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Sectioning the anterolateral ligament did not increase tibiofemoral translation or rotation in an ACL-deficient cadaveric model

Yousif Al Saiegh[1] · Eduardo M. Suero[1] · Daniel Guenther[1] · Nael Hawi[1] · Sebastian Decker[1] · Christian Krettek[1] · Musa Citak[1] · Mohamed Omar[1]

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Abstract
Purpose The anterolateral ligament (ALL) has been proposed as a possible extra-articular stabiliser of the knee. Injury to the ALL may result in residual instability following surgical reconstruction of a ruptured anterior cruciate ligament (ACL). Few studies have evaluated the biomechanical role of the ALL. The purpose of this study was to investigate whether sectioning the ALL would have an influence on tibiofemoral translation or rotation during the anterior drawer, Lachman, pivot shift, external rotation, and internal rotation tests in an ACL-deficient knee.
Methods Only whole-body specimens having an ALL were included in this study. Lachman, anterior drawer, external rotation, and internal rotation tests were performed manually. Pivot shift test was done using a mechanised pivot shifter. The amount of tibiofemoral translation and rotation was recorded by a navigation system. Each specimen was tested in its native state, after sectioning the ACL, and after combined sectioning of the ACL and the ALL.
Results In six out of 14 cadaveric knees, an ALL could be identified. The ACL-deficient knee had significantly more tibiofemoral translation and rotation compared to the native knee ($P < 0.05$). However, no changes in the magnitudes of translation or rotation were seen after subsequent sectioning of the ALL compared to the ACL-deficient knee ($P > 0.05$).
Conclusion Adding an ALL lesion in an ACL-deficient knee did not increase tibiofemoral instability in this cadaveric model. It remains unclear whether injury to the ALL would result in substantial knee instability in the setting of ACL injury in vivo. Further research is warranted to fully elucidate the role of the ALL during knee kinematics and to determine in which scenarios ALL repair would be warranted. Understanding the function of the ALL may improve the current treatment strategies for ACL ruptures.

Keywords Anterolateral ligament · Anterior cruciate ligament · Tibiofemoral translation · Tibiofemoral rotation · Pivot shift test · Biomechanics

Introduction

The anterolateral structures of the knee are known to be a secondary restrain to anterior tibial load and internal tibial rotation [1]. Recent reports have identified an anterolateral ligament (ALL) in this area as a potential extra-articular stabiliser of the knee [2–7]. While biomechanical studies have been limited, it has been proposed that the ALL may contribute to the anterolateral stability of the knee, preventing anterolateral subluxation of the proximal tibia on the femur. Some authors have suggested that unaddressed injury to the ALL may be partially responsible for persistent knee instability after isolated anterior cruciate ligament (ACL) reconstruction. Critics mention that a thickening of the capsule itself leads to a ligament-like appearance and the biomechanical function of this structure is low. However, an in vivo study exploring the kinematics of the knee in 17 patients has shown that isolated single-bundle ACL reconstruction techniques do not restore native

Yousif Al Saiegh and Eduardo M. Suero contributed equally to the study and are thus both considered first authors.

✉ Mohamed Omar
omar.mohamed@mh-hannover.de

[1] Trauma Department, Hannover Medical School, Carl-Neuberg-Straße 1, 30625 Hannover, Germany

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knee kinematics and, in some patients, do not successfully address rotational instability [8].

Extra-articular reconstruction techniques were popular in the early phases of ACL reconstruction, but raise concerns regarding over-constraining of the knee with limited range of motion and high pressure on the lateral compartment [7, 9–13]. Recent studies have shown that there may be a role for combined intra- and extra-articular reconstructions in patients with persistent postoperative rotational instability or with injury to the anterolateral structures of the knee. By understanding the biomechanics of the anterolateral structures, we may be able to identify cases in which repair or reconstruction may improve clinical outcomes after ACL rupture.

The aim of this study was to evaluate the role of the ALL as anterolateral knee stabiliser in a cadaveric model. It was hypothesised that sectioning the ligamentous structure would increase tibiofemoral translation and rotation in an ACL-deficient knee.

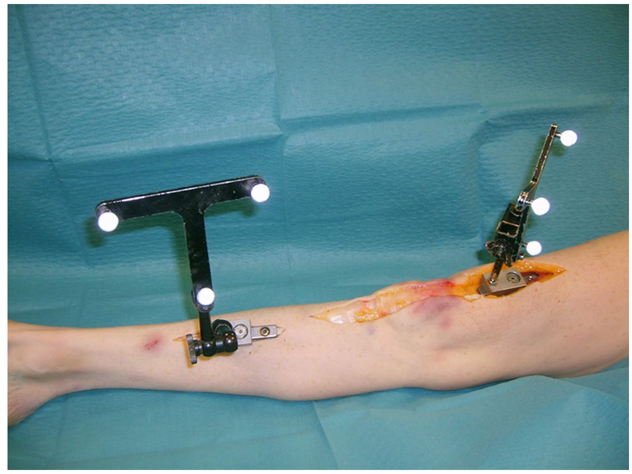

Fig. 1 Right leg cadaveric specimen after attachment of reflective reference arrays to the femur and the tibia, and medial parapatellar arthrotomy

Materials and methods

Fourteen paired knees from seven fresh whole cadavers were initially enrolled in this study. Specimens were thawed overnight for 48 h at room temperature before testing. Each whole-body specimen was laid in the supine position on an operating table, ensuring unrestricted motion at the hip and knee joints. A skin incision was performed and the underlying soft tissue was carefully dissected leaving the joint capsule intact. The iliotibial band was carefully detached from the underlying capsule leaving its distal attachment at Gerdy's tubercle intact. The anterolateral structures were observed by two authors. All specimens without an anterolateral ligamentous structure were excluded from the study prior to biomechanical testing, thus leaving 6 out of the 14 enrolled specimens available for testing. There was 1 female and 2 male cadaver specimens, with a mean age of 42 years (SD = 20.5 years). A medial parapatellar arthrotomy was performed to digitise the reference landmarks within the knee joint. Care was taken to preserve the meniscal attachments and to prevent damage the capsule beyond the trajectory of the incision. A surgical navigation system with ACL-specific software and with an accuracy of 1 mm and 1° (Brainlab, Munich, Germany) was used for kinematic data acquisition. Reflective reference arrays were attached to the femur and the tibia, 10 cm above and 20 cm below the joint line, using bicortical screws (Fig. 1). Stability testing consisted of the anterior drawer test; the Lachman test; the pivot shift test; and the internal and external rotation tests. Lachman, anterior drawer, internal rotation, and external rotation tests were performed manually. For the Lachman test and the anterior drawer test, the knee was flexed to 30° and 90°, respectively, and an anterior pulling force of a mean 120N was applied 7 cm below the joint line [14]. The maximum internal and external rotation of the tibia was assessed at both 30° and 90°, respectively. In order to reduce test–retest variability and ensure more accurate examinations, a mechanised pivot shifter was used to perform the pivot shift manoeuvres (Fig. 2) as described previously [15–17]. Each leg was loaded onto the mechanised pivot shifter and fixed in internal rotation. A constant valgus force of 40–50N was applied 5 cm below the joint line on the lateral side of the proximal third of the leg. Axial compression was applied manually to the ground plate of the mechanised pivot shifter. Tibial translation and tibial rotation were measured from the tibiofemoral resting

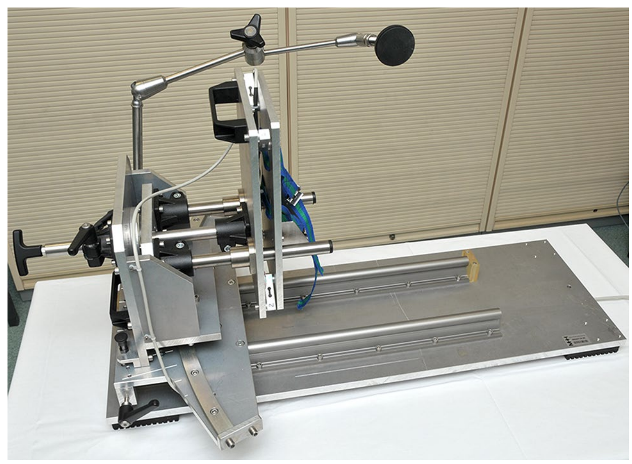

Fig. 2 Mechanised pivot shifter. Pivot shift manoeuvres were hereby consistently performed throughout the specimens in order to reduce test–retest variability and ensure more accurate examination

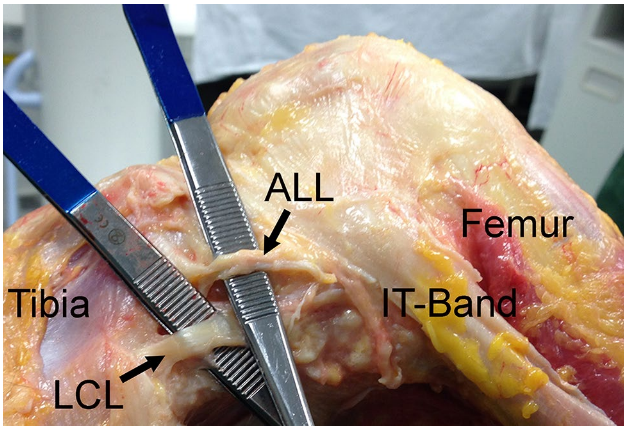

Fig. 3 Lateral view of the knee. The anterolateral ligament (ALL) originates on the prominence of the lateral femoral epicondyle, anterior to the origin of the lateral collateral ligament (LCL). The ALL then runs an oblique course towards the anterolateral side of the proximal tibia. To improve visualisation of the ALL in this figure, the distal portion of the IT band was removed. For biomechanical testing, the distal attachment of the ALL at Gerdy's tubercle was left intact

point at the beginning of each trial to the maximum anterior position or to the maximum angle of rotation of the tibia with respect to the femur.

Three trials of the anterior drawer; Lachman; external and internal rotation at 30° and 90°; and pivot shift tests were performed at each tested condition to ensure repeatability: native knee; ACL-deficient knee; and ACL- and ALL-deficient knee. After testing the intact knee, a #15 blade was used to section and resect the ACL, with visual and tactile confirmation performed by two examiners. The ALL was subsequently sectioned in the same fashion (Fig. 3). All tests were repeated after sectioning each ligament.

Approval for this study was obtained from Institutional Ethics Committee of Hannover Medical School (#2022-2013).

Statistical analysis

All statistical analyses were performed using Stata/MP 13.0 (StataCorp LP, College Station, TX). A mixed model with the restricted maximum likelihood method was used to analyse the effect that sectioning the ACL and the ALL had on tibiofemoral translation and rotation, with knee condition as a fixed effect and specimen as a random effect. Subsequent pairwise comparisons were performed, and the comparison-wise error rate was adjusted using the Bonferroni method. Statistical significance was set to $\alpha = 0.05$. Test–retest reliability was measured using Lin's concordance coefficient. Results are presented as mean and 95 % confidence interval (95 % CI), or mean and standard deviation (SD), wherever appropriate.

Results

A ligamentous structure was identified in the area of the anterolateral capsule in 6/14 knees (43 %, Fig. 3). Sectioning the ACL resulted in an increase in both the tibiofemoral translation and rotation, respectively (Tables 1, 2; Figs. 4, 5, 6). This increase was significant in all performed test, except of the internal rotation test at 90° knee flexion. Additional sectioning of the ALL did not further increase tibiofemoral translation or rotation (Table 1, 2; Figs. 4, 5, 6). There were no significant differences between the ACL- and ACL-/ALL-deficient states for tibiofemoral translation in the pivot shift test (Table 1; Fig. 5), as well as for tibiofemoral rotation in the pivot

Table 1 Tibiofemoral translation of the native, ACL-, and ACL-/ALL-deficient knee

Test	Native		ACL-		ACL-/ALL-	
	Mean (mm)	95 % CI (mm)	Mean (mm)	95 % CI (mm)	Mean (mm)	95 % CI (mm)
Anterior drawer	6.6	5.4–7.8	15.1	13.8–16.3	13.8	12.2–15.5
Lachman	5.4	4.3–6.6	14.3	13.1–15.5	13.1	12.1–14.1
Pivot shift	0.5	0.0–1.0	7.5	6.2–8.8	6.8	5.5–8.0

Table 2 Tibiofemoral rotation of the native, ACL-, and ACL-/ALL-deficient knee

Test	Native		ACL-		ACL-/ALL-	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
External rotation 30	20.7°	17.7°–23.6°	23.1°	20.7°–25.5°	23.1°	20.8°–25.3°
External rotation 90	13.1°	10.2°–16.0°	17.4°	14.1°–20.6°	16.9°	13.7°–20.2°
Internal rotation 30	8.1°	5.4°–10.8°	13.2°	11.0°–15.4°	13.2°	11.2°–15.2°
Internal rotation 90	16.3°	13.6°–18.9°	19.5°	16.9°–22.1°	19.4°	17.0°–21.9°
Pivot shift	2.3°	1.5°–3.0°	6.6°	4.9°–8.3°	6.9°	5.1°–8.7°

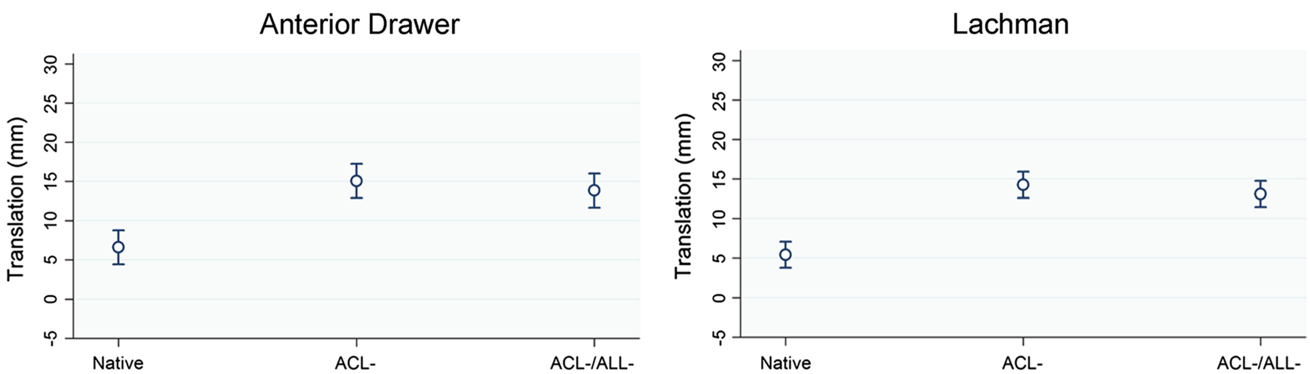

Fig. 4 Tibiofemoral translation of the native, ACL-, and ACL-/ALL-deficient knee in the Lachman and anterior drawer tests

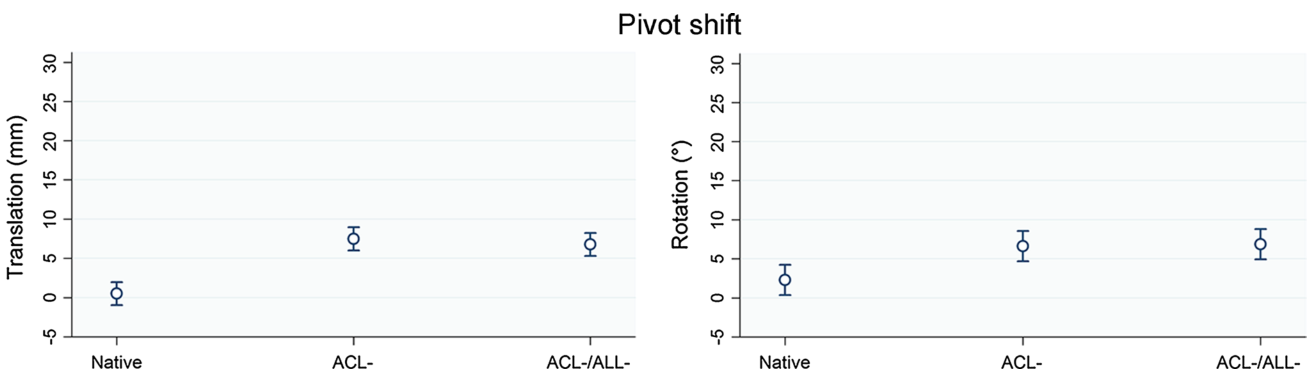

Fig. 5 Tibiofemoral translation and rotation of the native, ACL-, and ACL-/ALL-deficient knee in the pivot shift test

shift, external rotation and internal rotation tests (Table 2; Figs. 5, 6). While external and internal rotation tests at 30° knee flexion showed the same values for tibiofemoral rotation, the pivot shift test and external and internal rotation tests at 90° knee flexion resulted in a not significant reduction in tibiofemoral rotation between the ACL- and ACL-/ALL-deficient states (Table 2; Figs. 5, 6). There was high test–retest reliability, with correlation coefficients for each test within each condition ranging from 0.92 to 0.96.

Discussion

The most important finding of the current study was that there was no increase in tibiofemoral translation or rotation with combined ACL/ALL sectioning compared to isolated sectioning of the ACL. This is in conflict to recent studies, which have described the anterolateral structures of the knee as a potential restraint to internal tibial rotation [5, 6]. It is thought that persistent postoperative rotational instability after ACL reconstruction may be due to injury to the anterolateral structures of the knee in some patients. This theory serves as the basis for extra-articular ACL reconstruction strategies.

Anatomical descriptions of an ALL have varied. Claes et al. [2] described the anatomical location of the ALL, which was identified in 40 of 41 cadaveric knees. They found the ligament originating on the prominence of the lateral femoral epicondyle, anterior to the origin of the lateral collateral ligament (LCL), and proximal and posterior to the insertion of the popliteus tendon. The ALL then runs an oblique course towards the anterolateral side of the proximal tibia. Dodds et al. [3] basically confirmed Claes' findings by identifying the ALL in 33 of 40 fresh specimens. They were able to clearly differentiate this structure from the eponymous one described earlier by Vincent et al. [18], which attached to the lateral meniscus and did not extend to the tibial plateau. However, Stijak et al. [19] were not able to reproduce these findings, clearly identifying the ALL in only 50 % of the studied specimens. Their anatomical description of the ligament appears to differ from that of previous studies, emphasising the capsular attachment of the ALL anteriorly. In a comprehensive study encompassing MRI imaging, anatomical dissection, and histological analysis, Caterine et al. [20] confirmed the existence of the ALL as

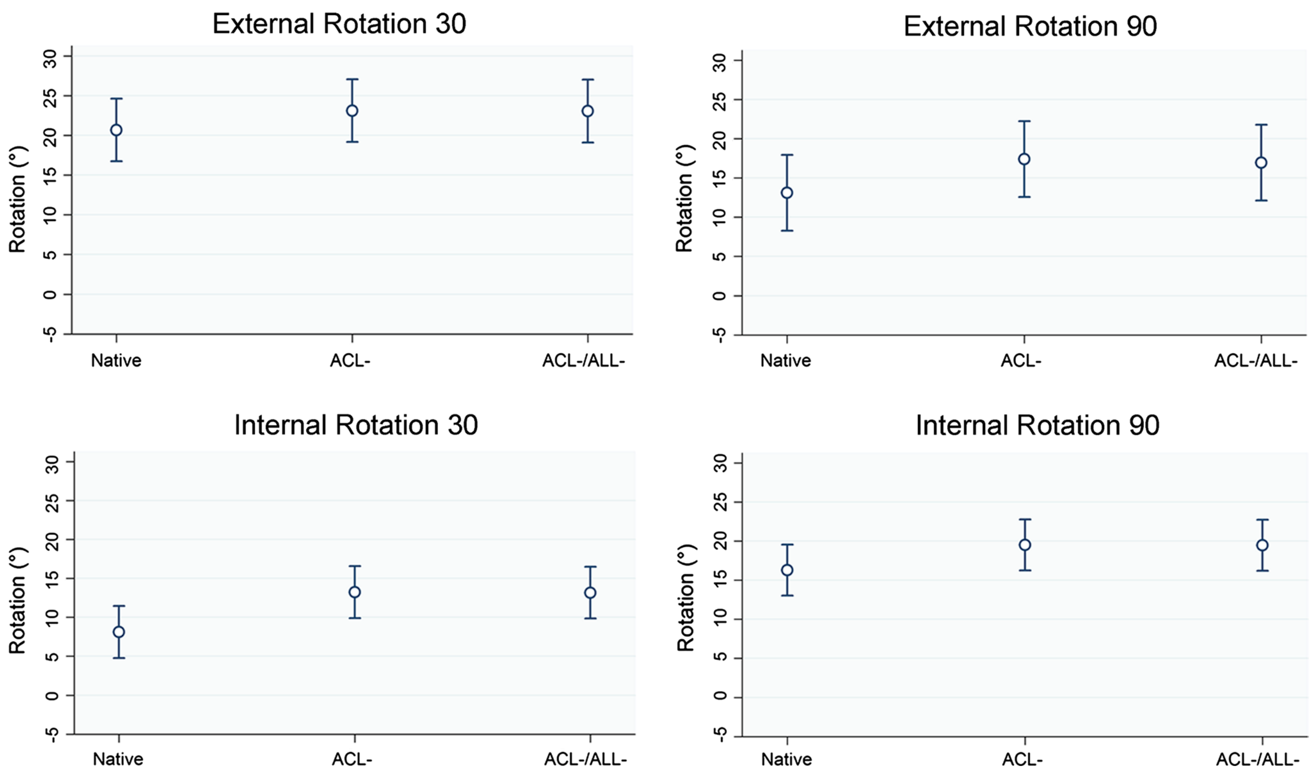

Fig. 6 Tibiofemoral rotation of the native, ACL-, and ACL-/ALL-deficient knee in the external and internal rotation tests

a distinct ligamentous structure. They described a variable femoral insertion of the ligament either posterior proximal or anterior distal to the femoral origin of the LCL. The tibial attachment was consistently found midway between Gerdy's tubercle and the fibular head. Porrino et al. [21] identified an anterolateral ligamentous structure in MRI studies of 53 normal knees, but determined that radiologic discrimination of an isolated ALL was too difficult for routine workflow and suggested that radiologists continued to refer to the region of anterolateral knee stabilisers as the lateral capsular ligament. In a subsequent review of 20 MRI studies of cases of Segond Fracture, they were able to identify a clear insertion of the tibial component of the ALL onto the fracture fragment. De Maeseneer et al. [22] evaluated MRI images of patients with Segond fractures and found that the ALL inserted on the Segond bone fragment in 10 out of 13 cases; the iliotibial (IT) band in 11 out of 13 cases; and the anterior arm of the biceps tendon did not insert on the Segond fragment in any of the cases. The insertion of both the ALL and the IT band on the Segond fracture fragment contradicts Claes et al.'s hypothesis of the ALL having a unique role in the aetiology of this injury. In the current study, we were able to identify the ALL in only 43 % of the specimens according to the descriptions made by Claes.

Regarding the biomechanical role of the ALL, the results of the current study are in conflict to recently published studies. Monaco et al. [23] performed serial sectioning of the ACL and the lateral capsular ligament and reported significantly increased anterior tibial translation at all flexion angles and of internal tibial rotation at 30° of flexion. They also reported higher pivot shift grades after sectioning of the ACL and the lateral capsular ligament compared to isolated ACL sectioning. However, these results should be interpreted with caution, as the pivot shift was performed manually and was graded by a single, non-blinded examiner. We were not able to reproduce these results in the current study, with combined ACL and ALL sectioning not increasing translation or rotation in any of the measured variables compared to the ACL-deficient knee. Parsons et al. [6] studied the biomechanics of the ALL using a robotic testing system. They concluded that the ALL does not provide resistance to anterior tibial translation during the anterior drawer test and that the ligament is an internal tibial rotation antagonist at high flexion angles. This could possibly explain why sectioning the ALL did not elicit a higher-magnitude pivot shift in our study, given that the pivot shift phenomenon usually occurs at lower flexion angles. A major difference between the study by Parons et al. and the current study is that we did not transect the IT band. As previously shown in a similar test setting, the IT band serves as an important stabiliser for anterotibial translation [24]. This is an important methodological variation that should be considered when comparing both studies, as a disrupted IT band could hamper the rotatory stability of the knee [25].

There are several potential limitations to this study. There is current controversy as to whether the anterolateral ligament is a true ligament or rather a thickening of the anterolateral capsule [5]. In our study, we worked under the assumption that the anterolateral ligament was indeed a true ligament, as described previously by Claes et al. This explains why eight specimens were excluded from further biomechanical testing. Given that our study protocol specifically aimed to test whether sectioning the ALL would affect knee laxity, any specimens in which the anterolateral ligament was not identified had to be discarded. Additionally, we did not test whether capsular injury would result in increased knee laxity. Previous research has shown conflicting results in this area. Matsumoto [26] studied the effect of sectioning the lateral capsule on the stability of the knee in three specimens and found no significant change in rotation. On the other hand, Monaco et al. [23] demonstrated a significant increase in the grade of the pivot shift after sectioning the anterolateral capsule. A possible limitation of that study is that a single examiner performed all the manual pivot shift tests. However, Arilla et al. [27] reproduced these findings in seven cadaveric knees, observing a significant increase in knee laxity after sectioning the lateral capsule, and with the advantage of having used three examiners per test. Exploring the biomechanical role of the capsule remains an interesting topic for further research. A further limitation is that the intact state of the knee was defined as the state after performing a medial arthrotomy. While this may have altered the kinematics of the knee, prior studies have shown that this effect is minimal [27]. It is also possible that our setup is not sufficiently sensitive to detect minor differences in tibiofemoral translation compared to other biomechanical setups. However, we performed a series of simulated clinical tests that are routinely used to diagnose ACL injuries by assessing tibiofemoral translation and rotation. In particular, the pivot shift test closely reproduces the phenomenon that occurs when the ACL is injured, and is considered the most specific clinical test for diagnosing ACL rupture [28–30]. In this context, our results may indicate that the ACL is primarily responsible for anterior tibial and rotational knee stability and that a concomitant injury to the ALL does not necessarily increase anterior tibial translation or rotational instability of the knee. The current study does not answer the question of whether isolated ALL injury or unrepaired injury to the ALL after ACL reconstruction would result in knee instability. In our anecdotal experience, it has proven difficult to simulate clinically significant knee instability in cadaveric models with an intact ACL, despite aggressive dissection of the anterolateral structures (capsule, lateral meniscus attachment, or ALL).

This study failed to find any evidence supporting the notion that injury to the ALL creates substantial knee instability that should be surgically addressed. Therefore, no changes to the current management of ACL injured knees can be recommended.

Conclusion

Dissection of the ALL in an ACL-deficient knee did not increase instability in this cadaveric model. Although at least minor instabilities in terms of anterior tibial translation or tibial translation during the pivot shift test were expected, these were not detectable by the pivot shift test. Since this test is the most specific clinical test for tibiofemoral instability, it remains unclear whether injuries to the ALL have a clinical impact on knee stability.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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