computed. Adjustment for the presence or site of meniscal lesions was done to control for its confounding effect; interaction was tested (and excluded) to assess an effect modification of surgery by meniscal lesions. Differences and odds ratios (OR), respectively, were estimated together with their 95% confidence intervals (95% CI).

Results

ALL could be visualized at MRI in all 62 patients. In 42 (68%) patients, an ALL lesion was evident. It was localized at the femoral side in 21 (50%) patients, at medium third of the ligament in 13 (31%) patients, and at the distal tibial side with no Segond fractures in eight (19%) patients. In the first group, we included patients with the isolated ACL lesion and in the second group patients with ACL + ALL-associated lesion.

Table 2 Group 1: ALL lesions; Group 2: Not ALL lesions; Group 3: Not meniscal tears; Group 4: meniscal tears

	IKDC	KOOS	Lysholm
Group 1	93.1	95.6	94.7
Group 2	97.3	98.8	99
Mean tot. of patients	95.2	97.2	96.8

The two groups of patients are homogeneous for age, gender and clinical characteristics.

The mean follow-up period was 21 months (SD 7 months, range 11–35). The overall re-injury rate in our cohort of patients was 4.8%. A lower, but not significant, rate of neo-ACL failure was reported in the group of patients without ALL lesion. The comparison of functional outcome and knee stability between the two groups is highlighted in Tables 1 and 2. A small (around 4 points) but statistically significant difference was observed for the three functional scores (IKDC, KOOS and Lysholm), favoring the isolated ACL-lesion group ($p < 0.05$). Similarly, a better Lachman score was observed in the isolated

ACL-lesion group, with no patients with grade 2 or 3, though the difference did not reach statistical significance ($p = 0.77$). Overall, the rate of positive test was higher in the group of patients with the associated ALL lesion (rate difference 14%). Moreover, we observed a significant difference of residual rotatory instability (positive pivot-shift test) in the two subpopulations ($p = 0.036$). No patients in the isolated ACL-lesion group showed either jerk or subluxation, while in the ACL + ALL lesion group, 9% of patients had either of them (Table 1). Overall, an excess of positive tests was observed in the latter group (rate difference 33%, $p = 0.006$).

Discussion

In our experience, ALL was recognizable at MRI in almost all cases, and about 70% had an ACL with associated ALL lesions. At a mean follow-up of 21 months, good functional and clinical results were elicited. Moreover, our study shows that patients with isolated ACL lesion perform significantly better than patients with an associated ALL lesion, though the observed differences in IKDC, KOOS and Lysholm scores are small in size. As expected, given the surgical technique, the Lachman test does not discriminate between the two groups. Conversely, the pivot-shift test shows a marked and significant reduction in the residual rotatory instability in the isolated ACL-lesion group (rate difference 33%, $p = 0.006$).

The preoperative imaging examinations were carried out with different 1.5 Tesla MRI devices, with standard sequence setting for ACL with at least coronal T2-weighted fat-suppression sequences or PD sequences. In 62 (95.4%) patients, ALL was visualized. The date is in line with the recent literature. In a case series using 1.5-T MRI, Helito et al. demonstrated the possibility to visualize the ALL in routine imaging. Partial visualization was possible in 97.8% of cases. The meniscal portion was the easiest to identify (94.8%), followed by the femoral (89.7%) and the tibial (79.4%) portions. Visualization of the thin structure resembling the ALL was most easily achieved in coronal T2-weighed or PD planes [16]. LaPrade et al. were able to identify the MLCL (later ALL) with a sensitivity of 93.8% and specificity of 100% in T1-weighed 1.5 T MRI planes [24]. Kosy et al. were able to identify the ALL partially in 94.0% and fully in 57.0% of cases reviewing 1.5-T MRI planes of patients without a known history of ACL ruptures or lateral compartment injuries. Anyway, the anatomical studies report an higher rate of ALL identification close to 100% of specimens, from 83 to 100% [5, 7, 14]. MRI studies instead show a lower rate of ALL identification. This difference could be due to different causes. Firstly, all patients included in our study sustained a knee injury and had a different degree of joint swelling or hemarthro at the moment of the MRI. The higher pressure in knee joint makes easier ALL identification. On the other hand, different MRI studies in the literature are carried out on uninjured knee. Moreover, the images in coronal planes are suitable for ALL description, but the study of the coronal planes is demanding for topographic identification of ALL. Surely, a 3-Tesla MRI machine and a MRI study planes tailored on ALL will improve the ALL identification rate [13].

Claes et al. [6, 7] showed an ALL lesion rate of 78.8% in a retrospective study carried out on preoperative MRI images of patients who underwent ACL reconstruction. Claes highlighted that ALL lesion occurred at the tibial side in 77.8% of cases. Conversely, in our study only 50% of ALL lesions occurred at the meniscal and tibial sides and the other 50% involved the femoral side of the ligament. Helito highlighted in a biomechanical study the ALL rupture pattern and obtained more femoral-side than tibial-side ALL ruptures with a maximum strength of 204.8 N [14]. Kennedy shows a higher incidence of Segond fracture in his cadaveric biomechanical study with a mean maximum load similar to other studies (175 N) [22].

Despite satisfactory clinical results, isolated ACL reconstructions do not restore normal kinematics and biomechanics of the knee [20], and they particularly do not fully control knee rotational instability.

A positive pivot-shift test persists in up to 25% of patients after ACL reconstruction [8].

A systematic review by Mohtadi et al., however, suggested a 19% incidence of pivot shifts II° and higher after ACL reconstruction with either hamstring (single- and double-bundle) or patellar tendon graft [25]. Therefore, repair of the ALL lesions should be considered to improve the control of rotational stability provided by ACL reconstruction according to Sonnery-Cottet [30].

Our study demonstrates patient's functional, objective and subjective results similar to those previously reported with ACL reconstruction [13]. In the current literature, at 2-year follow-up, the rate of graft rupture is similar to the rate of contralateral ACL rupture.

In our study, comprehensive ACL graft rupture rate (4.8%) was similar to those previously reported with ACL reconstruction [17]. Interestingly, there is a higher risk of re-injury in the group of patients with the associated diagnosis of ALL lesion than in the group with intact ALL (0%). It seems to be connected to the lack of rotation stability due to the not-repaired ALL lesion. The development of the double-bundle ACL reconstruction prompted a new interest in this lack of rotational control. The discovery of the posterolateral bundle allowed a more "anatomic" restoration of the ACL with an expectation of improved biomechanical behavior. However, the clinical benefit of these double-bundle reconstructions continues to be debated [29]. From another point of view, many authors consider the lateral structures of the

knee, the key of the anterolateral instability control. There are different studies that consider a peripheral lever arm, as ALL or its reconstruction with lateral extra-articular tenodesis, more effective in control knee rotation [1]. Monaco et al. [27] support the role of an additional lateral extra-articular reconstruction in control internal rotation of the knee at 30° of flexion. In a computer-assisted study, they had better results in patients with additional extra-articular augmentation than in the group with isolated standard single-bundle ACL reconstruction and anatomic double-bundle reconstruction. A recent study also demonstrated that the lesion of the anterolateral ligament or "anterolateral femorotibial ligament" increases the tibial rotation, and it is correlated with pivot-shift phenomenon [29]. In line with these findings, our study highlighted a higher rate of residual pivot-shift test in the group of patients with associated ALL lesion ($p = 0.006$). The residual positive pivot-shift test is recognized to be correlated with subjective instability feeling and discomfort.

Thus, in our study, the subjective scoring systems, IKDC, Lysholm and KOOS, assessed at average 2-year follow-up, showed significant differences between the two study groups, and the group without ALL lesion performs better. These evidences support the important role of ALL and its reconstruction-repair procedures to control knee stability recovering better life quality and return to sport. Also, the histological studies carried out by Caterine [4] revealed a large amount of peripheral nerves and mechanoreceptors in ALL tissue. These evidences suggest a proprioceptive role of the ALL [5] that could explain the better functional outcomes in the group of patients without ALL lesion. In conclusion, possible indications for combined ACL and ALL reconstructions might be a high-grade pivot shift, revision ACL reconstruction, patients with proven anterolateral knee pathology on preoperative imaging, and young patients participating in high-demand sport, and perhaps, finally, patients with ligamentous hyperlaxity [4].

Limits of the study

This study has some limits. Firstly, it is a retrospective study. We assume that physiological knee stability for each patient was the contralateral uninjured knee. For the same reason, we collected MRI scans from different radiologists by using different machines, and this could affect some results. However, the visualization rate of ALL is very high, so possibly no influence of the different setting was present. Moreover, two-year FU could be too short to elicit significant results about damages on knee joint. This needs to be explored in further studies. Obviously, a more precise instrument for objective evaluation of residual knee instability after surgery will provide more effective results.

In conclusion, the association of ACL and ALL tears seems to be predictive for worse functional outcomes and residual rotatory instability after ACL standard reconstruction procedure, if ALL-associated lesion has not been fixed. Therefore, additional ALL reconstruction/repair surgery should be considered in patients with evident ALL tear at the preoperative MRI.

Compliance with ethical standards

Conflict of interest The author(s) declare that they have no competing interests.

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