CLINICAL SCIENCE

IMPORTANCE OF THE DIFFERENT POSTEROLATERAL KNEE STATIC STABILIZERS: BIOMECHANICAL STUDY

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PURPOSE: The purpose of this study was to evaluate the relative importance of the different static stabilizers of the posterolateral corner of the knee in cadavers.

METHODS: Tests were performed with the application of a varus and external rotation force to the knee in extension at 30 and 60 degrees of flexion using 10 cadaver knees. The forces were applied initially to an intact knee and then repeated after a selective sectioning of the ligaments into the following: section of the lateral collateral ligament; section of the lateral collateral ligament and the popliteofibular complex; and section of the lateral collateral ligament, the popliteofibular complex and the posterolateral capsule. The parameters studied were the angular deformity and stiffness when the knees were submitted to a 15 Newton-meter varus torque and a 6 Newton-meter external tibial torque. Statistical analysis was performed using the ANOVA (Analysis of Variance) and Tukey's tests.

RESULTS AND CONCLUSION: Our findings showed that the lateral collateral ligament was important in varus stability at 0, 30 and 60 degrees. The popliteofibular complex was the most important structure for external rotation stability at all angles of flexion and was also important for varus stability at 30 and 60 degrees. The posterolateral capsule was important for varus stability at 0 and 30 degrees and for external rotation stability in extension. Level of evidence: Level IV (cadaver study).

KEYWORDS: Knee; Ligaments; Joint instability; Biomechanics; Cadaver.

INTRODUCTION

The posterolateral corner of the knee presents complex and controversial anatomy and biomechanics. Its main components are the lateral collateral ligament (LCL), the popliteus tendon, the popliteofibular ligament and the articular capsule with its reinforcements. These structures function jointly as posterolateral stabilizers, particularly for varus stress and for external rotation. However, there is disagreement about the isolated role that each structure performs.

Several biomechanical studies have been proposed in an attempt to elucidate this information, using the selective section of ligaments and observing the behavior of these knees after each section[1-6] or assessing the tension of these ligaments during the application of deforming forces on the knees.[7,8]

Posterolateral instability was described by Hughston et al.[9] as a posterior rotational subluxation of the lateral tibial plateau in relation to the femoral condyle, with the tibia rotating externally in relation to the knee axis, and with the posterior cruciate ligament (PCL) intact. The isolated lesion of the posterolateral corner is more rarely identified in practice, and the association of this lesion with that of the PCL is more commonly observed.

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The goal of determining the specific function of each structure is to provide objective data that should enable surgeons to better understand the articular biomechanics and to apply this knowledge in surgical procedures. New surgical procedures can be developed based on this knowledge, making the treatments of these lesions more effective and reestablishing articular stability.[10-11]

The aim of this study was to evaluate, in an anatomical specimen, the stabilization function of the different structures of the posterolateral corner of the knee through selective section of the ligaments of this region.

METHODS

This study was conducted after institutional approval of our research protocol. For this survey, we used the knees of cadavers whose lower limbs did not present any sign of osteoarticular disease or sequelae of traumatic lesions in the lower limb during the physical examination and upon joint inspection. Knees of cadavers with metabolic diseases, such as diabetes, or with infectious diseases were excluded. Medial parapatellar arthrotomy was undertaken for the exclusion of any intra-articular pathology, such as lesions on the cruciate ligaments, meniscuses or advanced articular degeneration.

The study inspected 10 knees from 10 cadavers. According to data obtained from the death certificates, the average age at death was 54 years, ranging from 42 to 65 years. Six cadavers were male and four female, whereas five cadavers were one from African descent and five Caucasian descent. Six left and four right knees were used.

Removal and preparation of the anatomical pieces

The femur was osteotomized 20 cm above the articular interline, and the tibia and the fibula were osteotomized 20 cm below the same interline at the same level where the soft parts were sectioned.

The knees were kept at negative 15°C. On the eve of the tests, the pieces were thawed for 12 hours until they were at room temperature prior to the performance of the procedure. The maximum time between freezing of the piece and its thawing was six weeks.

Before the performance of the tests, the soft parts around the knee were removed, preserving all the capsulo-ligamentary structures, the popliteus muscle with its tendon and the peripatellar portion of the quadriceps muscle with its tendon.[10-14] The fibula was fastened to the tibia at a distance of 4 cm distal to the proximal extremity of the fibula, using a 4.5 mm diameter cortical screw[13-15], and afterwards the fibula was sectioned 2 cm distal to the screw.

After preparation of the knee, the LCL was carefully identified and isolated with white surgical threads, and the popliteous tendon was identified above the origin of the popliteofibular ligament (hence, we will call it the popliteofibular complex; PFC) and identified with green surgical threads (Figure 1).

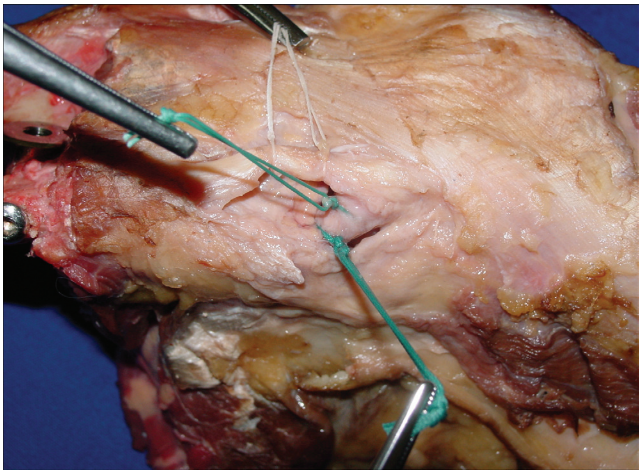

Figure 1 - Photograph of the lateral aspect of the left knee. A- Popliteofibular complex (popliteus tendon + popliteofibular ligament isolated by green surgical threads). B- Collateral lateral ligament (isolated by white surgical threads).

Mechanical trials

The mechanical trials were carried out on a KRATOS® 5002 mechanical testing machine with a load cell of 100 kgf adjusted to the scale of 50 kgf (Figure 2 and 3). The precision for force reading was 0.49 N and 0.01 mm for linear displacement of the mobile crossbeam, and the linear displacement speed was 20 mm/min. The parameters of force and displacement were recorded by the testing equipment and transmitted to the computer via a LYNX® ADS 2000 data acquisition system.

Each knee was evaluated in terms of its angular deformity

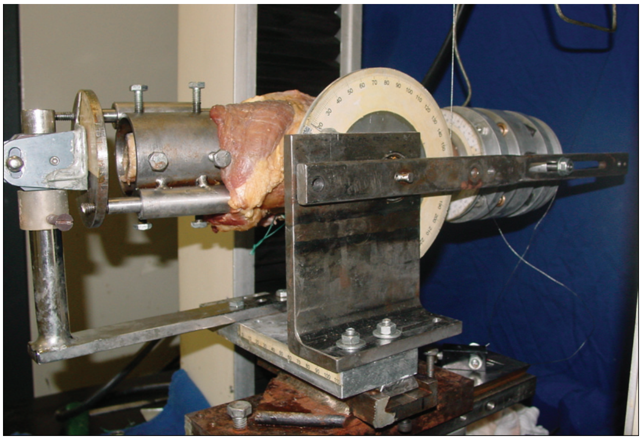

Figure 2 - Image of the knee fixed to the device.

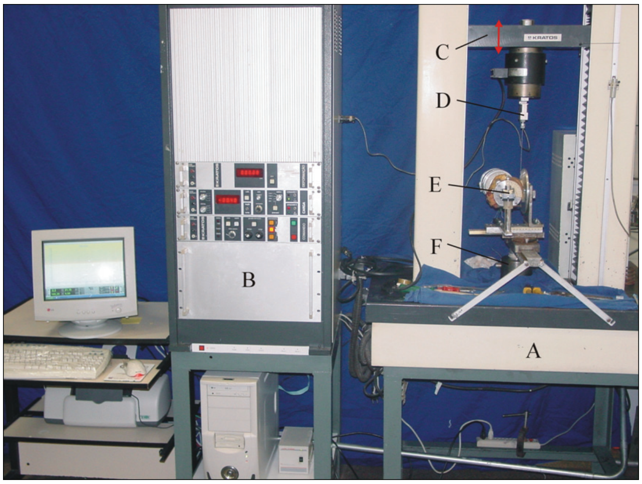

Figure 3 - KRATOS® testing machine used for the biomechanical study. A. Mechanical testing device. B. Data acquisition system. C. Testing machine pivo (arrow indicates direction of movement). D. Load cell (100 kgf). E. Knee fixed to the device. F. Base image of the knee fixed to the device.

capacity when submitted to a given moment. The moments applied were defined for this study as flexion for the varus movement and torsion for the external rotation movement.

Two repetitions were performed for each type of trial, whereas only the last repetition was registered by the computer. The sequence and type of trial are described below: 1) varus trial with the knee in extension, 30º of flexion and 60º of flexion; and 2) external rotation trial with the knee at 60º of flexion, 30º of flexion and in extension. Each knee was analyzed biomechanically through the trial sequences described above under four different structural conditions. The resulting groups were as followed: intact joint (INT); lateral collateral ligament sectioned (group A); lateral collateral ligament and popliteofibular complex sectioned (group B); and lateral collateral ligament, popliteofibular complex and posterolateral capsule sectioned (group C).

The entire trial was performed with the ligaments intact. Upon completion of the intact knee trial, the lateral collateral ligament was sectioned. This knee then became part of group A, and the whole sequence of tests as already described was executed once again. This methodology was repeated when the knee entered group B and then group C.

Parameters analyzed

The parameters studied were angular deformity and stiffness when the knee was submitted to the flexion moment (varus) of 15 N.m and to the external rotation moment of 6 N.m. Stiffness was measured with a basis on each graph of the varus and external rotation trials and was defined as the ratio of variation of moment (N.m) and the variation of angular deformity (degree) between two points in the elastic region.

Statistical analysis

Each parameter was compared among groups using the repeated measures analysis of variance (ANOVA) test and the Tukey's test for multiple comparisons. The level of significance adopted was 5% (p = 0.05).

RESULTS

The data obtained with the application of force in varus or in external rotation on the knees was captured by the computer and stored up to the second decimal place in Newtons and degrees. During the biomechanical trials, it was not necessary to exclude any knee or to repeat any biomechanical test. The results are presented as angular deformation and stiffness in varus and external rotation in extension and under 30° and 60° of flexion. The statistical analysis compared the four groups with each other in all the positions analyzed.

Angular deformity

With regard to angular deformity in varus (Tables 1 and 3), we observed that in comparison A (LCL section) x B (LCL and PFC section), there was no significant difference between the two situations when the knee was tested in extension. In other words, the PFC section did not increase angular deformity in varus with the knee in extension after the previous section of LCL. At 30 and 60 degrees of flexion, the differences were significant.

Table 1 - Angular deformity of the knee during the application of force in varus and in external rotation (mean ± standard deviation).

	Angular deformity (°)					
	Varus			External rotatio		
	0°	30°	60°	0°	30°	60°
Intact	14±4.45	16.24±5.2	16.06±5.29	24.48±4.28	25.62±4.4	26±5.12
A	17.13±4.65	20.16±4.59	18.99±5.52	27.8±5.79	27.6±5.13	26.64±4.74
B	18.79±4.8	22.55±5.2	20.89±6.04	33.61±5.35	38.17±6.5	34.96±6.55
C	22.14±6.23	25.08±6.97	22.34±7.4	36.99±5.06	40.71±6.23	36.37±6.29

Table 2 - Stiffness during the application of a deforming force in varus and external rotation (mean ± standard deviation).

	Stiffness (N.nm/°)					
	Varus			External rotatio		
	0°	30°	60°	0°	30°	60°
Intact	1414.63±293.93	1431.32±309.1	1535.69±313.02	522.65±48.48	544.97±62.32	562.44±94.21
A	1356.04±232.76	1381.52±268.92	1340.33±271.03	505.63±46.89	518.83±44.22	521.68±62.11
B	1276.52±193.03	1267.38±190.63	1179.53±206.25	446.33±31.75	421.14±43.74	342.71±62.52
C	1208.52±209.45	1186.19±200.02	1078.4±237.92	412.92±34.03	380.15±48.64	318.5±61.77

Table 3 - Comparative table and *p* values for the situations in varus testing to angular deformity.

ANGULAR DEFORMITY TO VARUS								
	0°			30°			60°	
P	p < 0,0001	*	p	p < 0,0001	*	p	p <0,0001	*
INT x A	P < 0,01	*	INT x A	p < 0,001	*	INT x A	P < 0,001	*
INT x B	P < 0,001	*	INT x B	p < 0,001	*	INT x B	P < 0,001	*
INT x C	P < 0,001	*	INT x C	p < 0,001	*	INT x C	P < 0,001	*
A x B	P > 0,05	**n.s.**	A x B	p < 0,05	*	A x B	P < 0,05	*
A x C	P < 0,001	*	A x C	p < 0,001	*	A x C	P < 0,001	*
B x C	P < 0,001	*	B x C	p < 0,01	*	B x C	P > 0,05	**n.s.**

Table 4 - Comparative table and *p* values for the situations in varus testing to stiffness.

STIFFNESS TO VARUS								
	0°			30°			60°	
p	p < 0,0001	*	P	p < 0,0001	*	p	P <0,0001	*
INT x A	P > 0,05	n.s.	INT x A	p > 0,05	n.s.	INT x A	P < 0,001	*
INT x B	p < 0,001	*	INT x B	p < 0,001	*	INT x B	P < 0,001	*
INT x C	p < 0,001	*	INT x C	p < 0,001	*	INT x C	P < 0,001	*
A x B	P < 0,05	*	A x B	p < 0,01	*	A x B	P < 0,01	*
A x C	p < 0,001	*	A x C	p < 0,001	*	A x C	P < 0,001	*
B x C	P > 0,05	n.s.	B x C	p > 0,05	n.s.	B x C	P > 0,05	n.s.

We also observed that, in comparison to B x C, there was no significant difference among the values obtained with the knee at 60° of flexion. In other words, the PLC section did not increase angular deformity in varus with the knee at 60° of flexion after the previous section of the LCL and of the PFC. In extension and at 30° of flexion, the differences were significant (Figure 4).

With regard to angular deformity in external rotation (Tables 1 and 5), we observed that in the INT x A comparison, no significant differences occurred when the knees were tested at 30° and at 60° of flexion. Hence, the LCL section did not increase angular deformity for external rotation in the abovementioned positions, despite having increased with the knee in extension. The B x C comparison did not present significant differences with the knee at 30° and at 60° of flexion either. In other words, the PLC section did not increase angular deformity in external rotation with the knee at 30° and at 60° of flexion after the previous section of the LCL and of the PFC. In extension, the differences were significant (Figure 5).

Stiffness

With regard to stiffness for varus (Tables 2 and 4), there was no significant difference in the stiffness found comparing the INT x A situation when the knee was in extension and at 30° of flexion. At 60° of flexion, the difference was already significant, and the LCL section altered stiffness in varus. The B x C comparison did not present significant differences at any angle of flexion tested. The PLC section did not exhibit

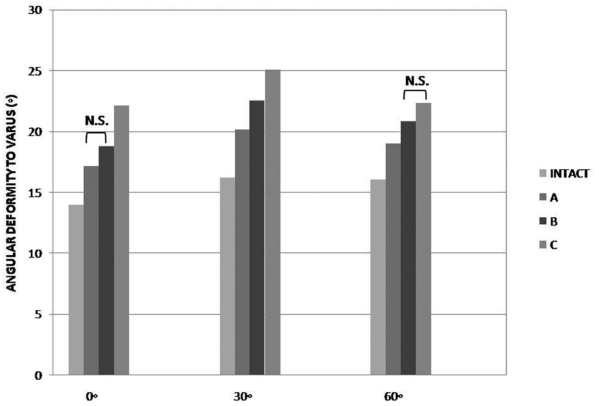

Figure 4 - Comparison of angular deformity to varus among groups with 0, 30 and 60 degrees of flexion. All values were significant, except where notated N.S. (not significant).

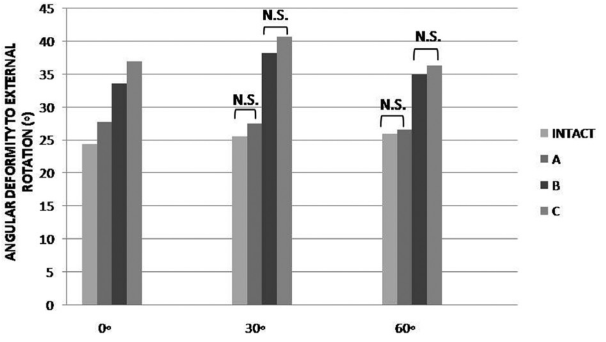

Figure 5 - Comparison of angular deformity to external rotation among groups with 0, 30 and 60 degrees of flexion. All values were significant, except where notated N.S. (not significant).

altered stiffness in varus after the previous section of the LCL and of the PFC (Figure 6).

With regard to the stiffness for external rotation (Table 2 and 6), there was no significant difference in the INT x A comparison at any angle of flexion tested. The LCL section did not alter stiffness in external rotation in extension, at 30°, or at 60° of knee flexion. We failed to identify any significant difference in the B x C comparison at any angle of flexion tested. The PLC section did not alter stiffness in external rotation after the previous section of the LCL and of the PFC (Figure 7).

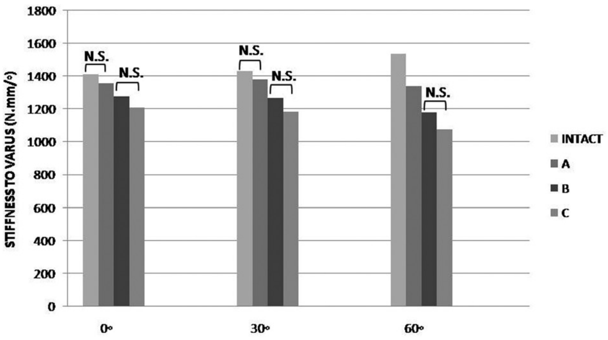

Figure 6 - Comparison of stiffness to varus among groups with 0, 30 and 60 degrees of flexion. All values were significant, except where notated N.S. (not significant).

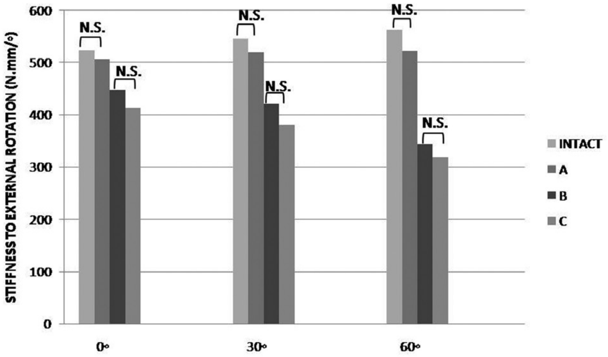

Figure 7 - Comparison of stiffness to external rotation among groups with 0, 30 and 60 degrees of flexion. All values were significant, except where notated N.S. (not significant).

DISCUSSION

Ligament lesions of the posteolateral corner of the knee continue to represent a challenge to orthopedic surgeons. In spite of all the papers that have already been published, there is still a great deal of uncertainty concerning the function

Table 5 - Comparative table and *p* values for the situations in external rotation testing to angular deformity.

				ANGULAR DEFORMITY TO EXTERNAL ROTATION				
	0°			30°			60°	
P	P < 0,001	*	P	p < 0,001	*	p	p < 0,001	*
INT x A	P < 0,05	*	INT x A	p > 0,05	**n.s.**	INT x A	p > 0,05	**n.s.**
INT x B	P < 0,001	*	INT x B	p < 0,001	*	INT x B	p < 0,001	*
INT x C	P < 0,001	*	INT x C	p < 0,001	*	INT x C	p < 0,001	*
A x B	P < 0,001	*	A x B	p < 0,001	*	A x B	p < 0,001	*
A x C	P < 0,001	*	A x C	p < 0,001	*	A x C	p < 0,001	*
B x C	P < 0,05	*	B x C	p > 0,05	**n.s.**	B x C	p > 0,05	**n.s.**

Table 6 - Comparative table and *p* values for the situations in external rotation testing to stiffness.

STIFFNESS TO EXTERNAL ROTATION								
0°			30°			60°		
p	P < 0,001	*	p	p < 0,001	*	p	p < 0,001	*
INT x A	P > 0,05	n.s.	INT x A	p > 0,05	n.s.	INT x A	p > 0,05	n.s.
INT x B	P < 0,001	*	INT x B	p < 0,001	*	INT x B	p < 0,001	*
INT x C	P < 0,001	*	INT x C	p < 0,001	*	INT x C	p < 0,001	*
A x B	P < 0,01	*	A x B	p < 0,001	*	A x B	p < 0,001	*
A x C	P < 0,001	*	A x C	p < 0,001	*	A x C	p < 0,001	*
B x C	P > 0,05	n.s.	B x C	p > 0,05	n.s.	B x C	p > 0,05	n.s.

and biomechanics of structures of the posterolateral corner of the knee.

The loads used, namely 15 N.m for varus and 6 N.m for external rotation, did not induce any lesion on the part during the tests.

Results for angular deformity in varus

After the tests conducted in varus to measure angular deformation, we verified that the lateral collateral ligament was important in restricting this movement at all the flexion angles, particularly when the knee was at 30 and at 60 degrees of flexion. Several papers[1,2,5,8] have reported similar results, concluding that the LCL was important in the stabilization in varus at all degrees of flexion.

We also observed that the popliteofibular complex was not important for restriction in varus with the knee in extension. However, the popliteofibular complex section showed significant alteration in stabilization in varus with the knee at 30 and 60 degrees of flexion. Gollehon et al.[1] observed that the popliteus tendon section associated with that of the arcuate ligament generated varus increases at 90 degrees of flexion. Shahane et al.[5] tested the "popliteus complex" in varus, dividing it into two components: the popliteofibular ligament and the popliteus tendon. They concluded that the popliteus tendon section was not important in restriction for varus, but the popliteofibular ligament section was important at 60 and 90 degrees of flexion.

The two components were not isolated separately in our study, and we performed the unique section of what we call the popliteofibular complex. This complex involves two structures, and, when it is sectioned, both the popliteus tendon and the popliteofibular ligament are considered sectioned. Accordingly, our results should be compared with the section of the two associated structures (popliteus tendon and popliteofibular ligament).

Gollehon et al.[1] and Shahane et al.[5] argue that the popliteus tendon presents a static and dynamic stabilization function, and Shahane et al.[5] declare that static stabilization is produced by the popliteofibular ligament. When we section the popliteofibular complex, we are evaluating in a more objective manner the popliteofibular ligament, which loses its function in this situation. The study by Shahane et al.[5] shows data that contributes toward this reasoning. In his study, the popliteus tendon section did not alter stabilization in varus, whereas the popliteofibular ligament section remained important. In our study, because we sectioned these two components (popliteofibular complex) together, a significant difference occurred. We noted that this difference was to the detriment of the popliteofibular ligament section.

Pasque et al.[6] and LaPrade et al.[8] in turn reported that the popliteus tendon and the popliteofibular ligament were not important in the stabilization of varus at any degree of flexion, contradicting our results and those obtained by Gollehon et al.[1] and Shahane et al.[5] We note that in the study of Pasque et al.[6] these structures were evaluated in knees that had the LCL intact, whereas in our study, the LCL had been previously sectioned. Knowing that the LCL is the main knee stabilizer for varus[1,2,5,8] and with it intact, the isolated section of the popliteus tendon (in its joint portion with the popliteofibular ligament) did not lead to any increase in angular deformity. In the work of LaPrade et al.[8] the measurement of force on the popliteus tendon and on the popliteofibular ligament with varus application was also performed with the LCL intact, which limited deformity in varus and prevented these structures from being exposed to a greater deforming load.

From the data above, we conclude that, during the application of a deforming force in varus, the LCL would exhibit a lesion before the popliteofibular complex. A rupture of the PFC would only occur after the rupture of the LCL.

The results also show that the PLC was important as a restrictor for varus, particularly with the knee in extension; however, this importance was lost as the knee was flexed. In extension and at 30 degrees, there were significant alterations in the angular deformity, but the differences among the mean values were greater with the extended knee than at 30 degrees. With the knee flexed at 60 degrees, the alterations with the PLC section were not significant. This discovery can be explained by the fact that the PLC relaxes as the knee is flexed.

Results obtained for stiffness in varus

The results show that the LCL has no influence on the stiffness of the posterolateral complex at 0 and 30 degrees of flexion. At 60 degrees of flexion, the stiffness of the LCL becomes significant. The PLC and the popliteus tendon relax, which impacts the decrease in stiffness of the posterolateral complex, thus making the LCL important for this property.

The PLC alone did not prove important for stiffness in the varus application tests at any degree of flexion, although it did interfere with the angular deformity for varus at 0 and 30 degrees of knee flexion.

Results obtained for angular deformity in external rotation

We observed that the lateral collateral ligament was important for posterolateral stabilization of the knee under external rotation when the latter was in extension. As the knee was flexed to 30 and 60 degrees, the lateral collateral ligament was not important for this function. Our results resemble those published by LaPrade et al.[8] with respect to the function of the LCL as stabilizer for external rotation in extension, although they observed that the LCL also acts in the limitation of external rotation at 30 degrees of flexion. Wrobe et al.[2] also observed that there was an increase of external rotation with the LCL section, particularly when the knee was close to extension, in knees that previously had undergone sectioning of the ACL. The popliteofibular complex was important for stabilization under external rotation at all degrees of flexion when the LCL was previously ruptured. In extension, even after the LCL section (group A) was significant when compared with the intact knee in external rotation, the posterior section of the popliteofibular complex was significant once again. We conclude that the popliteofibular complex was important for external rotation in extension.

In the comparison of group A (LCL section) with the intact knee, there was no significant increase at 30 and 60 degrees of flexion, and in comparing groups A and B (LCL section + popliteus tendon), we observed a significant increase. We conclude that this increase occurred to the detriment of the popliteofibular complex section, which is also important in stabilization for external rotation at 30 and 60 degrees. These discoveries corroborate the study of Shahane et al.,[5] who, after the popliteus tendon section, observed an increase in external rotation at 60 and 90 degrees and, after the popliteofibular ligament section, observed an increase in external rotation at all the degrees of flexion tested. In our study, we evaluated whether the popliteofibular complex section involves the joint section of the popliteus tendon and of the popliteofibular ligament. For this reason, our results should be compared with groups where the two structures were sectioned, such as in the study by Shahane et al.,[5] who obtained results similar to ours. LaPrade et al.[8] discussed the interaction between the function of the LCL and that of the popliteus tendon and of the popliteofibular ligament, where the LCL acts mainly close to extension, and the latter two acquire importance as the knee is flexed. This synchronism was also observed in our experiment.

The PLC proved important in the restriction of external rotation only with the knee in extension. We can justify this fact through the analysis of articular biomechanics; as the knee is flexed, relaxation occurs. In this manner, the PLC would cease to play an important role already at 30 degrees of flexion, and continuing similarly at 60 degrees of flexion.

Results obtained for stiffness in external rotation

The results show that after the popliteofibular complex was already sectioned, the associated section of PLC did not show any difference at any degree of flexion. We assume that the popliteofibular complex is the most important structure in external rotational stabilization of the knee. Jointly observing the properties of angular deformity and stiffness, we identified that the only situations where significant differences occurred were those in which we were testing an intact popliteofibular complex with another in which this complex had been sectioned.

CONCLUSIONS

The results of this biomechanical study to evaluate the relative importance of the different static stabilizers of the posterolateral corner of the knee allow us to conclude that the following:

1. The lateral collateral ligament was important in knee stabilization for varus at all the flexion angles tested (0°, 30° and 60°);
2. The popliteofibular complex was the most important structure in knee stabilization for external rotation among the structures tested because it also participated in stabilization for varus with the knee at 30 and 60 degrees of flexion;

3. The posterolateral capsule during extension was important for stabilizing the varus and for external rotation. However, at 30 degrees of flexion, it was only important for varus.

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