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Biomechanical comparison of anterolateral ligament anatomical reconstruction with a semi-anatomical lateral extra-articular tenodesis. A cadaveric study

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ABSTRACT

Background: To compare the biomechanical behavior of an anterolateral ligament (ALL) anatomical reconstruction and a semianatomical lateral extra-articular tenodesis (LET) in the context of an anterior cruciate ligament (ACL) reconstruction combined with an anterolateral lesion.

Methods: Twelve cadaveric knees were studied using a testing machine to assess the internal tibial rotation and anterior tibial translation across six surgical states: intact knee, ACL lesion, ACL + ALL lesion, ACL isolated reconstruction, ACL + ALL anatomical reconstruction and ACL + LET procedure. ALL and LET grafts were fixed at full knee extension and neutral rotation.

Results: Presented with combined ACL and ALL lesions, isolated ACL reconstruction failed to restore the internal tibial rotation to intact-knee values ($P > 0.05$ for all angles). The addition of both an ALL reconstruction and LET procedure significantly reduced the internal rotation, restoring the rotation laxity to intact-knee values at 0° and 30° of flexion ($P < 0.05$) and with a certain level of overconstraint at 60° and 90° (mean 3° ± 2SD). A higher tendency to overconstraint was observed with the LET, but there was no significant difference when comparing the ALL reconstruction with the LET ($P > 0.05$ for all angles).

Conclusions: Residual rotational laxity was found after isolated ACL reconstruction in the presence of an anterolateral lesion. The combination of ACL reconstruction with anatomical ALL reconstruction or the LET procedure resulted in restoration to intact-knee values but with a certain degree of overconstraint in higher flexion angles. Both techniques showed optimal biomechanical results with no data supporting the advantage of one over the other.

1. Introduction

Anterior cruciate ligament (ACL) reconstruction is one of the most common procedures in orthopedic surgery. However, despite a deep understanding of knee anatomy and the development of advanced techniques and devices, there is still a certain group of patients with persistent rotatory laxity and pivot shift phenomenon after ACL surgery [1,2] that could ultimately lead to impairment in demanding activities or secondary degenerative osteoarthritis [3]. One of the potential causes for these suboptimal results, among others, could be the underestimation of the lesions of the anterolateral structures of the knee [4–6].

Abbreviations: ACL, Anterior cruciate ligament; ALC, Anterolateral complex; ALL, Anterolateral ligament; ANOVA, Analyses of variance; ITB, Iliotibial band; LCL, Lateral collateral ligament; LET, Lateral extra articular tenodesis; ICC, Intraclass correlation coefficient; IRB, Institutional Review Board.

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Surgical techniques for anterolateral stabilization are much older than our current understanding of the anatomy and biomechanics of the anterolateral ligament. The first extra-articular stabilizing procedure was described by Lemaire in 1967 [7]; since then, numerous techniques and modifications have been described [8], commonly referred to as lateral extra-articular tenodesis (LET). Although these procedures were thought to be abandoned for many years, they were still a resource for cases of revision and persistent rotatory laxity of the knee and regained popularity over recent years as an augment to ACL reconstruction, with some long term follow-up studies that support its efficacy [9–11].

Recently, interest in the anatomy and function of the anterolateral structures of the knee has been focused around the anterolateral ligament (ALL). Although the subject is still under debate [12], at present, many authors advocate for this ligament's existence as an anatomical structure and its role as a secondary stabilizer controlling the internal rotation of the knee in the context of an injured or insufficient ACL [13–15].

Based on the detailed description of the anatomy, histology and biomechanics of the ALL as an anatomical structure [16–18], in recent years, there has been an effort to develop an anatomical reconstruction technique with the reasoning that the restoration of the normal anatomy would produce an optimal biomechanical result. Numerous anatomical techniques have been described [19] with variations according to which anatomical description they were trying to replicate, especially regarding the femoral insertion [20]. Some series have reported promising clinical results regarding the return to sports and graft failure [21]. However, several biomechanical studies reported controversial results about the advantages and drawbacks regarding efficacy, technique and possible articular constriction [22–24].

The purpose of this study is to compare the biomechanical behavior of an anterolateral ligament anatomical reconstruction and a semianatomical lateral extra-articular tenodesis in the context of an anterior cruciate ligament reconstruction combined with an anterolateral lesion.

The hypotheses were that an anterolateral lesion increased the internal rotation knee laxity compared to an isolated ACL injury, that an isolated ACL reconstruction could not restore rotational stability in the presence of a combined ALL–ACL lesion and that a more recent anatomical ALL reconstruction could restore intact-knee kinematics better than the described LET procedure. The clinical relevance is that there is still a debate on how to address residual rotational laxity after ACL reconstruction with some surgeons relying on more experience with the LET procedure and others relying on the promising concept of an anatomical ALL reconstruction; this study provides data to help the surgeons with their decision.

2. Methods

2.1. Specimen preparation

This study was performed after approval from the Institutional Review Board at the University (IRB00003099). Twelve cadaveric knee specimens from donors (mean age 70; six females and six males) were obtained from the tissue bank. No donor had a history of knee injury or prior surgical intervention. The specimens were kept at −20 °C and were thawed at room temperature 24 h before the experiment. The femur and tibia diaphyses were cut 250 mm from the joint line. The skin and subcutaneous fat were removed along with soft tissue more than 150 mm from the joint line. An initial arthroscopic assessment was performed to look for any damage to the cruciate ligaments, or other intra-articular structures. In such cases, the specimens were excluded.

2.2. Biomechanical measurements

Two main variables were analyzed, the internal tibial rotation under a torque force of seven newton meters and the anterior tibial translation under an anterior tibial load of 90 N; no axial load was applied. The specimens were secured on an external fixation construct designed to allow free range of articular movement from 0° to 100° and mounted on a testing machine (Mecmesin Vortex-D) capable of applying torque force and measuring rotation with a precision of 0.1°. The machine was programmed to apply an internal rotation torque force of seven newton meters over the tibial side with an automatic stop at resistance. The anterior tibial translation was evaluated under a 90 N anterior tibial force applied by a manual dynamometer (100Force Meter spring dynamometer) attached to the tibial tuberosity by a transosseous wire. The translation measurements were made over K-wires drilled on anatomical landmarks with an electronic millimeter gauge (Neiko 01407A Electronic Digital Caliper). Another surgeon then repeated the measurements and then averaged them. The interobserver agreement was analyzed using the intraclass correlation coefficient (ICC).

The measurements were performed at 0°, 30°, 60° and 90° of knee flexion for each of the six surgical states sequentially: one degree intact knee, two degrees ACL deficient, three degrees ACL deficient + ALL deficient, and four degrees ACL isolated reconstruction + ALL deficient. At this point, the paired knees were randomized to undergo further reconstruction and testing according to two sequences to minimize soft tissue elongation bias [25]. Sequence 1: ALL reconstruction and test, remove ALL graft, then LET procedure and test. Sequence 2: LET procedure and test, remove LET graft, then ALL reconstruction and test.

2.3. Surgical technique

All the procedures were performed by the same orthopedic surgeon. First, initial measurements were performed in the intact knee. Then, the ACL was resected arthroscopically, and ACL-deficient measurements were performed. A longitudinal incision was made on the posterior aspect of the iliotibial band, and through careful dissection, the ALL was identified as described by Daggett

et al. [26]. A deep incision was made to release the ALL attachment site on the tibia, located midway between the Gerdy tubercle and the fibular head preserving the lateral collateral ligament (LCL); in addition, proximal attachments of the iliotibial band (ITB) to the femur were identified and carefully transected [27].

ACL reconstruction was performed arthroscopically using bone–patellar tendon–bone autografts obtained from the same knee and fixated using an anatomical single bundle technique [28]. The femoral and tibial bone blocks were fixed with interference screws (Smith & Nephew).

2.4. ALL reconstruction

ALL reconstruction was performed using a gracilis tendon autograft [15,29] obtained from the same knee. Anatomical landmarks were used to find the insertion sites. The femoral attachment was located on a point proximal and posterior to the lateral epicondyle and the lateral collateral ligament [30]. The distal attachment was located halfway between the Gerdy tubercle and the fibular head in the position described as the tibial attachment of the ALL, approximately 10 mm distal to the cartilage line. The gracilis tendon autograft was folded in two and firmly whipstitched at both ends. A six millimeter cannulated drill bit was used to create two bone sockets in the mentioned femoral and tibial positions to a depth of 20 mm. The knee was taken into the fully extended position to ensure the foot is in neutral rotation; then, the graft was passed superficial to the LCL, and the tibial and femoral ends were fixed with two interference screws (Smith & Nephew) (Figure 1). In the case of the ALL reconstruction, we used the technique described by the ALL consensus group [15], with the graft in the ALL anatomical position tensioned in full extension, as we think would appear to provide the most optimal ALL reconstruction kinematics by preventing excessive external rotation [14,31].

2.5. LET (semi-anatomical technique)

An ITB autograft was harvested. A one centimeter wide and 10 cm long strip centered over the Gerdy tubercle was elevated leaving the distal attachment to the tibia intact. The proximal end was firmly whipstitched and then passed deep to the LCL [31]. The femoral attachment site was the same tunnel described for ALL reconstruction [32]. The graft was fixed with an interference screw (Smith & Nephew), with the knee taken into the fully extended position to ensure the foot is in neutral rotation. Passing the graft deep to the LCL appears to provide a more optimal lever arm, as well as providing a more forgiving position of fixation, in terms of avoiding overconstraint, as the LCL attachment serves as a fulcrum (Figure 1).

2.6. Statistical analysis

The statistical analyses were performed using Statistical Package for Social Sciences (SPSS) software (version 23.0.0; IBM Corp). The means and standard deviations were calculated for each continuous variable. The Shapiro–Wilk test was used to assess normal data distribution and it was confirmed by using a Q–Q plot. Two-way repeated-measures analyses of variance (ANOVA) were used to compare the dependent variables obtained from the mean values of anterior tibial translation and internal tibial rotation across the independent categorical variables of surgical state and knee flexion angle. Tukey post hoc comparisons were performed. The statistical significance was set at $P < 0.05$. A power calculation for a two-way analysis of variance test including a six-level

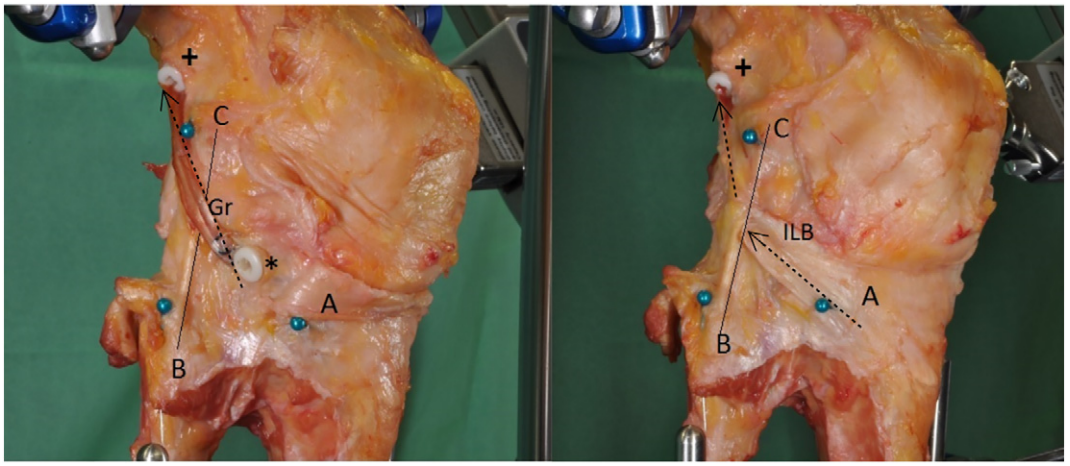

Figure 1. Anterolateral view of a right knee with all the periarticular soft tissues dissected to illustrate graft placement. Left image: anatomical anterolateral ligament (ALL) reconstruction with a double bundle gracilis autograft; right image: lateral extra-articular tenodesis (LET) procedure with a fascia lata autograft (semianatomical Lemaire); A: Gerdy's tubercle; B: head of fibula; C: lateral epicondyle; continuous line: lateral collateral ligament (LCL); Gr: double bundle gracilis autograft passing superficial to the LCL; ILB: strip of iliotibial band autograft passing deep to the LCL; dotted arrows: direction of the graft trajectory, note the pulley effect with the LET.

categorical independent variable with a significance level of five percent has a power of 84% to detect mean value differences in continuous dependent variables with a sample size of 12 cadaveric knees. For repeated measures, a reliability analysis was performed using the intraclass correlation coefficient for a two-way mixed absolute agreement model with a 95% confidence interval.

3. Results

3.1. Internal tibial rotation and anterior tibial translation attributed to the isolated ACL lesion and ACL + ALL lesion

Compared to the intact knee, anterior tibial translation increased in all flexion angles in response to an anterior tibial load for both the ACL lesion ($P < 0.001$) and ACL + ALL lesion ($P < 0.001$) (Table 1). Compared to each other, the differences of anterior tibial translation in the ACL lesion and ACL + ALL lesion were not significant ($P > 0.05$ for all). In the case of the internal rotation in response to internal tibial torque of seven newton meters, the ACL isolated lesion did not have a significant effect compared to that of the intact-knee state ($P > 0.05$) except for a significant increase observed at the 30° flexion angle ($P = 0.02$). The ACL + ALL lesion showed a significant increase of internal tibial rotation values at all flexion angles tested compared to those in the intact knee and the ACL isolated lesion ($P = 0.01–0.03$) (Figures 2 and 3).

3.2. Effect of the isolated ACL reconstruction over internal tibial rotation and anterior tibial translation in the presence of a combined ACL + ALL lesion

After performing an isolated ACL reconstruction, the anterior tibial translation values were restored to the level of the intact knee at all the flexion angles tested ($P > 0.05$ for all). Conversely, the internal tibial rotation values remained significantly different compared to those observed in the intact knee at all the flexion angles tested ($P = 0.01–0.03$) (Figures 2 and 3).

3.3. Effect of the ALL reconstruction and LET procedure combined with the ACL reconstruction in the presence of a combined ACL + ALL lesion

Having the ACL reconstruction in place, the augmentation of both LET and ALL reconstruction produced anterior tibial translation values that did not differ significantly from those observed in the previous isolated ACL reconstruction ($P > 0.05$ for all angles), and those were already not different compared to those in the intact-knee state values (Figures 2 and 3).

The internal tibial rotation values with both LET and ALL reconstruction were not significantly different to those observed in the intact-knee state in the tests performed at 0° to 30° of knee flexion ($P > 0.05$). However, at 60° and 90° of flexion, both techniques showed overconstraint in terms of reduced laxity compared to that at the intact-knee tibial level ($P = 0.01$ and 0.02 respectively); although, the level of overconstraint was relatively small (mean 3° ± 2SD) (Table 1).

In a comparison of LET and ALL reconstruction, although both showed a level of overconstraint at higher knee flexion angles, there was no significant difference regarding the internal rotation laxity ($P > 0.05$ for all) (Figure 3).

Finally, the intraclass correlation coefficient obtained from the two observed data was considered excellent (0.91; 95% confidence interval (CI), 0.82 to 0.96).

4. Discussion

The most important finding of this study is that, in the presence of a combined ACL–ALL lesion, both the LET procedure and the ALL anatomical reconstruction were able to restore the internal rotation to the intact-knee values at low knee flexion angles (0° and 30°), where it is supposed to engage and prevent a pivot shift phenomenon. However, both techniques also produced a

Table 1
Kinematics data for each surgical state and the respective knee flexion angles tested. Values expressed as the mean (± standard deviation). Internal tibial rotation in response to an internal rotation torque force of seven newton meters expressed in degrees (°). Anterior tibial translation in response to an anterior tibial load of 90 N expressed in millimeters (mm). ACLd = anterior cruciate ligament deficient, ALLd = anterolateral ligament deficient, ACLr = anterior cruciate ligament reconstructed, ALLr = anterolateral ligament reconstructed, LET = lateral extra-articular tenodesis.

	Internal rotation (°)				Anterior translation (mm)			
	0°	30°	60°	90°	0°	30°	60°	90°
Intact knee	14.3 (±2.4)	19.1 (±2.5)	16.1 (±2.6)	14.1 (±2.7)	7.1 (±2.1)	8.9 (±1.5)	7.3 (±1.2)	6.4 (±2.1)
ACLd	16.1 (±2.3)	20.7 (±2.4)	17.8 (±2.4)	15.8 (±2.5)	19.8 (±2.2)	21 (±1.9)	19.7 (±2.7)	20.6 (±2.5)
ACLd + ALLd	19.3 (±2.2)	24.4 (±2.2)	21.2 (±2.3)	19.2 (±2.3)	20 (±2)	23.1 (±2.4)	20.1 (±2.8)	20.4 (±2.4)
ACLr + ALLd	18.4 (±1.9)	23.6 (±2.1)	21.9 (±3.1)	18.4 (±1.9)	7.9 (±3.1)	11.3 (±2.2)	9.9 (±2.4)	8.3 (±2.6)
ACLr + ALLr	14.8 (±2.5)	19.4 (±2.2)	15.1 (±2.1)	12.9 (±2.1)	7.6 (±2.2)	11 (±1.5)	9.6 (±2)	7.4 (±2.1)
ACLr + LET	13.8 (±2.3)	18.6 (±2.1)	13.9 (±2.2)	11.9 (±2.3)	7.7 (±3)	10.8 (±2.4)	9.7 (±2.5)	7.9 (±1.9)

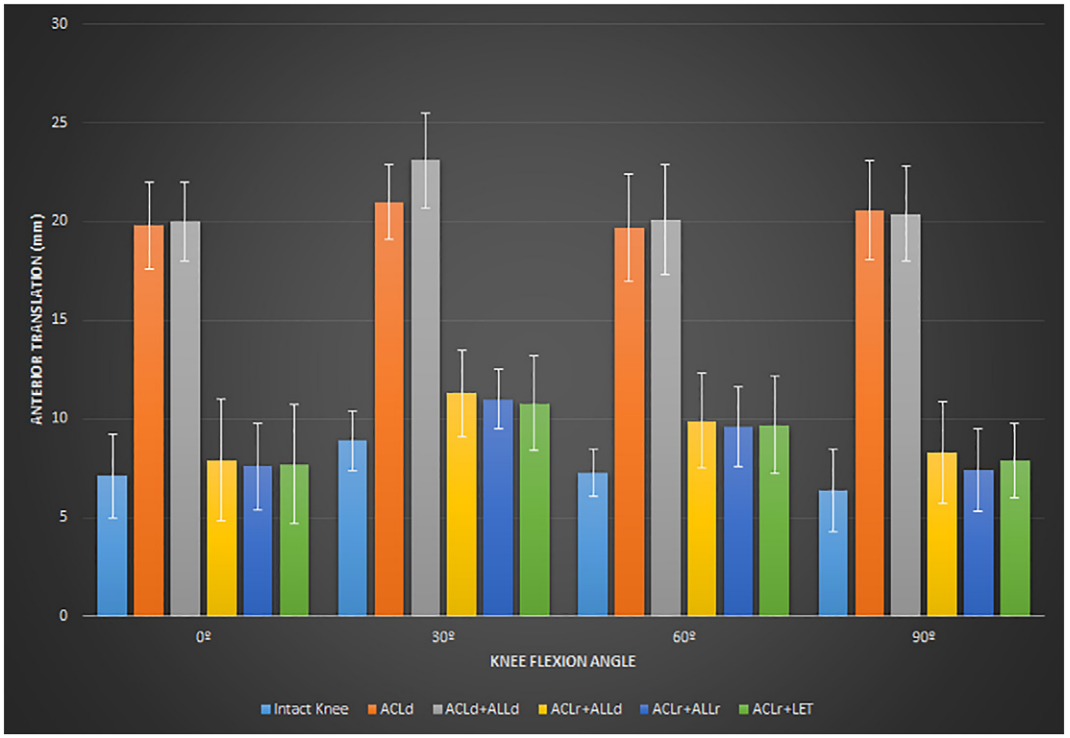

Figure 2. Mean anterior tibial translation in response to an anterior tibial load of 90 N at the respective knee flexion angles. One standard deviation is displayed over the bars. ACLd = anterior cruciate ligament deficient, ALLd = anterolateral ligament deficient, ACLr = anterior cruciate ligament reconstructed, ALLr = anterolateral ligament reconstructed, LET = lateral extra-articular tenodesis.

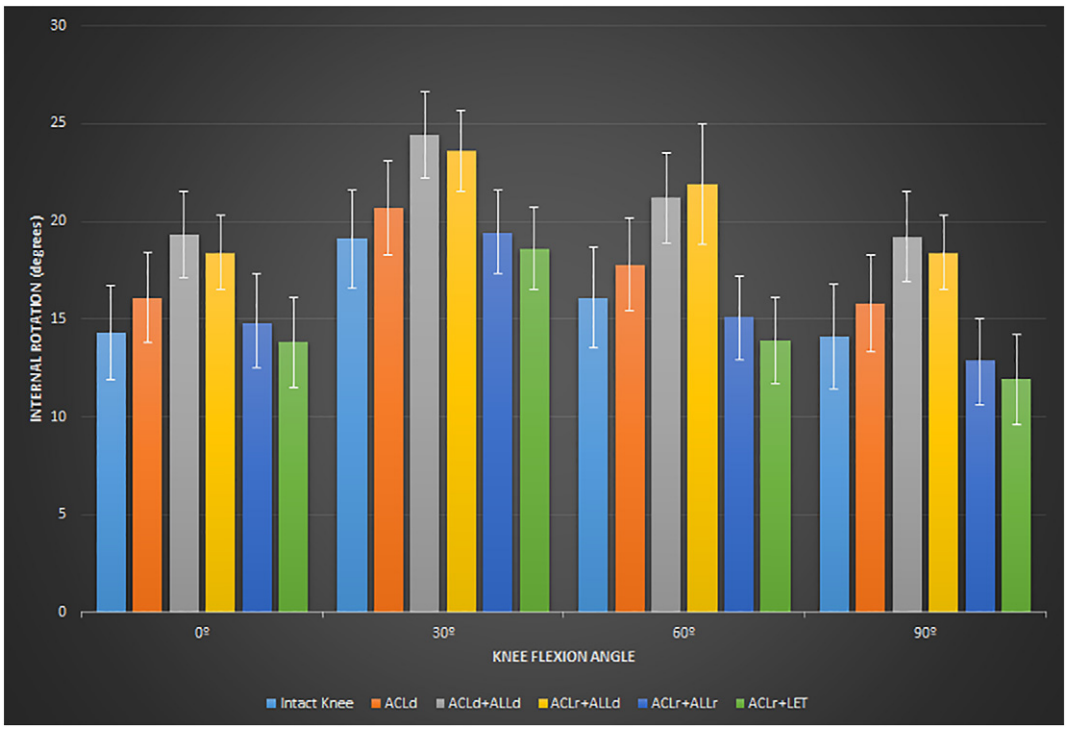

Figure 3. Mean internal tibial rotation in response to an internal rotation torque force of seven newton meters at the respective knee flexion angles. One standard deviation is displayed over the bars. ACLd = anterior cruciate ligament deficient, ALLd = anterolateral ligament deficient, ACLr = anterior cruciate ligament reconstructed, ALLr = anterolateral ligament reconstructed, LET = lateral extra-articular tenodesis.

small level of reduced internal tibial rotation laxity at higher flexion angles (60° and 90°), interpreted as overconstraint. Contrary to our hypothesis, both techniques obtained optimal results restoring the kinematics to the intact-knee level without significant differences found between the two procedures. The isolated ACL reconstruction was able to restore anterior tibial translation but failed to restore internal rotation to intact-knee values. These findings confirmed what was reported in previous studies [25,32,33], that a rotatory laxity secondary to a high-grade anterolateral lesion in the knee could not be resolved only with an isolated anatomical ACL reconstruction.

One explanation for the similar results obtained in the two techniques could be that the study used the same femoral attachment point for both types of grafts and defined the same fixation angle with neutral rotation to prevent an excess of external rotation for both procedures. A previous study [31] demonstrated that different fixation angles did not have a detrimental effect on the laxity of LET and by fixating the graft in a neutral position, the excess of external rotation and excessive overconstraint effect could be prevented.

The ALL reconstruction has the drawback of the sacrifice of a gracilis autograft, and, depending on the technique, it could have a higher implant cost. Also, the adjunct of an additional tibial socket for ALL fixation could be considered as a drawback. Although ALL is indeed an anatomical structure with a biomechanical role as a secondary stabilizer of internal rotation, it may not be the only one. The ITB is another important internal tibial rotation restrictor [27,34] that is also injured as a part of the anterolateral complex (ALC) of the knee. Thus, the isolated anatomical ALL reconstruction may not address the full extent of the lesion in terms of purely anatomical reconstruction. On the other hand, a hypothesis for a better performance of the LET procedure could be because of the pulley effect that maintains the graft in a posterior plane and perpendicular direction with respect to the axis of rotation of the knee providing a wider range of action because of the longer lever arm. The principal drawback for the LET used to be the unknown effect of the reduced internal tibial rotation commonly defined as overconstraint but, according to our results, the level of overconstraint is similar for the LET and the ALL reconstruction. However, it should be noted that at present there is no clinical evidence reported of accelerated OA or persistent clinical stiffness. A study of the lateral compartment contact pressures after LET [35] found there was not a significant increase of pressure in the lateral compartment compared to that in normal physiological loading during knee cycle.

In recent years, numerous biomechanical studies have assessed the ALL and its reconstruction techniques [19,30], and others have revised the results of LET procedures [33] with long follow-up series [8,11,37]. However, the comparison between the two main groups of techniques is often difficult because of different protocols and variations of surgical techniques. Only a few studies have tried to compare the results of LET vs. ALL anatomical reconstruction with the same testing conditions. In two comparable biomechanical studies using similar lesion protocols and reconstruction techniques, Geeslin et al. [25] reported that by using the technique described by Sonnery-Cottet for ALL reconstruction, they were able to restore the natural kinematics of the knee as well as with the LET procedure with some degree of overconstraint with the latter. In contrast, Inderhaug et al. [32] after testing different variations of LET and ALL reconstruction, concluded that their results do not support ALL reconstruction because, in comparison with the LET procedure, it seemed to have a lesser effect in restoring the native knee laxities.

Presented with two techniques that show similar optimal biomechanical laboratory results, the element that could tip the balance in favor of one or the other should be the clinical performance. The specific minimal clinically important difference for internal rotation and anterior translation is yet unknown [38,39]. Therefore, further clinical research with long-term ollow-up is needed.

There were limitations associated with this study. This laboratory biomechanical study tested at time zero and could not assess possible changes due to cyclic loading or rehabilitation. The injuries were surgically created representing a wide lesion of the ALC including the ALL and the ITB femoral attachments. Since the thigh was transected 250 from the joint line, the iliotibial complex was not intact as an internal rotation restrictor, but this was common to each compared surgical state thus not influential on the study results. There could be a certain variability of lesions according to the magnitude of the trauma; however, this protocol provided a reproducible lesion already used in other studies in order to obtain more homogeneous comparisons.

5. Conclusion

A residual rotational laxity was found after the isolated ACL reconstruction in the presence of an anterolateral lesion. A combination of the ACL reconstruction with anatomical ALL reconstruction or LET procedure resulted in the restoration of intact-knee values but with a certain degree of overconstraint at higher flexion angles. Both techniques showed optimal biomechanical results with no data supporting the advantage of one over the other.

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