Behavior of the anterolateral structures of the knee during internal rotation

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ABSTRACT

Introduction: Since the recent descriptions of the anterolateral ligament (ALL), the role played by the anterolateral peripheral structures in the rotational control of the knee is again being debated. The objective of this study was to identify the structures during internal tibial rotation and then to define their anatomical characteristics. We hypothesized that internal rotation would tighten several anatomical formations, both superficial and deep, with the ALL one part of these structures.

Material and methods: Nine fresh-frozen cadaver knee specimens were studied. The anterolateral structures tightened were identified from superficial to deep at 30° of flexion. Each was selectively dissected, identifying its insertions and orientations, and measuring its size. The length variations of the ALL during internal tibial rotation were measured by applying a 30-N force using a dynamometric torque wrench at the tibiofibular mortise.

Results: The superficial structures tightened were the iliotibial tract and the Kaplan fibers. In internal tibial rotation, the Kaplan fibers held the iliotibial tract against the lateral epicondyle, allowing it to play the role of a stabilizing ligament. The Kaplan fibers were 73.11 ± 19.09 mm long (range, 63–82 mm) and at their femoral insertion they were 12.1 ± 1.61 mm wide (range, 10–15 mm). The deep structures tightened covered a triangular area including the ALL and the anterolateral capsule. The ALL was 39.11 ± 3.4 mm long (range, 35–46 mm) in neutral rotation and 49.88 ± 5.3 mm long (range, 42–58 mm) in internal rotation (p < 0.005). Its femoral insertion area was narrow at 5.27 ± 1.06 mm (range, 3.5–7 mm) and was mainly proximal and posterior at the lateral epicondyle. Its tibial insertion zone was wide, with a clearly differentiated anterior limit but a posterior limit confused with the joint capsule. In the vertical plane, this insertion was located 6.44 ± 2.37 mm (range, 2–9) below the joint space.

Discussion: This study demonstrates two distinct anterolateral tissue planes tightened during internal rotation of the tibia: a superficial plane represented by the iliotibial tract and the Kaplan fibers, which acts as a ligament structure, and a deep plane represented by a triangular capsular ligament complex within which the ALL and the anterolateral capsule are recruited.

Level of evidence: Descriptive cadaver study IV.

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1. Introduction

Rotational control of the knee is one of the main objectives of anterior cruciate ligament reconstruction. The insufficient control in this area [1–6] has renewed interest in the anterolateral ligament of the knee. Reference to the work of Segond [7] was the starting point for the research conducted by Claes et al. [8] and their description of the anterolateral ligament (ALL). The appeal for this ligament has been confirmed by several articles on its anatomy [9–11], its arthroscopic description [12], and its identification in ultrasound [13] and MRI [14–17]. Nonetheless, its precise anatomy and its possible involvement in rotational control and stability continue to be debated.

The objective of this study was to identify the anterolateral tissue structures tightened by internal tibial rotation and then to define their anatomical characteristics. We hypothesized that internal tibial rotation would tighten several anatomical formations, both superficial and deep, suggesting that understanding
the peripheral control and rotational stability should include the analysis of all of these structures, with the ALL only one of them.

2. Material and methods

Ten fresh-frozen knee specimens on whole-body cadavers were used for this work: three knees from the Strasbourg Anatomy Laboratory and seven from the Tours Anatomy Laboratory. All the knees were dissected by the same operator. The bodies were placed at room temperature for 24 h before beginning the dissections. One knee presented degenerative lesions and was excluded. The nine remaining knees, from five females and four males, with a mean age of 77.7 years (range, 63–86 years) presented no signs of major osteoarthritis or cutaneous scars. The range of motion in extension, flexion, and internal rotation were within physiological norms.

The condition of the cruciate ligaments was checked by manual testing and direct visualization via anteromedial arthrotomy.

For the dissection, the limbs were installed at 90° knee and hip flexion, maintained by lateral augment and distal support. The insertion points of the anatomical structures were identified using colored needles.

For the measurements, the knees were maintained at 30° flexion, the position verified with a goniometer with the center placed at the lateral epicondyle. This value was obtained to observe the behavior of the anterolateral structures in the pivot shift clinical position and to compare these results with other similar studies [15–17].

Dissection ablated a rectangular flap of skin and subcutaneous adipose tissue to expose the extensor apparatus, the lateral patellar retinaculum, the iliotibial tract, the distal part of the femoral biceps, and the head of the fibula (Fig. 1).

Application of 30 N of force in internal tibial rotation using the dynamometric torque wrench placed at the tibiofibular mortise made it possible to observe the behavior of the iliotibial tract during this movement.

This was then resected transversally 10 cm proximally from the lateral epicondyle and then pulled back distally, exposing the Kaplan fibers for study of their behavior during internal rotation of the knee, measurement of their length between the distal insertion on the subcondylar tubercle and proximally at the femoral metaphyseal-diaphyseal junction and their width. These fibers were then cut and the iliotibial tract folded back to expose the anterolateral capsule.

Internally rotating the knee then allowed tightening the ALL as well as the capsule located between this ligament and the lateral collateral ligament (LCL).

The ALL insertion points were detailed at the femur by the distance at the center of the lateral epicondyle and at the tibia by the distance to the most protuberant part of the subcondylar tubercle and at the summit of the tubular head.

The variations in ALL length were measured using a caliper in millimeters, with the knee flexed at 30°, based on a position in neutral rotation identified by the femur-tibia-foot alignment in dorsal flexion, to a position of internal tibial rotation by applying a 30-N force using the above-described method.

Statistical analysis: the data were described for each series of values with their mean (± standard deviation) and the range for each series.

ALL lengths were compared using the Student t-test for matched series. The correlations were calculated with the Pearson coefficient and are presented with their values and 95% confidence intervals. A P-value less than 5% was considered significant.

3. Results

3.1. Iliotibial band and Kaplan fibers

Internal rotation of the knee originated the tension of the iliotibial tract, predominant on the posterior fibers (Table 1).

Once it had been transversally resected proximally, the internal rotating of the knee still showed substantial tension of this fascia in its posterior portion, whereas this resected structure should have released. In the anterior view, this tension was made possible by the action of the Kaplan fibers, which, by holding the iliotibial tract against the lateral epicondyle, allowed its distal portion to act as a ligament and tighten in internal rotation. As soon as the Kaplan fibers were resected at their proximal insertion, the remaining iliotibial tract relaxed, releasing its control over the internal rotation.

The distal insertion of the Kaplan fibers was shared by the superficial part of the iliotibial tract on the subcondylar tubercle. Their ascending trajectory was characterized by a twisting of its fibers going from a sagittal plane distally to a frontal plane proximally. Their proximal insertion is located at the diaphyseal-metaphyseal junction of the femur opposite the linea aspera. Their length was 73.11 ± 19.09 mm (range, 63–82 mm) and their length at the femoral insertion was 12.1 ± 1.61 mm (range, 10–15 cm) (Fig. 2).

3.2. “Triangular capsular ligament complex” and anterolateral ligament

After having folded back the iliotibial tract, the anterolateral capsule was exposed. The ALL was the anterior part of a “triangular anterolateral capsular complex.” The posterior, vertical, part of this complex was made up of capsular fibers that inserted onto the LCL, and the base, distal, comprised the insertion of the capsule on the
Table 1
General characteristics and measurements of the anterolateral tissue structures of nine cadaver knees: measurements taken on the knee at 30° of flexion.

<table>
<thead>
<tr>
<th>Knee/side</th>
<th>General characteristics</th>
<th>Kaplan fibers</th>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Sex</td>
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<td>8D</td>
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<td>81</td>
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<tr>
<td>9D</td>
<td>M</td>
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<tr>
<th>Knee/side</th>
<th>ALL</th>
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<th>Triangular complex</th>
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<td>Length in internal rotation</td>
<td>Length in medial rotation</td>
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<td>3.5–16</td>
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<td>4–14</td>
</tr>
<tr>
<td>9D</td>
<td>40</td>
<td>53</td>
<td>7–15</td>
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ALL: anterolateral ligament; GT: Gerdy tubercle; LCL: lateral collateral ligament.
tibia (Fig. 3). In this triangle, in internal rotation, the fibers were oblique and layered from top to bottom from the insertion on the LCL toward the ALL (Fig. 3). This triangle measured $43 \pm 4.43$ mm (range, 36–50 mm) for the posterior edge, $24.22 \pm 5.65$ mm (range, 19–32 mm) for the base, and $49.88 \pm 6.55$ mm (range, 42–58 mm) for the anterior edge.

The ALL was identified more clearly when the knee was placed in internal rotation; in neutral rotation, its relief disappeared within the capsular thickness.

The dissection of its femoral insertion was difficult because of the convergence of its fibers with those of the LCL on the lateral epicondyle. This femoral insertion was defined in relation to the center of the lateral epicondyle: on two specimens it was located distally (2 and 3 mm) and on seven specimens proximally at 9.85 mm (range, 6–20 mm). In the anteroposterior plane, this insertion was anterior (3 mm) on one specimen, posterior (1, 2, 4, and 5 mm) on four, and at the center of the epicondyle on four (Fig. 4). The tibial insertion was more widespread, located $6.44 \pm 2.37$ mm (range, 2–9 mm) below the joint space; the center of this insertion was $22.11 \pm 2.71$ mm (range, 18–25 mm) posterior of the center of the subcondylar tubercle and $16 \pm 4.38$ mm (range, 10–23 mm) anterior of the top of the fibular head (Fig. 5).

Its length was a mean $39.11 \pm 3.4$ mm (range, 35–46) in neutral rotation and $49.88 \pm 5.3$ mm (range, 42–58) in internal rotation ($P < 0.005$).

There was a correlation between the ALL in internal rotation, the size of the femur ($P = 0.02$), and the size of the tibia ($P = 0.008$), but no correlation was found between the anteroposterior ($P = 0.26$) or epicondylar diameters ($P = 0.25$).

4. Discussion

This study describes two distinct anterolateral tissue layers that are tightened when going from neutral rotation of the tibia to internal rotation:

- a superficial plane represented by the iliotibial tract and its deep Kaplan fibers;
- a deep plane represented by a “triangular capsular complex” integrating the ALL.

The Kaplan fibers held against the iliotibial tract on the lateral epicondyle in internal rotation of the tibia provided an anchorage point at this level and allowed it to be tightened. Its bone insertions therefore give it a ligament-type passive stabilizing role, a role also suggested by the orientation in the sagittal plane of the distal part of its fibers. In his article studying the entire iliotibial tract, Kaplan [18] observed that this remained tensed in the cadaver even though there was no muscle contraction. He deduced that the iliotibial tract, in its distal section, was not a fascial tendon of the tensor fascia latae or the gluteus maximus but acted as a ligament. Its passive stabilizing action was made possible by its femoral and tibial bone insertions. This important point in the iliotibial tract dynamics was confirmed by Terry et al. [19] and Viera et al. [20]. For these authors, the deep and capsular and bone fibers acted as an anterolateral ligament of the knee, ensuring rotational stability in synergy with the anterior cruciate ligament. These anatomical observations suggest an anterolateral locking of internal tibial rotation by the iliotibial tract, in particular the Kaplan fibers, which was recently confirmed by the study reported by Parsons et al. [21].
An application in clinical practice of these findings would be to keep the Kaplan fibers intact during iliotibial tract harvesting in view of ACL reconstruction or lateral tenodeses.

For the deep plane, there has been a relative lack of clarity in nosology terms since the description in 1897 by Segond [7]: “a resistent, pearly, fibrous band, which, in an exaggeration of the inward rotational movement, is always subjected to an extreme degree of tension.” Several terms have indeed been used to describe this region without defining the content precisely. In 1982 Muller [22] used the term “lateral femorotibial ligament.” Terry et al. [19] and Viera et al. [20] described the existence of capsular-bony fibers of the iliotibial tract that they considered to be an anterolateral ligament, thus generating confusion with the current description. For Johnson [23] this was a “lateral capsular ligament,” for Campos et al. [24] an “antero oblique band,” and for Hughston et al. [25], LaPrade and Terry [26], Haims et al. [27], and Goldman et al. [28] the “mid-third lateral capsular ligament.”

Recent studies [8–10,29] as well as the present study have detailed the descriptive anatomy of the anterolateral ligament. Our measurements of the ALL are in line with those found in the literature (Table 2). The variations in length between the different authors can be explained by the problems identifying the femoral insertion of this ligament and by the knee position, in flexion and rotation, which varied from one study to another.

One of the main conflicting points concerns the femoral insertion. In the study reported herein, it was for the most part proximal to the lateral epicondyle. This contradicts the studies conducted by Vincent et al. [11], Claes et al. [8], and Helito et al. [29], even if these authors agreed on the problems inherent to individualizing this insertion because of the many connections with the femoral insertion of the LCL and the fibers coming from the fascia of the lateral vastus muscle. The differences in the femoral insertion in our study are an additional argument for this difficulty. For Dodds et al. [10] the ALL originates proximally to the lateral epicondyle on 33 knees where it could be individualized. Caterine et al. [9] explained these disparities in the insertion by the existence of anatomical variations and proposed a three-stage classification according to the differences in femoral and tibial insertions.

We observed a significant variation in ALL length in internal rotation at 30° flexion measuring more than a mean 10 mm, findings similar to those reported by Dodds et al. [10] (mean lengthening, 9.9 mm). This variation in length corresponds to the ALL tightening observed and suggests its involvement in the control of internal tibial rotation. The meaning of this lengthening should nonetheless be weighed against the disparity of the femoral insertion of this ligament and its thickness.

Integrating the ALL within the “triangular capsular ligament complex” revives the notion of “mid-third lateral capsular liga-

Table 2

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<td>Length (mm)</td>
<td>34.1 ± 3.4</td>
<td>38.5 ± 6.1</td>
<td>59 ± 4</td>
<td>40.3 ± 6.2</td>
<td>39.1 ± 3.4</td>
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<tr>
<td>Proximal width (mm)</td>
<td>8.3 ± 2.1</td>
<td>11.2 ± 2.5</td>
<td>11 ± 2</td>
<td>11.1 ± 2.4</td>
<td>11.7 ± 3.2</td>
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<td>Tibial length (mm)</td>
<td>5</td>
<td>6.5 ± 1.4</td>
<td>18 ± 3</td>
<td>23.4 ± 3.4</td>
<td>15.6 ± 2.6</td>
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<tr>
<td>Gerdy tuberance distance (mm)</td>
<td>21.6 ± 4</td>
<td>17 ± 3</td>
<td>23.9 ± 5.5</td>
<td>16 ± 4.7</td>
<td>23.4 ± 3.2</td>
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<tr>
<td>Fibula head distance</td>
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<td>Distal</td>
<td>Proximal</td>
<td>11 distal cases</td>
<td>8 proximal cases</td>
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<tr>
<td>Insertion/lateral epicondyle</td>
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<td></td>
<td>2 distal cases</td>
<td>7 proximal cases</td>
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powerful isometric ligament in flexion-extension, the boom would be the tibial meniscocapsular insertion, and the trailing edge the anterior capsular pillar represented by the ALL. The anchoring of this complex on the LCL and the horizontal orientation of the capsule fibers could explain their successive recruitment during internal rotation depending on the degree of knee flexion. When the rotational movement continues, the ALL breaks or is torn at its tibial insertion, thus producing a Second fracture: this relation between the ALL and the Segond fracture has been demonstrated by several authors [8,16,28,31–33].

The existence of an anatomical region including the LCL and the ALL was also proposed by Claes et al. [14] using the term “lateral col-

Fig. 6. Lateral view of the knee—comparison of deep anterolateral stabilizers with a boat sail.

lateral ligament complex (LCLC).” Finally, Helito et al. [29] defined a triangle drawn by the ALL in front and the tendon of the popliteal muscle (PMT) behind, with the top on the lateral epicondyle in common: with the PMT involved in posterolateral rotational control, they deduced that the ALL should be involved in the anterolateral control of rotation for reasons of symmetry.

According to this reasoning, the superficial and deep tissue planes described in the present study could be a point of the anterolateral corner involved in the control of anterolateral laxity, just as the point of the posterolateral corner is for posterolateral laxity.

There are several limitations to this study:

- the small number of cadaver specimens dissected and the age of the donors greater than that of the subjects who usually experience ACL rupture;
- the need to reset the iliotibial tract to expose the ALL, which could falsify the tension measurements of this ligament’s fibers;
• the measurements taken at only a single angulation ($30^\circ$) and a single rotational force (30 N), with notably the absence of any kinematic analysis of the ALL, from external rotation to internal rotation;
• the cruciate ligament was intact in this study, whereas the ACL is ruptured in clinical situations calling on rotational control of the knee;
• the absence of objective functional analysis of the role played by each of the structures described, but this will be the subject of a complementary study.

5. Conclusion

This study describes the tightening of two distinct anterolateral tissue planes during internal rotation of the tibia: a superficial plane represented by the iliotibial tract and the Kaplan fibers, which act as a ligament structure by holding it to the lateral epicondyle, and a deep plane represented by a triangular capsular ligament complex within which can be found anterolateral ligament and anterolateral capsule recruitment.

A navigated functional anatomical study will complete this descriptive study to define the quantitative and respective role of each of these structures.

A better analysis of the anatomical structures involved in the knee’s rotational control is an indispensable foundation for the development of surgical technical strategies aiming to improve this control.

Disclosure of interest

B, Sonnery-Cottet is a consultant for Arthrex. The other authors declare that they have no conflicts of interest concerning this article.

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